Quantification of genotypic variation and consumer segmentation related to fruit quality attributes in apple (*Malus x domestica* Borkh.)

By

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DECLARATION

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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SUMMARY

Quantification of genotypic variation and consumer segmentation related to fruit quality attributes in apple (*Malus x domestica* Borkh.)

Limited information is available on the apple preferences of the South African consumer market, which is characterised by diverse consumers from different age and ethnic groups with different food preferences. White, coloured and black consumers from different age groups were selected from the Stellenbosch area, Western Cape, South Africa. Consumer preference analysis for apple eating quality and appearance, and descriptive sensory analysis (DSA) were performed on nine commercial apple cultivars. Analysis of variance (ANOVA) conducted on mean preference scores for each age and ethnic group showed that preference generally differed between these groups. However, Ward's statistical clustering that was applied to the same data set showed that the socio-demographic composition of consumer groups with similar apple preferences is not homogenous. Three consumer clusters were identified with similar preferences for apple eating quality (E1-3) and appearance (A1-3): E1 liked firmness and therefore tolerated sour taste and disliked mealiness. Although E1 liked sweet fruit, they indicated lower preference for sweet fruit compared to E2 and E3. E2 liked sour taste and apple flavour more compared to the other clusters while E3 disliked sour taste and had the highest preference for sweetness. Although coloured and black consumers generally disliked sour taste and E3 constituted a larger proportion of these consumers, the coloured and black consumers who liked or tolerated sour taste constituted approximately 41% of the total consumer population in the Western Cape. White and younger (<26 years) consumers were mostly in cluster E1 liking firm fruit. Peel colour preferred by the appearance preference clusters were: Green and pink bi-colour (A1), green/yellow and red-striped (A2); and red peel colour (A3).

Consumers preferred the appearance of cultivars that associated with the eating quality attributes that they liked. When consumers' preference for the eating quality of five cultivars were analysed during presentation with different levels of visual pictorial information (no, correct and incorrect photograph), mismatches between expected and actual eating quality preference resulted in lower preference scores.

Apple breeding is time-consuming and expensive. Comprehensive knowledge of fruit quality parameters that drive consumer preference is required to streamline the breeding process. Eating quality and appearance attributes of four apple breeding families were subjected to instrumental and individual assessment by a trained assessor and DSA by a trained panel. Instrumental measurements could not predict the sensory attributes analysed by the individual assessor.

Sensory textural attributes, apple flavour and sweet taste as quantified by DSA and instrumental measurement of titratable acidity (TA) and total soluble solids (TSS)/TA, but not TSS, could predict consumer preference. The assessor responsible for individual assessment could not predict the preference of the total consumer group. A quantitative genetic analysis of the data was carried out to quantify within- and between-family variation using ANOVA, variance components and heritability estimates. Variation between families was shown for attributes relating to colour and acidity, but not for sweet taste, TSS and apple flavour. Strong genetic control that was generally shown for colour attributes predicts a rapid selection response. Most attributes were inherited quantitatively, but TA showed complicated inheritance mechanisms.

OPSOMMING

Kwantifisering van genotipiese variasie en verbruikersegmentasie wat verband hou met eienskappe van vrugkwaliteit in appels (*Malus x domestica* Borkh.)

Min inligting is beskikbaar oor die appelvoorkeure van die diverse Suid-Afrikaanse verbruikersmark wat bestaan uit verbruikers van verskillende ouderdomme en etnisiteite met verskillende voedselvoorkeure. Wit, bruin en swart verbruikers van verskillende ouderdomsgroepe is geselekteer in Stellenbosch in die Wes-Kaap, Suid-Afrika. Verbruikersvoorkeuranalise vir die eetkwaliteit en voorkoms van appels en beskrywende sensoriese analise (BSA) is uitgevoer op nege kommersiële appelkultivars. Analise van variansie (ANOVA), uitgevoer op gemiddelde voorkeurdata per ouderdom en etniese groep, het getoon dat die voorkeure van hierdie verskillende groepe oor die algemeen verskil het. Volgens Ward statistiese groepering op dieselfde datastel was die sosiodemografiese samestelling van verbruikersgroepe met soortgelyke voorkeure egter nie homogeen nie. Drie verbruikersgroepe is geïdentifiseer met soortgelyke voorkeure vir appel eetkwaliteit (E1-3) en voorkoms (V1-3). E1 het ‘n voorkeur vir fermheid, ‘n afkeur vir melerigheid en verdra suurheid. Alhoewel E1 van soet vrugte gehou het, het hulle ‘n laer voorkeur vir soetheid as E2 en E3. E2 het ‘n voorkeur vir suurheid en appelgeur terwyl E3 ‘n afkeur vir suur smaak en die hoogste voorkeur vir soetheid getoon het. Alhoewel swart en bruin verbruikers meestal ‘n renons in suur smaak getoon het en meer van hierdie verbruikers tot E3 behoort, maak swart en bruin verbruikers wat suur smaak aanvaar ongeveer 41% van die totale verbruikersgroep in die Wes-Kaap uit. Wit en jonger (<26 jaar) verbruikers was meestal in E1 en het ‘n voorkeur vir fermheid getoon. Vrugkleurvoorkeure was vir groen en pienk (tweekleurig) (V1), groen/geel en rooi gestreep (V2) en rooi (V3).

Verbruikers het ‘n voorkeur gehad vir die voorkoms van kultivars waarvan hulle die eetkwaliteit verkies het. Die effek van gevestigde kleur en smaak assosiasies is getoets deur verbruikers te versoek om die eetkwaliteit van vyf kultivars te evalueer tydens aanbieding daarvan met drie vlakke van visuele inligting, naamlik geen, korrekte en verkeerde foto. Verwarring tussen verwagte en werklike eetkwaliteit het gelei tot ‘n laer voorkeur.

Teling van appels is tydrowend en duur. Uitgebreide kennis van die vrugkwaliteit parameters wat verbruikersvoorkeur dryf, is noodsaaklik vir effektiewe teling. Eienskappe wat verband hou met die eetkwaliteit en voorkoms van saailinge is in vier appelfamilies geanaliseer. Die eienskappe is geassesseer deur middel van instrumentele en individuele evaluasie deur ‘n opgeleide assessor asook deur BSA deur ‘n opgeleide paneel. Instrumentele analise kon nie die vlakke van sensoriese eienskappe voorspel soos waargeneem deur die individuele assessor nie. BSA van sensoriese tekstuureienskappe, appelgeur en soetheid, en instrumentele meting van titreerbare suur (TS) en totale oplosbare vastestowwe (TOV)/TS, maar nie TOV nie, kon verbruikersvoorkeur voorspel. Die assessor wat individuele evaluasies uitgevoer het, kon nie die voorkeur van ‘n groot verbruikersgroep akkuraat voorspel nie. Kwantitatiewe genetiese analise van die data is uitgevoer en binne- en tussen-familie variasie is gekwantifiseer deur middel van ANOVA, variansie komponente en oorerflikheidsskattings. Variasie tussen families is gevind vir kleureienskappe en suurheid, maar nie vir soet smaak, TOV en appelgeur nie. Resultate het getoon dat kleureienskappe meestal aan sterk genetiese beheer onderworpe is en dit dui op vinnige vordering met seleksie vir vrugkleur. Vrugeienskappe is meestal kwantitatief oorgeërf. Oorerwing van TS blyk ingewikkeld te wees.

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The language and style used in this dissertation are in accordance with the requirements of the International Journal of Food Science and Technology. This dissertation presents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters, therefore, has been unavoidable.

CHAPTER 1
General introduction

South Africa's total production value of apples for the 2010/2011 season is estimated at R3.1 billion (DAFF, 2012), showing that apples are among the most important agricultural commodities. Despite an increasing consumer segment that can afford and demand high quality novel cultivars (Fick, 2011), fresh sales have decreased from approximately 40% of the total production volume in 1999/2001 to 30% in the 2009/2011 seasons (DFPT, 2011). A clear understanding of local consumers' demands for apple quality is therefore required to increase local sales, considering that this market still constitute a large proportion of the total sales. Quality factors that drive consumer preference for apples include appearance, texture and flavour attributes (Daillant-Spinnler *et al.*, 1996; Cliff *et al.*, 2002). Colour is the most important visual cue perceived by consumers and is a major pre-selection criterion when consumers purchase apples, by providing clues as to edibility, flavour identity, flavour intensity and maturity (Jaeger & MacFie, 2001; Shankar *et al.*, 2010; Steyn, 2012). A novel flavour experience (Yue & Tong, 2011) and firm, crisp texture (Daillant-Spinnler *et al.*, 1996) are major drivers of consumer preference during eating. Apple breeders should be familiar with the attributes required by South African consumers to meet their demands.

Data generated by descriptive sensory analysis (DSA) can be used to predict the sensory attributes that drive consumers' preference when it is projected onto consumers' preference dimensions using multivariate statistical techniques (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998; Carbonell *et al.*, 2008). Consumer groups have diverse preferences for apple attributes (Daillant-Spinnler *et al.*, 1996). Consumers can be grouped based on socio-demographic characteristics (Thybo *et al.*, 2003) or on similar preference patterns (Daillant-Spinnler *et al.*, 1996; Carbonell *et al.*, 2008). Limited information is available on the apple preference of the South African population (Fick, 2011) that constitute consumers from different ethnic groupings with different food habits and preferences (Viljoen & Gericke, 2001). There is a general perception among retailers that coloured and black consumers, who constitute the largest proportion of the South African consumer group (STATSSA, 2006), prefer sweet cultivars and dislike a sour taste (Fick, 2011), but the extent to which this is true is not known. Furthermore, the relative proportion of consumer groups that prefer sweet and sour apples is not known.

Fruit breeding is a time-consuming and expensive process, where thousands of seedlings have to be maintained in the field for an extended period at high costs (Lespinasse, 2009). A consumer-driven breeding programme that optimises the parameters and methodologies used to quantify the genotypic diversity and heritability estimates of quality attributes that drive consumer preference could streamline the breeding process. The biggest apple breeding programme in South Africa is conducted by the Agricultural Research Council (ARC). The aims of the Breeding and Evaluation Division of ARC Infruitec-Nietvoorbij include breeding of new apple cultivars with good marketing potential and high external and internal fruit quality (Labuschagnè, 2012). Fruit quality assessment is essential in all four phases of breeding in the ARC apple breeding programme.

Instrumental measurements of fruit quality have become one of the cornerstones of fruit quality assessment in the apple industry and breeding programmes. The relevance of these measurements depends on the accuracy with which they are able to reflect sensory attributes (Oraguzie *et al.*, 2009) and predict consumer preference. The use of small teams (2-4) of expert tasters or individual assessors has continued to be the mainstay of germplasm evaluation, despite their inability to predict the preference of a larger group (Hampson *et al.*, 2000; Oraguzie *et al.*, 2009). There is limited information on the validity of using small teams of expert tasters and single assessors, as is used in the ARC breeding programme, compared to larger trained panels to conduct DSA (Hampson *et al.*, 2000; Oraguzie *et al.*, 2009).

A comprehensive literature review was conducted on the estimation of genetic parameters of apple quality and different techniques of fruit quality analysis, as well as the statistical methods applied to relate these parameters to consumer preference. Knowledge was obtained about protocols for instrumental (the specific instruments used to analyse fruit quality parameters), sensory (panel size, scales used to measure attribute intensity) and consumer preference (group size, scale used to test preference, mean preference of the total group or preference for each segment) analysis of apple and the statistical analysis of the different data sets. Insight was gained into current limitations and the most efficient techniques for analysis of an apple breeding programme.

This study was undertaken in collaboration with the Departments of Horticultural Science and Food Science at Stellenbosch University, South Africa, among consumers in the Western Cape Province. The study constituted three separate projects: 1) Individual assessment by an expert assessor, DSA by a trained panel and consumer preference analysis were conducted during three harvest seasons to quantify the genotypic variation in eating quality and appearance in four apple breeding families in the ARC apple breeding programme for attributes that drive consumer preference (2008-2010); 2) Instrumental analysis and DSA were applied to nine commercially available apple cultivars to identify the drivers of liking for consumers from different age and ethnic groups (black, coloured and white). Consumer segments with similar preferences for apple eating quality and appearance were identified by statistical clustering and the socio-demographic composition of the different clusters were compared (2010); 3) Consumers' expectations created by cultivar appearance were analysed and their preference tested for commercial apple cultivars when these fruit were presented with three different levels of visual information that were presented in different orders. DSA and instrumental analysis were conducted to study the impact of established appearance and flavour/texture associations on the eating experience of consumers of apples (2010).

The presentation order of the research in this dissertation is not reflective of the chronological order in which it was conducted, but represents the order of design for a breeding programme: Consumer preference should be determined first and the target markets and consumers should be identified, which determine the breeding objectives. The most efficient methods to analyse fruit quality parameters that drive consumer preference for each of these markets should be determined. Functions from multivariate statistical analysis could be developed for the different consumer segments and for the consumer group as a whole to streamline selection of promising genotypes. Once breeders are familiar with the different drivers of liking, the relative ease of selection for these attributes should be determined.

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CHAPTER 2

Literature review

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1. APPLE PRODUCTION AND CONSUMPTION

1.1 Introduction to apple consumption

During the last 20 years the per capita consumption of fresh apples has shown substantial increases in developing countries and decreases in several developed countries (FAO, 2011). The per capita consumption in regions that have little or no domestic production of apples (FAO, 2011) has shown significant increases since 1990, with four regions showing a fourfold increase, viz. Eastern Africa, Middle East, Western Africa and South-Eastern Asia (O'Rourke, 2011). Asia and the Russian Federations have seen increases of 160% and 100%, respectively (Fig. 1) (O'Rourke, 2011). Declines of more than 20% have been reported in four of the eleven European Union (EU) countries and 10.5% in the United Kingdom (UK) (Fig. 1) that are important export markets for South African apples (DFPT, 2011; O'Rourke, 2011). Relatively high levels of per capita income in these countries indicate that consumers could mostly afford a substantially higher annual expenditure on fruit and vegetables.

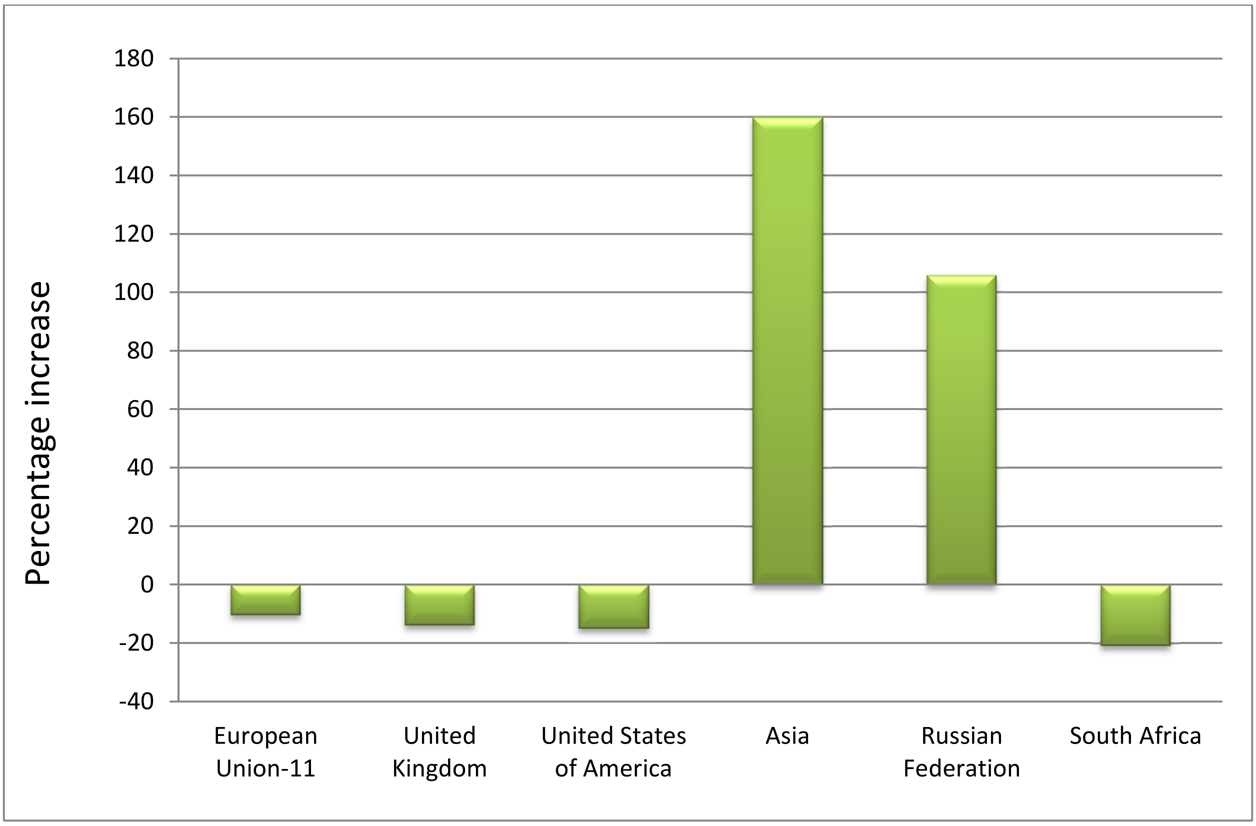

Figure 1 Estimated increase of per capita consumption of fresh apples for the period 2008-2010 compared to 1991-1993 in selected regions. Source: O'Rourke (2011).

Apples have lost market share to fruit such as bananas, berries and tropical fruit that have gained popularity (Fig. 2) (O'Rourke, 2011). In most developed countries, apples are faced with very crowded produce shelves, because consumers prefer to choose from a greater variety of fruits. In many cases they substitute minor fruits for the more traditional fruits like apples and oranges (Fig. 2) (O'Rourke, 2008), because conventional fruits such as apples, plums and pears are seen as less exciting (O'Rourke, 2011). On the South African market, fruit such as persimmons, pomegranates, figs and dragon fruit have gained shelf space during the past few years (DAFF, 2012). Furthermore, fresh apples are facing competition from manufactured snacks and beverages that are convenient and offer consistent eating quality that can easily be changed to adapt to changing consumer preferences (O'Rourke, 2011).

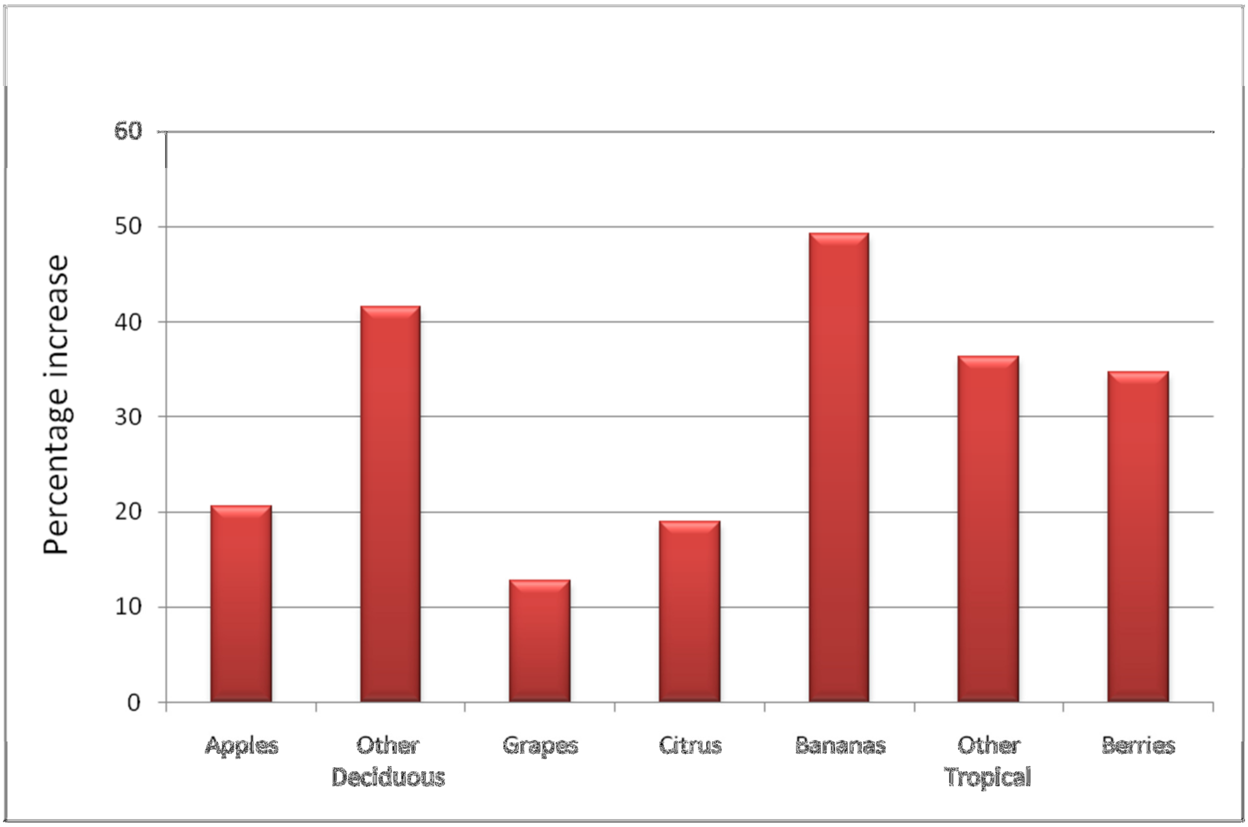

Figure 2 Percentage increase in world production of major fruits for 1997/99 to 2007/09. Source: FAO (2011).

Fruit quality should not be considered as an absolute variable, but rather a concept that changes dynamically across time with consumers' expectations (Harker *et al.*, 2003). A desire for novel flavour experiences, as a major driver for consumers' preference, has led consumers to experiment with new fruits and new variants of existing fruits (Yue & Tong, 2011). The intense competition between apple industries has created a growing awareness of brand differentiation (Axelson & Axelson, 2000). It is therefore important to understand consumers' preference for apple cultivars and to continually position new and viable cultivars (Hughes, 1996; Harker *et al.*, 2003) in order to satisfy the needs of evolving markets and to gain a competitive advantage (Buckley *et al*., 2007) that could lead to price premiums for the supplier (Yue & Tong, 2011). The consumer-oriented development and commercialisation of new cultivars is therefore a strategic necessity for apple breeders and suppliers (Reid & Buisson, 2001; Jaeger *et al*., 2003; O'Rourke, 2011) and consumer research should be carried out from the early stages of the fruit breeding process (Hampson *et al*., 2000).

O'Rourke (2011) classified apple cultivars into four broad categories: 1) Traditional majors, such as Red Delicious, Golden Delicious and Granny Smith; 2) new majors, including Gala/Royal Gala, Fuji and Braeburn with new cultivars, such a Cripps' Pink steadily moving into this category; 3) regional cultivars, which include a wide range of traditional cultivars grown in local production areas and 4) new cultivars that have been commercialised within the last decade, but whose production peak is expected only in the future. The 2010 top ten cultivars such as Golden Delicious, Delicious, Fuji, Granny Smith, Braeburn and Jonathan are predicted to lose market share by 2020 to the new major cultivars (O'Rourke, 2011).

1.2 South African production, consumption and export of apples

Apples are among the most important agricultural commodities in South Africa. The preliminary total production value of apples for the 2010/2011 season was estimated at ca. R3.1 billion (DAFF, 2012). Although the export markets still offer the highest revenue (R6.210 per ton), producers received R5.089 per ton of fresh apples on the local market (DAFF, 2012). Fresh sales on local markets have decreased from approximately 40% in the 1999/2000 season to 30% in the 2009/2010 season (DFPT, 2011). However, the growth of the high income consumer group (STATSSA, 2006) could create a market segment that desire high grade export quality apples (Fick, 2011).

Figure 3 South Africa's most important export markets in 2002 and 2011, expressed as a percentage of the total export volume (in tons) of sea exports. Source: DFPT (2011).

South Africa has managed to maintain its competitive position in the UK market in the last decade, where approximately 29% of the export volume is destined (Fig. 3). Exporters of South African apples will have to expand to other markets in order to show a continual growth (O'Rourke, 2011). Increased consumption in Sub-Saharan Africa could signify enormous potential as output for South African apples, due to the geographic proximity of South Africa compared to other competitors (O'Rourke, 2011). During the past decade, the African, Far Eastern and Asian markets have been increasingly important (Fig. 3) (DFPT, 2011).

Golden Delicious and Granny Smith are the most important apple cultivars in South Africa. Approximately 24% and 21% of the total apple production area in South Africa is planted to each of these cultivars, respectively. In the last decade, total hectarage for the traditional major cultivars (Granny Smith, Golden Delicious, Topred and Starking) decreased steadily (Fig. 4). The total area planted to new major cultivars (Royal Gala, Cripps' Pink and Fuji) has increased notably by 2011. Hectarage planted to 'Braeburn' and 'Cripps' Red' has also shown slight increases. Although Golden Delicious and Granny Smith showed the highest export volumes in 2011 (31.2% and 23.7%, respectively) these cultivars are currently losing market share to new major cultivars such as Royal Gala (18.4%) and Cripps' Pink (9.6%) (DFPT, 2011).

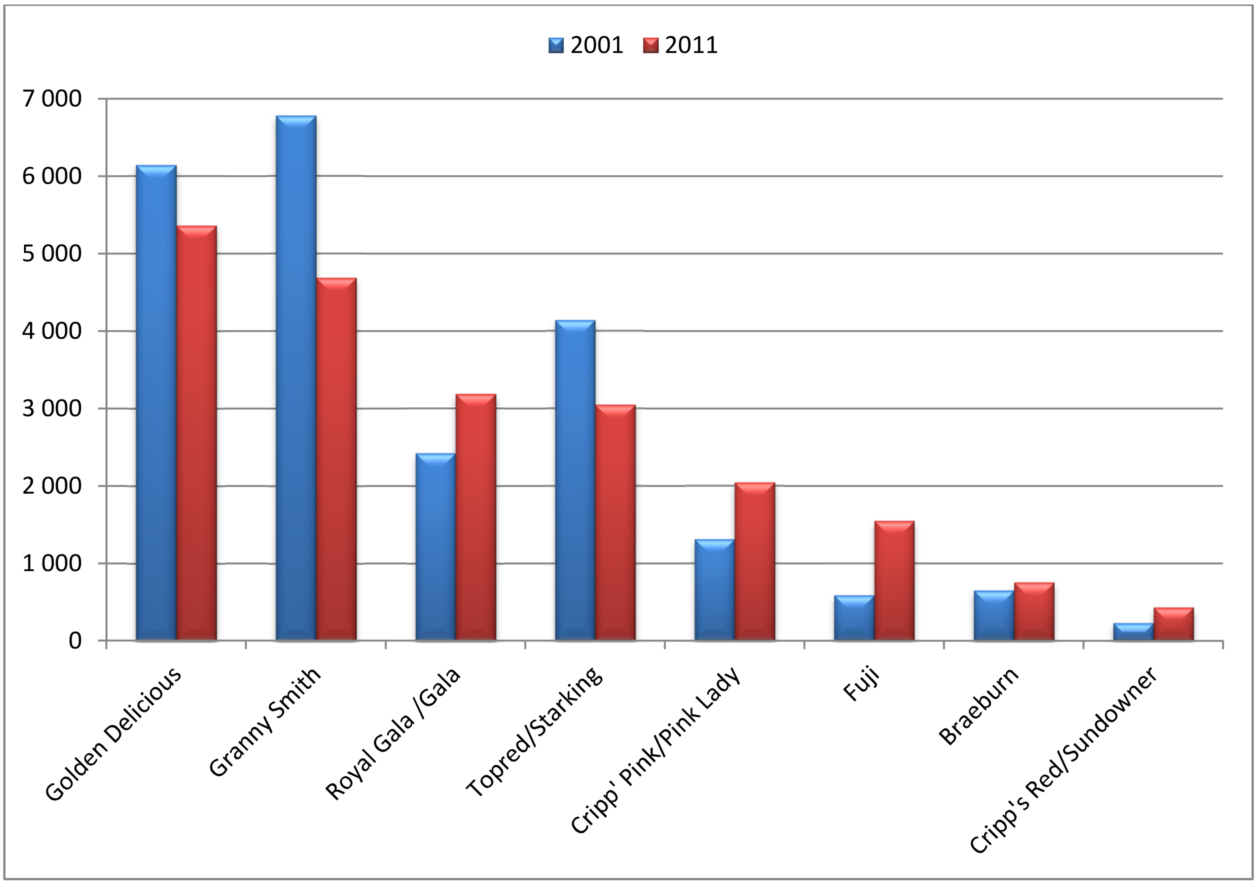

Figure 4 Area (hectares) planted per apple cultivar in 2001 and 2011. Source: DFPT (2011).

2. QUANTITATIVE AND QUALITATIVE ANALYSES OF FACTORS THAT INFLUENCE CONSUMERS' APPLE PREFERENCES

Quality analysis of fresh produce is one of the key aspects of applied postharvest biology (Brookfield *et al.*, 2011). Although it is difficult to describe fruit quality, it is usually defined by physical attributes such as shape and size, colour, texture (including mouthfeel) and flavour (including volatile compounds and sweet, sour, salt and bitter tastes) (Karlsen *et al.*, 1999). Eating quality is difficult to measure objectively (Hampson *et al.*, 2000) and can be viewed from two different perspectives: In a product-oriented approach, quality is seen as a bundle of attributes that is inherent in a product; while a consumer-oriented approach is more difficult to quantify and defines quality in terms of consumer satisfaction, but can sustain changes in consumer demand and expectation (Shewfelt, 1999). Although factors relating to fruit quality will influence consumers' initial purchase decisions (Corrigan *et al.*, 1997), the demand for fruit could be reduced by damaging return sales if consumers are not satisfied with the eating quality (Harker *et al.*, 2008). Although consumers represent the only reliable source of preference and acceptability of eating quality, they may not be aware of the sensory properties that drive their preference judgements and are unable to express their rationale for these preferences (Shewfelt, 1999; Harker *et al.*, 2003).

While instrumental tests provide specific information about the physical composition of a commodity, sensory analysis provides means to study integrated parameters of the products by using human subjects acting as judges. The sensory scientist is mainly involved with the analysis of appearance, flavour and texture parameters of a particular commodity (Heintz & Kader, 1983). The Sensory Evaluation Division of the Institute of Food Technologists, USA, created the following definition in 1975: "Sensory evaluation is a scientific discipline used to evoke, measure, analyse and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing" (Lawless & Heymann, 2010). Sensory science constitutes two basic divisions, viz. sensory analysis and consumer analysis. In sensory analysis, descriptive sensory analysis (DSA) is used to quantify the sensory attributes relating to food quality. Panellists are selected and trained for their ability to discriminate between small variations in sensory attributes and the goal is to study the variations in the food products and not the judges (Lawless & Heymann, 2010). The test conditions are often not related to normal food consumption and the individuals are not representative of the consuming public (Heintz & Kader, 1983). Within consumer analysis one can test for consumer liking, i.e. preference and acceptability, and consumer perceptions, opinions and purchase intent (Lawless & Heymann, 2010). Consumer panellists are chosen from a representative portion of the consuming public to which a specific product is targeted. The panel should be large enough to overcome the extreme variability that can occur among individuals when analysing their preference (Heintz & Kader, 1983).

The application of different methodologies of fruit quality analysis and the correlation of this data with consumers' degree of liking will be discussed in the following sections. Table 1 provides a summary of the most important studies that will be discussed below.

2.1 Measurement of fruit quality using descriptive sensory analysis

DSA is a generic research technique used by sensory scientists to produce objective descriptions of products in terms of perceived sensory attributes. This technique usually involves 1) training of the judges to score the respective samples according to the specific sensory attributes on a line scale, 2) the determination of judge reproducibility, 3) analysis of the samples according to an experimental design, followed by analysis of variance (ANOVA) and/or appropriate multivariate statistical techniques. This sensory technique requires that a panel of judges is trained for consistency and reproducibility (Lawless & Heymann, 2010).

Early applications of DSA in the evaluation of apples include lexicon and procedure development for the sensory profiling of the eating quality of 'Cox's Orange Pippin' (Williams & Carter, 1977). These authors recognised the importance of clear definitions for the sensory attributes used in the analysis of fruit quality. They argued that preference should not be used as an indication of fruit quality, because reasons for preference differ between consumers. Almost 200 descriptors were generated in a detailed profile assessment that expanded on simplified attributes used in previous studies, such as texture, sweet-sour relationships and flavour. Flavour attributes included body/depth of flavour, acidity, sweetness, bitterness, astringency and an overall flavour rating, while texture attributes included crispness, hardness, toughness, mealiness and an overall texture rating. These attributes were rated on a structured five-point scale for peeled, as well as unpeeled samples. Average attribute values were reported, but not statistical analyses.

Dhanaraj *et al.* (1981) argued that the 200 descriptors that were used by Williams and Carter (1977) were impractical for routine quality analyses and recognised the importance of a more simplified routine method for DSA. Descriptors pertaining to optimal eating ripeness were used at one end of the structured scales and descriptors pertaining to overripe stages at the other end (Dhanaraj *et al.*, 1981). The panel could not distinguish between hardness, crispness and toughness and therefore used a combination of these attributes to describe texture related to degree of ripening ranging from hard and unripe to mealy and corky. Juiciness (juicy and watery to dry) and taste (raw, astringent to flat, off-taste) were also described as different dimensions of degree of ripeness. The assumption was made that texture, juiciness and taste were uni-dimensional attributes. Furthermore, terms such as greenish, full, flat and off-aroma were combined in a single scale, which did not pertain to good scientific practise. Redalen (1988) also used general terms to evaluate apple flavour attributes on a scale ranging from 1 (very poor) to 10 (excellent), a method that do not pertain to good scientific practise for the objective and uniform analysis of fruit quality. Redalen (1988) published one of the first known reports on the analysis of appearance attributes by a trained panel consisting of 6-8 judges. Watada *et al.* (1980) used crispness, hardness, toughness, mealiness and juiciness to analyse the different dimensions of apple texture on 100-point intensity line scales. The 14-member panel that partook in the study selected sweetness, acidity, astringency, mustiness, floral/fruitiness and starchiness as the most appropriate descriptors relating to apple flavour. In the early 1990's, DSA was used to evaluate eating quality differences among 'Gala', 'Red Delicious' and 'Jonagold' (Crassweller *et al*., 1991; Kappel *et al*., 1992; Greene & Autio, 1993).

Daillant-Spinnler *et al.* (1996) developed a highly successful DSA method for quantifying the eating quality of fresh apples, which has been used as the basis of DSA of apple in several studies (Jaeger *et al*., 1998; Andani *et al*., 2001; Kühn & Thybo, 2001). A 12-member trained panel analysed apple cultivars for an extensive list of sensory attributes. Attributes were evaluated on unstructured line scales ranging from zero intensity to prominent intensity and were divided into attributes relating to external appearance, external odour, internal odour, first bite texture, texture during chewing, flavour during chewing and afterswallow. The results indicated that the mean panel scores of each attribute for each cultivar could be considered accurate estimates of the cultivars' sensory profiles. Several associations were evident from principal component analysis (PCA) plots: 1) Positive correlations were found between appearance and flavour attributes relating to green apples, 2) green apples associated with acidic/sour, unripe apple and cooking apple attributes, and 3) spongy and fluffy textures associated with sweet attributes. Peeling did not affect the sensory profiles of most apple cultivars (Daillant-Spinnler *et al*., 1996).

A list of sensory attributes relating to texture (hardness, crispness, firmness, mealiness, juiciness and peel toughness) and flavour (sweetness, sourness, unripe flavour, apple flavour, duration of apple flavour after swallowing and overripe flavour) was developed during training sessions of panellists in a DSA study conducted by Kühn and Thybo (2001). A 15 cm unstructured line scale was used in this study, anchored with "none" at the low end and "very strong" at the high end. ANOVA illustrated that the six cultivars used in the study could be differentiated by the sensory attributes. PCA showed that sensory attributes such as hardness, crispness, firmness, sourness and unripe flavour associated with each other. Sweetness and perfumed flavour associated, and were situated closer to mealiness compared to sourness and unripe flavour. Although these authors referred to the sensory evaluation of appearance attributes, no descriptions of these attributes were reported. Later Seppä *et al.* (2012) quantified the visual sensory attributes relating to green colour, red colour, relative area of red and amount of peel wax.

Corresponding panellists were used in DSA studies by Daillant-Spinnler *et al.* (1996) and Andani *et al.* (2001). Andani *et al.* (2001) profiled three commercially available cultivars for attributes relating to first bite texture, texture during chewing and flavour during chewing. Attribute intensity was measured on 100 mm line scales. DSA data from each attribute were subjected to two-way ANOVA, where samples (cultivars and storage treatment) and assessors were used as main factors. Assessors could distinguish significantly (P<0.0001) between samples. Sample scores were thus averaged across assessors and replicates and sample mean values were used as input for PCA using a correlation matrix. Clear distinctions could be made between groups of attributes and the principal component that described differences between cultivars was spanned between red apple, pear-like and sweet flavour on one side, and unripe apple, acid/sour, green apple and cider flavour on the other side. Jaeger *et al.* (1998) conducted PCA on the DSA data obtained by Andani *et al.* (2001) and consumer data from a different consumer group. Differences in flavour and texture were explained by the first and second preference dimensions, respectively.

2.2 Measurement of fruit quality using instrumental analyses

Instrumental measurements of fruit quality attributes have become one of the cornerstones of quality assessment (Oraguzie *et al*., 2009). Legal standards for edible quality of apples have been set and the apple industry primarily uses quality standards that are based on numerical limits obtained by instrumental measurements (Harker *et al*., 2008; Oraguzie *et al*., 2009).

Apple flavour is a complex attribute that constitutes relative levels of sugars, acids and flavour volatiles (Rowan *et al*., 2009). Instrumental analysis of flavour volatiles requires expensive instrumentation such as gas chromatography-mass spectrometry (GC-MS) or the electronic nose that are not generally used for routine analysis of apple quality. The relative contribution of flavour volatiles to apple flavour is dependent on the apple cultivar and its maturity (Rowan *et al*., 2009). Destructive measurements of total soluble solids (TSS) and titratable acidity (TA) are measured as proxy for sweetness and acidity (Harker *et al*., 2008; Oraguzie *et al*., 2009). TSS in apple juice is measured with a refractometer and TA by titrating the juice with 0.1 M NaOH to an endpoint of pH 8.1. TA is expressed as the gram-equivalents of malic acid per litre of apple juice (Harker *et al*., 2002a).

The puncture test has become the most widely used instrumental measurement of apple texture (Harker *et al*., 1997). Fruit firmness can be determined using a Magness-Taylor penetrometer to test opposite sides of the fruit after the peel has been removed (Hampson *et al*., 2000; Harker *et al*., 2002b). Puncture measurements of apple are usually recorded as the maximum force required to push an 11 mm diameter probe with a convex tip into peeled apple flesh (Harker *et al*., 2002b). The data obtained by this method are expressed in terms of the force required to rupture cortex parenchyma cells, and thus represent a combination of cellular and macro cellular properties such as cell turgor and wall strength (King *et al.*, 2000). Other destructive instrumental measurements of apple texture include tensile measurements, the Kramer shear test, the twist test, measurements of chewing sounds and juice absorption (Harker *et al.*, 1997, 2002b). Sonic or vibrational methods are used as non-destructive measurements of apple texture (Abbott *et al.*, 1992).

Different dimensions of colour in apple peel can be measured by a chromameter. The Hunterlab method measures the colour in dimensions of hue, colourfulness and brightness. Hue angle is the attribute of visual perception according to which an area is perceived similar to one or two proportions of red, yellow, green and blue. Colourfulness relates to the amount of hue that an area exhibit. The relative perceived colourfulness (colourfulness in proportion to the brightness of white) is called chroma. Lightness describes the brightness of objects relative to that of a similarly illuminated white (Hunt & Pointer, 2011).

2.3 Instrumental measurement as a predictor of sensory response

The relevance of instrumental measurements in fruit quality analysis depends on the accuracy with which they are able to predict sensory responses (Oraguzie *et al.*, 2009). Although it is sometimes assumed that only instrumental analyses are unbiased and repeatable, these measurements do not accurately reflect the sensations perceived by humans (MacFie & Hedderley, 1993). Fruit flavour and texture are important drivers of consumers' liking for apples (Daillant-Spinnler *et al.*, 1996), but sensory analysis of these attributes is time consuming and many attempts have been made to replace sensory analyses with relevant instrumental measurements (Mehinagic *et al.*, 2004). Researchers are interested to determine whether the industry standards currently used for apple quality assessment are based on appropriate quality measurements (Harker *et al.*, 2008).

Several researchers have studied the relationship between sensory descriptors and instrumental measurements of texture (Child *et al.*, 1984; Watada *et al.*, 1985; Płocharski & Konopacka, 1999; King *et al.*, 2000; Harker *et al.*, 2002b). Harker *et al.* (2002b) correlated different instrumental texture measurements, conducted on peeled samples, with sensory data generated by a trained panel. Puncture tests consistently provided a good prediction of firmness, crispness and crunchiness, compared to tensile tests and Kramer sheer tests. Harker *et al.* (2002b) reported that several factors influenced the correlations between instrumental and sensory measurements, including the variation between the texture of apples at the point of instrumental measurement and the different regions of the fruit eaten by different panellists (Harker *et al.*, 2002b). They found that the prediction of sensory texture was equally good when using a single puncture measurement on the shaded side of the fruit compared to when averages were calculated from puncture measurements on the shaded, as well as the non-shaded side. Higher crispness in apples from the early compared to the late harvest was detected by the trained panel, but puncture tests could not predict these texture differences. Conversely, mechanical hardness had to increase above a certain threshold (6 N) before the panel could detect a texture difference with high certainty. Harker *et al.* (1997) reported that sensory perception of apple hardness could detect larger textural differences compared to instrumental measurement of firmness. Płocharski and Konopacka (1999) found that instrumental measurements were better able to distinguish between texture differences in very firm fruit than sensory measurements.

Oraguzie *et al.* (2009) conducted a study on a typical population used for postharvest studies in an apple breeding programme. Four expert assessors analysed perceived firmness on a 0-9 quality scale and results were compared to puncture measurements taken on the blushed, as well as shaded sides. The relationships between sensory and instrumental measurements were examined using scatterplots, augmented with non-parametric smoothed fits and modelled using ordinary least squares regression. Differences in correlations for sensory and instrumental measurements were reported between different assessors. Thybo *et al.* (2003) and Brookfield *et al.* (2011) reported that correlations between sensory and instrumental measurements are cultivar dependant and proposed that the variances in instrumental and sensory correlations reported in the literature could be ascribed to the different cultivars that were used. Thybo *et al.* (2003) used a trained panel to analyse sensory attributes of unpeeled samples and confirmed previous findings that the conventional puncture test cannot always predict the appropriate sensory response. 'Granny Smith', for example, showed the highest values for the sensory attributes cohesiveness, hardness and crispness, but did not have the highest instrumental texture values. The authors suggested that a possible reason for these contradicting results could be ascribed to peel toughness reflected in the sensory data, while the peel was removed for instrumental texture measurement. Mehinagic *et al.* (2004) considered the combined effect of the apple peel and flesh, and reported high Pearson correlation coefficients between puncture measurements and sensory assessment of crunchiness on unpeeled samples. "Crispness" has been used to describe perceived firmness (Harker *et al.*, 2002b; Oraguzie *et al.*, 2009; Brookfield *et al.*, 2011) and showed strong correlations with hardness due to perceptual interactions discussed earlier (King *et al.*, 2000).

Juiciness is an important measurement that drives liking for a large proportion of consumers (Daillant-Spinnler *et al.*, 1996) and also distinguishes between the texture of different apple fruit (Harker *et al.*, 1997; Barreiro *et al.*, 1998; Harker *et al.*, 2002b; Mehinagic *et al.*, 2004). Juiciness is influenced by the mechanical properties of tissue and strong correlations with crispness have been observed (Brookfield *et al.*, 2011) due to the stronger inter-cellular bonds in the middle lamella of adjacent cell walls of very crisp apple fruit and the juice released when cells break open during mastication (Harker *et al.*, 1997). Mealiness develops during storage (Mehinagic *et al.*, 2004) and is inversely correlated with juiciness (King *et al.*, 2000). These are complex sensations in the mouth that cannot accurately be predicted by puncture measurements and instrumental measurements of juice absorption (Barreiro *et al.*, 1998; Karlsen *et al.*, 1999; King *et al.*, 2000; Brookfield *et al.*, 2011). Linear discriminant analyses (LDA) was used by Brookfield *et al.* (2011) to search for a combination of sensory and instrumental texture measurements that best discriminate between the textures of different cultivars. Mehinagic *et al.* (2004) used multilinear regression on a combination of penetrometry, compression and spectroscopic data in order to provide more accurate predictions of juiciness. Penetrometers measure the force required to penetrate the fruit flesh and describe different mechanical aspects of fruit texture than compression data that measures the force associated with the deformation of apple flesh between two parallel plates (Gálvez-López *et al.*, 2012). Although Gálvez-López *et al.* (2012) could not accurately predict sensory measurements of mealiness and juiciness by compression data, Mehinagic *et al.* (2004) found that compression data were better predictors of juiciness and mealiness than penetrometer measurements.

The above-mentioned tests all constitute destructive measurements and attempts are currently being made to develop new, reliable, non-destructive analytical techniques based on near-infrared (NIR) spectroscopy to assess fruit texture (Mehinagic *et al.*, 2004). Such measurements would be of immense value to fruit breeders, where destructive methods cause difficulties in analysing limited amounts of fruit in breeding programmes. Non-destructive texture measurements on apple, including an acoustic texture measurement, Sinclair Quality Firmness Tester and NIR spectroscopy, associate with puncture measurement (Harker *et al.*, 2008), which is a better predictor of the sensory attributes firmness, crispness and crunchiness than visible/NIR wavelengths (Mehinagic *et al.*, 2003).

Texture influences the sensory perception of certain flavour attributes and higher correlations were obtained when flavour attributes were correlated to texture and volatile composition measurements simultaneously (Karlsen *et al.*, 1999). Juiciness acts as a carrier for flavour components and thus affects flavour perception (Hampson *et al.*, 2000), whereby assessors can rate sweetness higher than it actually is in juicier fruit (Visser *et al.*, 1968). This interaction could be ascribed to linkage perception. Furthermore, ripeness influence the texture of the fruit (Harker *et al.*, 2002b) and correlations between sensory and instrumental measurements have shown to vary with the degree of ripeness of the fruit (Dhanaraj *et al.*, 1981).

The instrumental-sensory relationship for attributes relating to apple flavour has not been as extensively studied as is the case with measurements of texture. TA and TSS are often used to study the instrumental-sensory relationship for taste attributes (Harker *et al.*, 2002a) and volatile compounds have been used to study sensory flavour attributes (Karlsen *et al.*, 1999). Plotto *et al.* (1997) reported that instrumental-sensory relationships for sweetness and sourness were not significant. They ascribed these low correlations to the complexity of human sensory receptors and the variability between and within fruit. Although instrumental measurements can assess the compounds of an extract, it cannot accurately assess the composition of the aroma within the fruit when it is being chewed in the mouth and enzyme action and oxidation occur (Harker *et al.*, 2003).

Harker *et al.* (2002a) investigated the relationship between instrumental and sensory analysis of flavour with a 20-member panel trained in DSA. TA correlated strongly with sour taste and was one of the best predictors of overall and apple flavour. Oraguzie *et al.* (2009) used expert tasters to assess sour taste on a 0-9 scale and reported high correlations with instrumentally measured TA. Phenotypic correlations between TA and sour taste reported by Kouassi *et al.* (2009) for three different storage dates were comparably high to the values obtained by Harker *et al.* (2002a) and Oraguzie *et al.* (2009).

Although it is difficult to objectively predict the sensory attribute sweet taste, TSS measurement was found to be the best predictor (Harker *et al.*, 2002a). Watada *et al.* (1985) reported that the relationship between instrumental (TSS) and sensory measurement of sweet taste was not significant. Oraguzie *et al.* (2009) described the relationship as problematic and found a wide range of correlation coefficients for four different expert judges. Panellists were less able to discriminate between differences in sweetness at high TSS levels and assessed firm fruit as sweeter than softer fruit. Kouassi *et al.* (2009) observed that the correlation between sweet taste and TSS increased for successive measurements conducted at different times during a storage period of four months. The instrumental-sensory relationship for sweetness at harvest was considerably lower than the correlations reported by Harker *et al.* (2002a) and Oraguzie *et al.* (2009), but the correlation at four months' storage was in agreement with results from the literature. Poor correlations between sweet taste and TSS values could be explained by: 1) The quantitative dominance of fructose in the sugar profile of apples and the high relative sweetness of fructose; 2) flavour volatiles that influence sweet and sour perception (Harker *et al.*, 2002a) and 3) the strong masking effect of sour taste on sweet taste (Watada e*t al.*, 1985; Oraguzie *et al.*, 2009). Sweet taste is more influenced by sour taste than *vice versa* and trained panellists are therefore more likely to under- or overestimate the sweetness in the presence of a high or low acid content, respectively (Visser *et al.*, 1968).

For breeding, as well as general quality control in the apple industry, it is vital to ascertain sensory-instrumental relationships. The establishment of a valid correlation with prediction potential will reduce research time and cost. Although previous research on horticultural crops demonstrated the usefulness of preference mapping in directing fresh fruit development, scope for improvement still exists. One such area is the lack of using instrumental (TA, TSS and firmness) measures of fruit quality as an additional source of "external data" for preference mapping. Due to the importance of these measurements in horticultural new product development, the inclusion of such measures in preference mapping can incorporate information that is immediate meaningful and highly relevant to horticultural scientists (Jaeger *et al.*, 2003).

2.4 Measurement of consumer preference

2.4.1 Consumer preference and intrinsic sensory drivers of liking

Although DSA and instrumental measurements form an important part of fruit quality analysis, it is important to verify whether these measurements are appropriate in determining consumer acceptance (Harker *et al.*, 2008). When apple breeders aim to uncover directions for consumer-driven new cultivar development, it is essential to use preference data as a basis of the analysis (Jaeger *et al.*, 2003). One approach to determine the attributes that drive consumer preference is to compare results obtained from DSA with results from consumer preference analyses. Consumers are usually asked to indicate their degree of liking on a nine-point hedonic scale that ranges from 1 (dislike extremely) to 9 (like extremely) (Lawless & Heymann, 2010).

Several studies have been conducted to establish the relationship between sensory attributes and consumers preference (Daillant-Spinnler *et al.*, 1996). Although Lawless and Heymann (2010) suggested that a trained panel should be used for DSA, Plotto *et al.* (1997) used an untrained consumer panel to analyse overall liking on the nine-point hedonic scale, as well as sensory attribute intensity on nine-point category scales. Sensory descriptors were statistically correlated with preference scores and positive correlations ($P \leq 0.001$) reported between sweetness and overall liking ($r=0.5$ to 0.6), flavour and overall liking ($r=0.7$ to 0.8) and between sweetness and flavour ($r=0.5$ to 0.6) in 'Gala' and 'Fuji' apples. Hampson *et al.* (2000) used a trained panel to assess sensory attributes on a unipolar 0 to 9 intensity scale (where 0=not detectable and 9=extremely intense), as well as liking on a nine-point hedonic scale. Multiple regression analysis was used to ascertain the importance of attributes on overall liking of texture and flavour. Crispness accounted for over 90% of the variation in texture liking and juiciness and hardness also contributed significantly. Peel toughness did, however, not contribute significantly to degree of liking. It was suggested that textural attributes other than crispness could be eliminated due to the overwhelming importance of crispness in degree of liking. Flavour liking was more complex and was not predicted by sweetness, sourness or aromatics. Sweetness was positively related to taste liking and sourness showed a poor, negative correlation with liking. Sensory sweetness and sourness were better predictors of liking and disliking than TSS and TA measurements, respectively, in regressions with aromatics and juiciness (Hampson *et al.*, 2000). However, Harker *et al.* (2003) argued that using a trained panel for preference tests did not pertain to good scientific practice. Descriptive sensory panels are trained to distinguish between sweet and sour tastes, while consumers tend to integrate these tastes along with flavour volatiles into an overall sweet or sour sensation that drives their preference.

The high level of variability in consumer preference, as well as the variability among fruit from the same treatment often makes it difficult to identify single product targets. Data may seem ambiguous when some consumers respond positively while others respond negatively to a change in eating quality (Harker *et al.*, 2003), but the latter is an inherent phenomena of consumer preference. Preference mapping is a sophisticated multivariate technique that has been widely used to relate preferences to product characteristics and to understand the key sensory attributes that drive consumer preference (Daillant-Spinnler *et al.*, 1996, Thybo *et al.*, 2003). It constitutes a group of statistical techniques that analyse preference data by taking individual differences in consumers' preferences into account (Harker *et al.*, 2003). In this technique, a limited number of products ($N_{products}$) are described by two sets of variables viz. 1) consumer preference (X) defined by $N_{individuals}$ respondents and 2) $N_{product\ descriptors}$ sensory (Y_1) and chemical, physical (Y_2) measurements. A bi-linear modelling method, e.g. principal component regression (PCR) or partial least squares regression (PLSR), is used for extracting the main patterns of relationship between these two data tables, X and Y. When the $N_{products}$X$N_{individuals}$ preference table is used as Y and the $N_{products}$X$N_{product\ descriptors}$ instrumental and sensory table used as X, this is known as "external preference mapping". Internal preference mapping refers to the analysis of preference directions and the associated consumer segments. Information about the sensory properties driving preference can be obtained by projecting sensory attributes onto the sample map spanned by the key internal preference dimensions (Jaeger *et al.*, 2003). In PCA, the dimensionality of a data structure is reduced to a two-dimensional data bi-plot that simplifies the visualisation of a complex data structure. The first principal component (PC1) lies along the direction of maximum variance, which explains the largest part of the variability in the data. Higher order PC-directions usually explains small differences in the data relating to stochastic noise. Elimination of the higher order PC-directions enables the researcher to identify the sensory attributes that explain the largest part of the variation in the preference data, i.e. to identify the most important drivers of consumers' preference (Esbensen, 2006).

Jaeger *et al.* (1998) used PCA to relate sample mean values for sensory attributes assessed by a trained panel to consumer preference data (measured on a nine-point hedonic scale) in order to understand consumers' preference for mealiness. In general, preference was positively driven by sweet and fruity/floral flavours, while mealiness was a negative driver of consumer liking. PC1 was more strongly correlated to flavour differences, while PC2 explained textural differences. Conversely, a similar study conducted by Daillant-Spinnler *et al.* (1996) showed that texture and flavour explained the largest percentage of the variance on PC1 and PC2, respectively, while aroma and appearance drove the third and fourth preference dimensions, respectively. Sensory attributes, such as sour taste, unripe flavour and green apple flavour associated with each other, and showed a closer association with hardness compared to red apple flavour, sweet taste and floral flavour (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998).

While it is possible to correlate instrumental measurements to consumer preference (MacFie & Hedderley, 1993), few such studies have been published. Harker *et al.* (2008) projected instrumental attributes (firmness, TA, TSS) onto a preference map for five commercially available cultivars, viz. Red Delicious, Gala, Fuji, Golden Delicious and Braeburn. These preference maps showed that firmness (measured by a penetrometer) is the primary edible quality factor that contributes to consumer acceptance and preference in the USA. Thybo *et al.* (2003) used preference mapping methodologies to combine DSA generated by a trained panel, instrumental and consumer preference data conducted on six apple cultivars.

Although the shape, colour and appearance of fruit greatly impact on consumer preference, limited studies have been published on the methodology involved in the analysis of consumers' preferences for apple appearance. In a study that examined the preferences of pear appearance and response to novelty among Australian and New Zealand consumers, Gamble *et al.* (2006) presented consumers with high quality colour images of pears. Photoshop 6.0 was used to transfer the surface colour and texture from an original pear photograph onto a new image. Consumers were presented with nine choice sets that each contained three stimuli (differences in shape, colour and russet) and were then asked to indicate which of the images in each group they preferred. Beta coefficients and chi-square tests were used to illustrate that shape was more important than colour, while colour was more important than russet.

Cliff *et al.* (2002) proposed that variables such as size, shape and colour cannot be studied in isolation, because they all vary concomitantly from cultivar to cultivar. These authors suggested that digital imagery could be a valuable tool to study isolated visual attributes in apples, considering that the validity of using images instead of real products has been proven in earlier work (Jaeger & MacFie, 2001). Images were modified to create conical, round and oblong shaped apples (Cliff *et al.*, 2002). Three colour images (red, yellow and green) were digitally created for each shape. Blushed and striped apple images were also created. Consumers were presented with laminated images and requested to indicate their liking for appearance on a five-point hedonic scale. Preference data were analysed using a general linear model (GLM). Colour and fruit shape had a significant effect on consumers' preference for appearance. It was found that red apples had the highest mean score and yellow apples the lowest. On average, round and conical shaped apples were preferred to oblong shaped apples. Green backgrounds were preferred to yellow backgrounds for blush-type apples.

2.4.2 Consumer preference and sensory expectation

Consumers' perception of flavour is a factor of the integration of information provided by multiple uni-sensory inputs, including olfactory, gustatory, auditory and most importantly, visual information (Shankar *et al.*, 2010). Visual stimuli show a unique contribution to flavour perception by providing consumers with information prior to their consumption or purchase of food (Hutchings, 1977; Imram, 1999). Appearance includes several sensory attributes such as colour, opacity, gloss, visual structure and visual texture, of which colour is the most important (Imram, 1999). Colour carries important messages about the flavour of the food, by providing clues as to edibility, flavour identity, flavour intensity (Shankar *et al.*, 2010) and maturity (Steyn, 2012). Colour therefore strongly contributes to the sensory expectations generated by consumers that can result from perceptions of current stimuli, memories of actual experiences, conclusions drawn from similar experiences or information from the media and other consumers (Deliza *et al.*, 2003).

The influence of consumers' expectations on flavour perception and preference has been studied widely (Shankar *et al.*, 2010). The importance of colour in flavour perception is illustrated by colour matching of fruit-flavoured sweets and beverages. A difference between the expected and actual sensory attributes of a product could cause "disconfirmation" (Cardello & Sawyer, 1992) and lead to a reduced preference for its eating quality (Shewfelt, 1999). Sensory expectations have shown to influence consumers' perception of flavour intensity when they perceived appropriately coloured foods to have a stronger intensity and better quality aroma and flavour than uncoloured or inappropriately coloured foods (Christensen, 1983). Calvo *et al.* (2001) studied the influence of colourant concentration on the intensity perception of flavour and sweetness in four different yoghurt flavours. All samples had the same amount of sugar and flavour, but the perceived flavour intensity increased with increasing pigment concentration for several flavours.

Red colour is known to increase the perception of sweetness, probably due to the accumulation of sugars and red pigmentation during fruit ripening. Green colour is associated with immature fruit and generally judged to be less sweet (Clydesdale, 1993). Sensory integration thus forms the basis for the learned association of sweet taste with red colour and sour taste with green colour (Steyn, 2012). Consumers perceived 'Royal Gala' apples with a green background to be less ripe compared to apples with a yellower background (Richardson-Harman *et al.*, 1998). Consumers associated 'Red Delicious' apples with a sweet taste, while 'Granny Smith' apples may be associated with a sour taste (Jaeger & MacFie, 2001). The association between cultivar appearance and eating experience is firmly established in the mind of regular consumers of apples (Harker *et al.*, 2003). Crisosto *et al.* (2002) showed that the colour of 'Brooks' cherry changed from full light red to full dark red as the TSS of the fruit increased. A trained panel of 15 judges also perceived an increase in sweetness and cherry flavour intensity with each successive increase in peel colour. Consumer preference was positively correlated to peel colour and full dark red cherries were preferred.

Sensory integration is not homogenous among consumer groups and consumers from different backgrounds may generate different sensory expectations of colour as a result of their prior associative experiences (Shankar *et al.*, 2010). For example, British consumers may associate a brown coloured drink with the taste of cola and would consequently experience a disconfirmation upon presentation of a sour brown coloured drink. Conversely, Taiwanese consumers may associate a brown coloured drink with the slightly acidic taste of grape juice and their expectations would be confirmed when they are presented with an acidic brown coloured drink. The association between fruit colour and eating quality therefore depends on the fruit that consumers grew up with (Shankar *et al.*, 2010). Cliff *et al.* (2002) reported differences in colour preferences in apple among consumers from two different areas in Canada (British Columbia and Nova Scotia) and New Zealand. They ascribed these differences to greater familiarity with certain colour types in markets in these areas. It was suggested that New Zealand consumers recognised and preferred the attributes, i.e. round and striped, associated with the locally developed 'Gala' apple (Cliff *et al.*, 2002). Consumers also had integrated shape associations and the authors speculated that the low mean score obtained by an oblong shaped apple could have been due to its similarity to Delicious, an older cultivar known to acquire a mealy texture and poor flavour during storage. Gamble *et al.* (2006) suggested that New Zealand consumers' familiarity and thus high expectations of the taste of full russet pears resulted in a higher percentage of New Zealand consumers that selected full russet pears, compared to their Australian counterparts.

Another factor relating to expectations created by fruit appearance that could influence consumers' perception and preference for fruit quality, is the "halo-effect" (Von Alvensleben & Meier, 1990; Imram, 1999). This interdependency between the appearance of the fruit and the eating quality perception occurs when positive experiences are transferred across a number of attributes and cause consumers to have a higher expected preference for the eating quality of fruit if the fruit also have an attractive appearance (Oraguzie *et al.*, 2009). Jaeger and MacFie (2001) found that consumers who normally ate red apples expected a novel red cultivar to have a lower sour taste, crispness and juiciness, while consumers who preferred green or bi-coloured apples had different expectations. This suggests that the past experiences of these consumers of red apples had led them to have lower expectations of the sensory properties of the fruit. It is also possible that the higher quality associated with speciality (green and bi-coloured) apples may have gradually led consumers to expect a more intense sensory experience from these cultivars (Harker *et al.*, 2003).

2.4.3 Consumer preference and extrinsic or non-sensory drivers of liking

In addition to the sensory attributes discussed previously, consumer preferences are complex functions of non-sensory factors, such as attitudes and extrinsic product attributes (Prescott, 1998; Johansen *et al.*, 2010). Extrinsic attributes are not directly observable and relate to product information provided on health aspects, kilojoule content, organic production, storage time, origin, price, cultivar and packaging (Jaeger *et al.*, 1998; Péneau *et al.*, 2006; Racskó *et al.*, 2009; Johansen *et al.*, 2010). Consumers can extract intrinsic or direct product information from extrinsic attributes. For example, the same apple cultivar grown at more southern latitudes are perceived to be sweeter than apples grown in northern countries (Karlsen *et al.*, 1999).

Consumer characteristics (hereafter referred to as consumer data) can relate to differences in culture, ethnicity, familiarity, socio-economic status, age, gender, and social norms (Cliff *et al.*, 2002). Of these factors, culture is believed to be one of the most important determinants of food choice and has thus been studied from a number of different perspectives (Prescott & Bell, 1995; Jaeger *et al.*, 1998; Jaeger, 2000; Andani *et al.*, 2001; Rødbotten *et al.*, 2009), but is poorly understood (Pangborn *et al.*, 1988). Markets are becoming increasingly international and products are exported to countries where consumers have different preference patterns (Jaeger *et al.*, 1998). Therefore, producers, growers and trade organisations need to investigate how consumer preference and product characteristics depend on the cultural context (Jaeger *et al.*, 1998). In order to understand cultural influences on preference, it is important to include non-sensory factors in cross-cultural preference studies (Prescott, 1998). Value orientations are a central component of culture and can be used to explore cross-cultural differences in food related behaviour (Jaeger, 2000).

Discrepancies on similarities in chemosensory perception across cultures have been reported in the literature (Prescott *et al.*, 1997; Prescott, 1998; Garcia-Bailo *et al.*, 2009). Bretz *et al.* (2006) and Garcia-Bailo *et al.* (2009) reported that preference differences between different ethnic groups and individuals within the same ethnic group could be attributed to genetic variation in taste receptors. Variability in taste perception could be explained by polymorphisms of genes that code for taste receptors (Garcia-Bailo *et al.*, 2009). Fushan *et al.* (2009) reported that differences in taste sensitivity to sucrose could be explained by the expression of C or T alleles. Humans who were homozygous or heterozygous carriers of T alleles had a reduced sensitivity to sucrose compared to homozygous carriers of C alleles. Carriers of C alleles were more frequent in populations outside Africa, while the carriers of T alleles were most prevalent in sub-Saharan African populations (Fushan *et al.*, 2009). However, Prescott and Bell (1995) and Druz and Baldwin (1982) reported that chemosensory perception was similar across cultures. Australian and Japanese consumers did not disagree on the intensity of manipulated flavours when they were presented with foods that were common to both cultures and of which the concentration of taste attributes (sweetness, sourness, saltiness and bitterness) varied (Prescott & Bell, 1995). Taste thresholds for sodium chloride, sucrose, citric acid and caffeine did not differ significantly among American, Nigerian and Korean consumers living in the USA (Druz & Baldwin, 1982).

Even when sensory panels agreed on the intensity of flavour attributes, differences in consumer preferences for products were reported (Druz & Baldwin, 1982; Prescott & Bell, 1995; Prescott, 1998). Although interindividual differences in sweet taste detection thresholds have been recognised (Henkin & Shallenberger, 1970), the additive genetic contribution to liking of a sweet solution was found to be stronger than the genetic contribution to the discrimination of the intensity of a sweet solution (Keskitalo *et al.*, 2007). Bretz *et al.* (2006) reported that variance to sucrose sweetness preference could be attributed to a significant heritable component. It is expected that populations from sub-Sahara Africa would have a higher preference for sweet taste, due to their reduced sensitivity to sweetness (Fushan *et al.*, 2009). Bertino *et al.* (1983) found that American students gave higher preference ratings to cookies compared to Taiwanese students, while Taiwanese students gave higher preference ratings to salty solutions, because they were more familiar with salty foods in their cuisine. The range and availability of food flavours and odours differ across cultures. Preferences for these flavours and odours appear to be dependent on the context in which they are experienced, and therefore cultural preference differences are most likely a function of the different dietary experiences of different cultures (Prescott & Bell, 1995).

When investigating the impact of culture on food preferences, it is essential to take the close relationship between culture and familiarity with certain foods into account (Prescott & Bell, 1995; Prescott, 1998). Dietary habits are closely related to preference responses to foods with sweet, sour, salty and bitter substances added to these foods (Druz & Baldwin, 1982). Food attitudes are formed early in childhood and food habits are reinforced by a diversity of familial, social and cultural influences (Rozin & Schiller, 1980). Eating habits developed during childhood can have a significant impact on fruit and vegetable intake among adults (Harker *et al.*, 2003). For example, a study conducted among college students by Cheng *et al.* (1997) demonstrated that the apple cultivar served in the home by the parents had a long-term influence on the preferences of their children. Prescott *et al.* (1997) suggested that an unbiased assessment of cross-cultural preference can only be possible with culturally novel foods. However, Jaeger *et al.* (1998) argued that a more realistic approach would be to ensure a similar degree of familiarity with products prior to cross-cultural comparisons. Apples appear to be familiar almost worldwide, judging by *per capita* consumption (FAO, 2011) and could further be explored as a source to investigate cross-cultural preferences in a South African context.

There are limited reports from the literature on the effect of ethnicity on food habits, perceptions and preferences in the South African context. Pangborn *et al.* (1988) investigated whether the degree of liking for popular food fragrances varied across regions due to differences in traditional food habits among consumers from 22 countries, including South Africa. Consumers in this study were born and raised in the regions where the study was conducted. PCA suggested regional hedonic similarities, with evidence for closer agreement among people within geographic proximity ascribed to regional food usage. This study reported no significant difference between black and white South African consumers for hedonic ratings of fragrances. Apart from country and ethnic origin that contributed to differences in preference, limited conclusions could be drawn due to the small number of cases studied. Viljoen and Gericke (2001) determined differences in food habits and preferences of five different ethnic groups in the South African army. Similar preference ratings were often reported for foods that these ethnic groups were equally familiar with.

Differences in apple preferences between consumers from different age groups and genders have been reported (Kühn & Thybo, 2001; Thybo *et al.*, 2003). Kühn and Thybo (2001) found that children respond more positively to attributes of sweetness and flavour of apple and that mealiness and sour taste do not affect their taste preference. Other authors reported that adults mostly respond positively to firmness and that they dislike mealiness and high levels of acidity in apples (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998). Consumers' taste sensitivity remains unimpaired until the late fifties, but shows a sharp decline thereafter. Older consumers tend to have higher thresholds for sucrose and acetic acid than younger consumers, and men higher thresholds than women (Mojet *et al.*, 2001). Thybo *et al.* (2003) investigated the relationship between preference and demographic (age, gender) and behavioural data (fruit choice). It was found that girls preferred the appearance of green apples, but the taste of red aromatic apples, while the opposite was seen for the boys. No conclusion about the effect of an increase in age on appearance preferences or choice of fruit could be made.

2.4.4 Consumer grouping

Average hedonic values indicate general drivers of consumer liking, but do not inform about groups of consumers that can prefer some products to other groups (Carbonell *et al.*, 2008). Apple preference maps have shown that variability among individuals within the same socio-demographic group is often so great that overlap between consumers from different groups is inevitable (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998; Kühn & Thybo, 2001). Researchers are interested in how product attributes relate to individual differences in acceptance patterns and other consumer data such as attitudes, values and/or demographics (Næs *et al.*, 2010). Although demographics were traditionally used as the basis for consumer grouping, these methods are becoming less practical in the analysis and prediction of consumer behaviour (Buckley *et al.*, 2007). Similar demographic groups do not necessarily respond homogeneously to marketing variables and marketers and distributors should ensure that grouping factors are highly correlated to buying patterns (Richards, 2000). This would allow marketing managers to target specific groups with advertising and communication (Buckley *et al.*, 2007). Differences between consumer groups can relate to differences in age, gender, attitudes, needs, eating and purchase habits (Westad *et al.*, 2004). It is necessary to determine which consumers, or group of consumers, will respond most positively to the particular bundle of attributes of a certain cultivar (Harker *et al.*, 2003). If fruit quality is to be improved, different targets will be needed for each consumer group (Jaeger *et al.*, 2003). Marketers are increasingly using consumer lifestyles for explaining consumer behaviour, due to the impact of changing consumer lifestyles on the food markets. The role of cognitive processes and the importance of contextual factors are increasingly used to predict consumer preference (Jaeger, 2000).

Different techniques can be used to identify groups of consumers with similar preference patterns (Carbonell *et al.*, 2008). A grouping technique can be based on consumer data, where consumers are grouped based on demographic data and the preferences of these demographic groups are analysed; or on preference data, where consumers are grouped based on similar preference patterns. Grouping according to consumer data can rely on ANOVA to determine the effect of consumer demographics on preference (Helgesen *et al.*, 1998; Jaeger *et al.*, 1998; Cliff *et al.*, 2002). In this method, demographic groups and preference scores are used as main and interaction effects in ANOVA and significant interactions are investigated (Cliff *et al.*, 2002). Another method to investigate the effect of consumer data is to divide consumers into groups for demographic categories and relate these categories to preference dimensions in PCA (Jaeger *et al.*, 1998; Kühn & Thybo, 2001).

Kühn and Thybo (2001) grouped consumers based on socio-demographic factors and related the preferences of these groups to sensory attributes on a PCA plot. Age, gender and familiarity with apples did not affect consumers' preferences for apple attributes. Thybo *et al.* (2003) used a multivariate bi-linear analysis approach to relate apple attributes (instrumental analysis) and preference data (appearance and eating quality, measured on a five-point hedonic facial scale) to consumer data of Danish children (age, gender, food choices and attitude to fruit in general). Eating quality preference was analysed on unpeeled apple slices and appearance preference on whole fruit. Preference mapping using PLSR was conducted to illustrate associations between product attributes and consumer data. Consumers could be segmented based on their preference for either texture or flavour. A large group preferred 'Jonagold' and 'Elstar' with high apple flavour and low crispness and hardness, while another group preferred 'Granny Smith' with high crispness, moistness and low apple flavour. It seemed that high levels of texture properties were important quality characteristics for children choosing green apples, while high levels of aroma properties were important for children choosing red apple cultivars. Although the mean preference for the appearance was the highest for red cultivars Gala and Jonagold, two minor groups preferred the appearance of either the wine-red Gloster or the yellow-green Mutsu.

Cliff *et al.* (2002) used a general linear model (GLM) to evaluate the main and interactive effects of location (British Columbia, Nova Scotia or New Zealand) on preference for apple appearance attributes. Significant location*colour-type*shape*background-colour interaction showed that apple appearance preferences were dependant on consumers' location. Differences in preferences for appearance attributes were tabulated and compared. Similarly, Cliff *et al.* (1999) used ANOVA to investigate the effect of location (British Columbia and Nova Scotia), cultivar and order of presentation on visual, flavour and textural preferences of consumers. ANOVA revealed significant location effects for visual, flavour and texture preferences, which were then compared between consumers from the two locations.

Péneau *et al.* (2006) considered the interactions between consumers' demographic characteristics and the importance ratings they gave to several apple attributes for freshness perception. The importance of each attribute was taken as a dependent variable in a three-way ANOVA with age, gender and consumption of apples as factors. PCA was performed to study the data structure of the consumer data in relation to the importance of product attributes. Apple appearance was more important to young consumers (<30 years of age), while this group did not regard cultivar as an important aspect when choosing an apple. The effect of gender was significant in the importance ratings of attributes regarding choice of apples. Taste, aroma, freshness and cultivar were more important in determining the choice of females than males, while males regarded apple size more important than females (Péneau *et al.*, 2006).

Consumers with similar preference patterns can be grouped by visual grouping, where consumers from different quadrants in a preference map are considered as different groups (Daillant-Spinnler *et al.*, 1996; Carbonell *et al.*, 2008). These segments can then be related to consumer data by tabulation or regression analysis (Næs *et al.*, 2010). Alternatively, statistical programmes can group consumers with similar preferences, in which case the term 'segmentation' would be used. Cluster analysis is such a segmentation technique, where a method such as Ward's clustering can be applied. The relationship between preference groups and socio-demographic groups can then be quantified by the P-value of the test of independence (chi-square) between these two partitions (Vigneau *et al.*, 2011). The exploration of the relation between consumer data and attribute preference discussed here will be based on the availability of three data sets, viz. the samples containing the attribute information; preference data; and additional consumer data (for example, demographics, attitudes or habits). Næs *et al.* (2010) distinguished between two different methods of cluster analysis for relating preference data to consumer data: 1) Consumer data can be used as part of the primary data analysis, which is known as "*a priori*" use of consumer data; 2) alternatively, if the acceptance data are analysed first and then related to additional consumer data afterwards, it is known as "*a posterior*" use of the information.

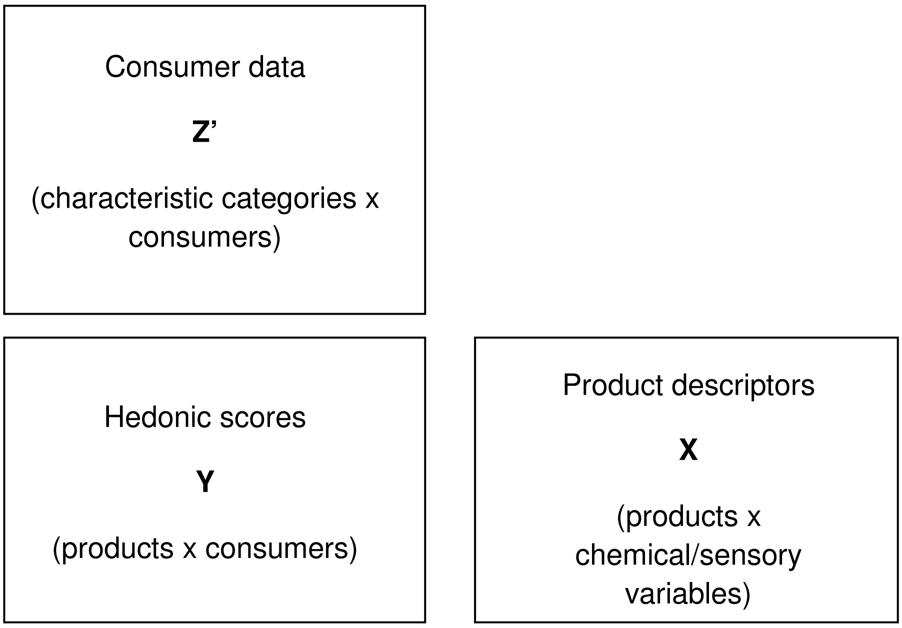

Figure 5 The L-shape structure of the data matrixes (adapted from Vigneau *et al.*, 2011).

An example of *a priori* use of consumer data is the L-PLS regression introduced by Martens *et al.* (2005) that combines all the data sets in the same model. A sum of interactions between some linear combinations of product descriptors and consumer characteristics approximate the acceptance data in L-PLS regression (Vigneau *et al.*, 2011). The focus of this method is on understanding the acceptance pattern directly as a function of the consumer data (Næs *et al.*, 2010). Double mean centred data (i.e. row and column centring) can be used in this procedure, which may reduce the component of differences in scale usage. Recently Vigneau *et al.* (2011) extended the clustering around latent variables (CLV) approach to a L-CLV approach, where data are organised in an L-shaped structure (Fig. 5). The L-CLV approach is similar to the L-PLS method introduced by Martens *et al.* (2005) in that three blocks of information are combined into a product matrix X, Y and Z and that the data structure is then investigated simultaneously. The main difference between these methods lies in the structure that is sought. A set of orthogonal PLS components are derived in PLS regression, which enable useful graphical displays; whereas L-CLV is devoted to the segmentation of consumers, with each consumer group that associates with latent variables with a focus on the interpretation of the obtained segments. An example of *a posteriori* use of the information is when a cluster analysis is conducted first, and the group membership is used as the categorical variable in further analysis. Multivariate techniques, such as PCA, can then be used to relate the group membership to preference dimensions (Næs *et al.*, 2010). In such a model, individual differences can be investigated further by using residuals from looking at the conjoint variables only. This method would result in a model without the random effects (Næs *et al.*, 2010).

Rødbotten *et al.* (2009) computed separate preference maps for Spanish and Norwegian consumers' preference for apple juice with different levels of sugar and acid. Similar preference patterns were generally shown for Spanish and Norwegian consumers. Jaeger *et al.* (1998) conducted a consumer preference study on British and Danish consumers in a cross-cultural context. Preference data from the British and Danish consumers were subjected to separate internal preference mapping. These two maps were then compared to examine whether visual clustering of these consumers' positions on the preference map related to cross-cultural differences. No evidence of a country specific grouping pattern could be observed. ANOVA was used to examine the influences of demographic characteristics and product use variables on consumer preference data. Demographic variables (age, gender and occupation) did not have a significant effect on consumers' preferences. Two groups could be distinguished for each of the two countries, viz. 1) a group with a higher preference for apple cultivars that associated more with crispness, hardness juiciness and grassy odour, whose preference was primarily driven by textural attributes, and 2) a considerably smaller group that showed a higher tolerance to the mealier samples and preferred sweet and floral flavoured apples, whose preference was primarily driven by flavour. Daillant-Spinnler *et al*. (1996) conducted an apple preference study among British consumers. Consumers who showed proximity on preference maps were assigned to similar preference groups. The distribution of individual consumers on these preference maps illustrated that two approximately equal size consumer groups could be distinguished, viz: a segment that preferred a juicy, sour apple ('Granny Smith') and a segment that preferred a sweet, hard apple ('Fuji').

Carbonell *et al.* (2008) suggested that the methods used by Daillant-Spinnler *et al.* (1996) and Jaeger *et al.* (1998) only take the information from the first two preference dimensions into account, while consumers who are closely represented on PC1 might show differences on the other preference dimensions. Carbonell *et al.* (2008) used the method described by Daillant-Spinnler *et al.* (1996) to group Spanish consumers according to their preference for apple eating quality, but additionally used a Ward's clustering method to statistically segment consumers with similar preferences. Both methods resulted in a four-cluster solution, but several consumers were assigned to different clusters when a different method was used. Approximately 30% of the consumers preferred sour and crisp 'Granny Smith' apples, while approximately 20% of consumers had a higher preference for 'Topred' apples that were sweeter and slightly mealier. The preferences of the remaining consumers were situated between sweetness and mealiness, and juiciness and sour taste. Hansen (2012) reported on an ISAFruit consumer segmentation study conducted in collaboration with several researchers in the EU. It was found that 68% of the consumers who participated in this study preferred sweet genotypes with a low acidity, while 26% of the consumers preferred sour, crisp apples. Harker *et al.* (2003) proposed that consumer preference for sour taste and firmness may partly reflect the biological limitations imposed by co-location of these genes on the apple chromosomes, as found by King *et al.* (2000). Repeated experiences have changed consumer preferences to match the biological limitations of the fruit (Harker *et al*., 2003).

New Zealand consumers were asked to rank their appearance preference for a set of pears in a study conducted by Jaeger *et al.* (2003). Hierarchical cluster analysis was used to establish four consumer segments based on liking and disliking of pear colour and shape. Each cultivar therefore needs to be considered in relation to the specific market niche and the group of consumers that will respond most positively to its particular bundle of sensory attributes (Harker *et al*., 2003).

Conjoint analysis can also be used to establish the relative importance of product attributes and consumer data on consumer preference. Different levels of a number of attributes are combined in a factorial design (Næs *et al*., 2010). Individuals are presented with hypothetical scenarios in which information such as quality, price, packaging and type of retail outlet are varied (Van der Pol & Ryan, 1996) and are then asked to indicate their degree of liking or purchase intent for each of these hypothetical scenarios/combinations of attributes (Næs *et al*., 2010), or to make a choice between a number of scenarios presented to them simultaneously (Gamble *et al.*, 2006). Jaeger (2000) investigated the effect of choice behaviour for an apple product by exploring cultural differences in food related behaviour among consumers from an individualist (New Zealand) and collectivist (Samoa) culture in a conjoint study. Cultural and demographic characteristics were analysed together in a PCA plot. Consumer groups that showed similar purchase behaviour could not be segregated from each other on the basis of socio-demographic information (Richards, 2000). Baker (1999) identified four consumer segments based on purchase behaviour: The biggest segment responded primarily to food safety issues; the second segment showed concerns for price, quality and safety issues; a small proportion responded primarily to levels of blemish on the apple surface; and a fourth segment responded primarily to price. Baker and Crosbie (1994) used conjoint analysis to identify groups of consumers with similar purchase behaviour, social values and demographic characteristics. Three consumer segments were identified: The first segment was characterised by consumers whose preference was driven primarily by price; the second segment was the biggest and represented the consumers who placed the highest value on apple quality; the third segment represented the consumers who were primarily concerned about pesticide use. Conjoint analysis is not used as a research technique in the current study and will therefore not be discussed in more detail.

3. APPLE BREEDING AND APPLICATION OF GENETIC PARAMETERS IN FRUIT BREEDING PROGRAMMES

3.1 Breeding new apple cultivars

In order to produce new cultivars of superior quality, breeding programmes should select and intercross only those individuals in each generation that show the ability to produce superior progeny (De Souza *et al.*, 1998). Fruit quality has steadily been improved through breeding by rejecting selections with inadequate internal and external fruit quality and poor storability. New selections are tested and selected for their suitability to modern storage conditions (Maliepaard *et al.*, 1999) and their ability to meet consumers' demands for eating quality (Hampson *et al.*, 2000). New breeding methods and strategies are required to improve the efficiency of specialised breeding programmes and to reduce the time in which novel cultivars can be produced (Maliepaard *et al.*, 1999; Brown & Maloney, 2003). The European Fruitbreedomics (http://fruitbreedomics.com/) and the RosBREED (http://www.rosbreed.org/) programmes are examples where latest molecular technology aims to speed up the conventional breeding process. Important areas for collaboration are the development of molecular markers for marker assisted selection and fruit quality assessment and sensory perception, which are not discussed in this review. Emphasis is placed on the application of quantitative analysis of genotypic variance of breeding families, which is the basis for marker assisted breeding.

Greater genetic diversity in apple breeding is necessary to develop new and innovative cultivars that meet consumer demands (Noiton *et al.*, 1996) and to reduce the risk of inbreeding depression (Kumar *et al.*, 2010). Breeders from around the world generally tend to work with a narrow genetic base, because they utilise the same popular cultivars as breeding parents for a large number of modern cultivars or they inter-cross cultivars from their own breeding programmes that performed the best (Noiton *et al.*, 1996; Kumar *et al.*, 2010). Currie and Oraguzie (2006) showed in a preliminary stochastic simulation study that this conventional method is not sustainable due to the erosion of genetic variation from the intense selection and the limitation of genetic variance in a breeding population. Furthermore, the genetic variance in breeding populations changes due to selection and selection pressure (Janick *et al.*, 1996).

Apple breeders are faced with several challenges that complicate the selection of promising new cultivars. Breeding new apple cultivars could take 15 to 25 years (Lespinasse, 2009), while the progeny resulting from a cross has to be maintained in the field at high costs until fruit quality attributes can be observed when the adult phase is reached. The long juvenile period of apple trees, strong self-incompatibility, slow growth and the polygenic and / or quantitative genetic nature of fruit quality attributes create major bottlenecks in breeding programmes (Liebhard *et al.*, 2003; Kenis *et al.*, 2008). Sensory and visual fruit quality attributes vary due to the heterozygous nature of apples and therefore large numbers of progenies need to be developed and screened to identify promising genotypes. In addition to eating quality attributes, attributes such as resistance against a variety of diseases and pests, growth habit, tree vigour and numerous generative attributes such as juvenile phase length, blooming habits and alternate fruit bearing should be considered

(Liebhard *et al*., 2003). Yearly climatic differences contribute differently to the variability of several attributes in fruit crops across different years and assessment of quality attributes should therefore be repeated for several harvest seasons (Labuschagné *et al*., 2000a; Kouassi *et al*., 2009). Selection for apples in a specific environment is complicated by large environmental effects that influence performance of apples in other environments (King *et al*., 2000). The development of procedures that can streamline the selection process can have substantial economic benefits in a breeding programme (Kenis *et al*., 2008).

3.2 Overview of current apple breeding programmes

Private and public apple breeding programmes are maintained in a number of countries around the world. Large breeding programmes were initiated more than 60 years ago in Europe and North America (Durel *et al*., 1998), but several of these programmes have been diminished, stopped or privatised in countries where production has declined or public funding rapidly reduced (Lespinasse, 2009). Private companies are increasingly interested in apple breeding to release trademark cultivars with profitable marketing potential (Lespinasse, 2009).

Despite very different locations, the breeding objectives of the respective programmes showed great uniformity. The main objectives in breeding programmes can be classified according to disease resistance of the apple scion, fruit quality and tree architecture. Resistance breeding includes resistance against apple scab (*Venturia inaequalis*), low susceptibility to mildew (*Podosphaera leucotricha*), fire blight (*Erwinia amylovora*) and storage diseases. Fruit quality relate to attributes such as texture, flavour, size, appearance, colour, transport resistance and shelf-life. Architecture refers to factors such as regular cropping and easy tree training (Lespinasse, 2009). The specific definition of fruit quality will vary depending on the specific programme and market requirements (Brown & Maloney, 2003). Most apple breeders do not focus on only one type of cultivar, but rather aim to release a wide range of selections with a variety of eating quality attributes and harvesting periods. Breeding programmes in China, Japan, Brazil and India focus on developing sweet tasting cultivars. The Summerland breeding programme in British Columbia, Canada, emphasises the importance of consumer preferences and sensory testing in the evaluation of their breeding programmes (Brown & Maloney, 2003). Some breeders select very specific types of fruit adapted to the preference of local consumers and growers. One breeding programme in Australia is aimed at selecting cultivars combining a red stripy outer colour, elongated shape with a firm, juicy and crunchy flesh (Laurens, 1999). In countries such as Finland and Russia, there is also a focus on the ascorbic acid content of the fruit (Laurens, 1999). Breeding goals could also encompass selections for specific environmental conditions. Examples include the Washington State University breeding programme that aims to develop cultivars adapted to the hot, dry and sunny climate of central Washington, the Fukushima Prefecture programme that aims to develop cultivars suited to Japan's warmer areas and Brazilian programmes that focus on low chilling requirement (Brown & Maloney, 2003). Several of these breeding programmes have successfully released apple cultivars to the market. Examples include 'Jonagold' from the breeding programme of the Cornell University in New York and 'Cripps' Pink'/'Pink Lady®' and 'Cripps' Red'/'Sundowner®' from the Western Australian breeding programme. The Centre for Plant Breeding and Reproduction Research in Wageningen, The Netherlands, has released several cultivars, of which Elstar is the most important. Honeycrisp™, Zestar™ and SweeTango® (a cross between the two cultivars) were released from the University of Minnesota fruit breeding programme in 1991, 1998 and 2009 respectively (Yue & Tong, 2011). Cultivars released from the national apple breeding programme in New Zealand include, Sciros, (Pacific Rose™), Sciearly (Pacific Beauty™), Scifresh (Jazz™) and Scilate (Envy™) (Kumar *et al.*, 2010).

The biggest apple breeding programme in South Africa is conducted by the Agricultural Research Council (ARC). The focus of the Breeding and Evaluation Division of ARC Infruitec-Nietvoorbij is the identification of promising new apple cultivars with good marketing potential, external and internal fruit quality that appeal to local and international consumers and adaptability to low winter chilling conditions. The programme aims to breed a full range of apple cultivars with ripening dates varying from early to late in the season (Halgryn *et al.*, 2000). The ARC apple breeding programme commenced in 1941 (Labuschagné, 2012) and African Carmine was the first major apple cultivar specifically developed for the export market. It was released in 1999 by the Breeding and Evaluation Division under controlled commercialisation in South Africa (Halgryn *et al.*, 2000).

Fruit quality evaluation of the ARC breeding programme can be divided into 4 phases: During the first phase, superior genotypes are selected from diverse breeding families. The second phase involves the testing of clonally propagated trees of the first phase selections in an evaluation site (one in Ceres and one in Grabouw) to evaluate fruit quality attributes, horticultural traits and disease resistance. Promising selections are identified during this phase and compared with commercial cultivars. During the third phase, these selections are given a semi-commercial status and are properly evaluated under varying climatic conditions. After evaluations in the third phase, cultivars reach the commercial phase, where it is released to the industry. The market potential is evaluated through collaboration with export companies (Labuschagné, 2012).

3.3 Application of genetic parameters in apple breeding

The success of breeding programmes depends on the genetic variability and the application of genetic parameters in the breeding plan (De Souza *et al.*, 1998). Estimation of genetic parameters such as heritabilities, variances and correlations among attributes under selection are extremely useful to predict genetic progress among offspring, especially when parental genotypes are selected on the basis of their own performance (De Souza *et al.*, 1998). These parameters provide a quantitative predictor of selection efficiency and can therefore be used to estimate the rate of genetic improvement in commercially important attributes (Daoyu *et al.*, 2002).

3.3.1 Estimation of genotypic variation within and between breeding families

Basic statistical analysis can be the first step in investigating the genetic variance in a population and usually includes the following statistical measurements for each attribute: Minimum and maximum values, mean, standard deviation and variance (Durel *et al.*, 1998). The total genotypic variation can be divided into genetic and non-genetic/environmental components (Falconer & Mackay, 1996). Studies of variation generally aim to partition variation into components that are attributable to different variance components, i.e., phenotypic (V_P), genotypic (V_G), additive (V_A), dominance (V_D), interaction (V_I) and environmental (V_E) components. The relative importance of a source of variation is the variance ascribed to that source, as a proportion of the total phenotypic variance. The magnitude of these components can be used to estimate the degree of resemblance between relatives and allows the breeder to estimate the role of heredity versus environment. The genotypic variance can further be divided into breeding value, dominance deviation and interaction deviation. V_A is the most important variance component and is the main cause of resemblance between relatives (Falconer & Mackay, 1996). Genetic and residual variance components can be estimated by restricted maximum likelihood (REML) that is considered as the optimum estimation or prediction procedure for unbalanced datasets (Durel *et al.*, 1998; King *et al.*, 2000). BLUP (best linear unbiased prediction) is an alternative method that can be used for parent selection based on their predicted breeding values, but utilises all information on individuals for which phenotypic values and pedigree are available. In this method, the correlation between predicted and true breeding values is maximised, as well as the probability of correctly ranking any two individuals.

ANOVA is usually conducted in order to quantify the total variance (σ^2_T) within and between progenies. ANOVA can be used to study the variance structure of seedlings in families, where standard quantitative genetic principles are applied to estimate the underlying causal components of variance (Labuschagné *et al.*, 2002a). The measurement of the degree of resemblance between relatives relies on the partitioning of the phenotypic variance into components corresponding to the grouping of individuals into families. The total observed variance can be portioned into two components by ANOVA, viz. between-family variance and within-family variance. The between-family component as a proportion of the total variance expresses the degree of resemblance between families and is known as the intraclass correlation coefficient (Falconer & Mackay, 1996). ANOVA is a useful method to quantitatively estimate the variance contributed by interactions such as genotype by environment interaction (G*E), genotype by season interaction and trees within genotype interaction. The variation that cannot be accounted for by the specified variances are incorporated in the error term and usually include measurement errors, variation of fruits within a tree and sampling variability (Thaipong & Boonprakob, 2005). The variance structure can be broken down into the following: Variance of seedlings within families of the same cross; variance between families; variance attributed by year; year*family interaction (Y*F); year by seedling interaction within families; environmental variance and genotype*environment (G*E) interaction (Falconer & Mackay, 1996). Breeders are particularly interested in the quantification of the environmental effect by determining the G*E interaction and the magnitude of this interaction on the heritability of fruit quality attributes (King *et al.*, 2000; Alspach & Oraguzie, 2002).

3.3.2 Heritability estimates

Heritability of an attribute is the relative importance of heredity in determining phenotypic values (Falconer & Mackay, 1996). Heritability can refer to genotypic values or to breeding values. Heritability in the broad sense (degree of genetic determination) refers to the ratio of V_G:V_P and expresses the extent to which individual's phenotypes are determined by their genotypes (Falconer & Mackay, 1996). It measures the relative importance of nature versus nurture in the expression of a quantitative attribute (Bernardo, 2002). Heritability in the narrow sense (or simply heritability) refers to the ratio of V_A:V_P and expresses the extent to which phenotypes are determined by the genes transmitted from the parents (Falconer & Mackay, 1996). Narrow-sense heritability determines the degree of average resemblance between relatives (Falconer & Mackay, 1996) and the amount of progress that can be made from selecting and recombining the best individuals in a population (Bernardo, 2002). While broad-sense heritability measures the variance due to the interaction effect of two alleles that constitute the genotype at a locus, narrow-sense heritability is a measure of the variance due to mean effects of single alleles (Abney *et al.*, 2001).

Calculation of heritability estimates is a useful method to study genetic changes in a breeding population undergoing selection (Falconer & Mackay, 1996). The estimation of heritability for any attribute requires the separation of the observed variation between genetic effects and environmental effects. Selection for attributes with high heritability in a population with high genotypic variability results in large genetic gains per generation (De Souza *et al.*, 1998), while attributes with low values for both narrow- and broad-sense heritability estimates would not be improved in a population (Daoyu *et al.*, 2002). Narrow-sense heritability values of 0.3-0.4 can be regarded as favourable and should increase the efficiency of mass selection in the field (Durel *et al.*, 1998). In addition to heritability, selection response is also a product of selection differential and a large selection response can therefore not be guaranteed by a high heritability value. The selection differential can be defined as the average amount by which chosen individuals exceed the population mean for a quantitative trait (Falconer & Mackay, 1996). Heritability is a function of the population's variability, the environmental conditions to which individuals are submitted

(Falconer & Mackay, 1996), the experimental design, size of the population, method of data collection and the statistical procedure used to produce the estimates (De Souza *et al.*, 1998; Oraguzie *et al.*, 2001). Single year heritabilities are expected to give a low precision and it is therefore recommended that heritability results should be supported by data of two or more years before the information can be incorporated into a breeding programme (Oraguzie *et al.*, 2001).

3.3.3 Genetic and phenotypic correlation

In genetic studies it is important to distinguish between two causes of correlation in attributes, viz. genetic (additive genetic component) and environmental correlation (all the rest) (Falconer & Mackay, 1996). Genetic correlation expresses the extent to which two attributes are influenced by the same genes and can result from pleiotropy or linkage effects. Pleiotropy is the property of a gene whereby it affects two or more attributes and linkage is a cause of transient correlation (Falconer & Mackay, 1996). Genetic correlation can be estimated by computing the offspring-parent relationship or the components of covariance of the two attributes from an analysis of covariance that corresponds to the ANOVA (Falconer & Mackay, 1996). Phenotypic correlation is the correlation between directly observable attributes (phenotypic values) and is a non-additive combination of genetic variance, environmental variance and G*E interaction (Lavi *et al.*, 1998). It is therefore the overall effect of all the segregating genes that affect both attributes (Falconer & Mackay, 1996) and can be estimated as the Pearson's correlation coefficients between the attributes in the progeny population (Alspach & Oraguzie, 2002). Genetic and phenotypic correlations are indicators of the possibility to simultaneously improve two attributes. Strong positive correlations between two attributes indicate that selection for simultaneous improvement of these attributes can be efficient, but is not desirable when the favourable attribute is associated with an unfavourable attribute, or when different degrees of expression of two attributes are required. A negative genetic correlation is not advantageous when it involves two favourable attributes (Falconer & Mackay, 1996).

3.4 Results from genetic studies in fruit breeding

Several methodologies can be used to estimate the success of selective breeding for favourable attributes. Estimation and quantification of genetic and environmental variance have been made in many fruit crops as part of ongoing breeding programmes, including guava (Thaipong & Boonprakob, 2005), mango (Lavi *et al.*, 1998), peach (Cantín *et al.*, 2010), kiwifruit (Daoyo *et al.*, 2002), avocado (Lavi *et al.*, 1993), strawberries (Shaw, 1990), almond (Chandrababu & Sharma, 1999) and melon (Zalapa *et al.*, 2008). Rowan *et al.* (2009) estimated heritabilities and genetic and phenotypic correlations of apple fruit volatiles. The inheritance of physiological attributes in apple trees has been studied (Gelvonauskis, 1999). Earlier studies have relied on illustrations of seedling distribution graphs and parental means to determine dominance of attributes, but modern breeders are interested in the quantification of the variance component contributed by genetic effects.

Several agronomic and fruit quality attributes have been quantified in published studies on apple, viz. tree height, trunk diameter, crown diameter and density, internode length and diameter, circumference of the trunk, stem diameter, plant height increment, leaf size, blooming time, blooming intensity and juvenile phase, powdery mildew resistance, over-colour, russet, size, weight, shape, firmness, juiciness, crispness, hardness, sponginess, granularity, mealiness, flavour, fruit cracking, waxiness of the fruit peel, acidity, TA, sweetness, TSS and astringency (Durel *et al*., 1998; Currie *et al*., 2000; King *et al*., 2000; Alspach & Oraguzie, 2002; Liebhard *et al*., 2003; Iwanami *et al*., 2008; Kouassi *et al*., 2009). The genetic variability of attributes associated with prolonged dormancy in apple progenies (i.e. time and extent of bud break, and flowering duration) planted in South Africa has been studied by Labuschagné *et al.* (2002a, b, c). Other than this, limited information is available from the literature on the genetic quantification of fruit quality attributes conducted on progenies planted in South Africa.

Apple colour is vital in determining consumer acceptance (Steyn, 2012). The red colour in apple fruit is produced by anthocyanins (Telias *et al*., 2011). The heritability of anthocyanin has been studied to explain the mechanisms of inheritance for attributes relating to fruit colour (Janick *et al*., 1996). The production of anthocyanin is a complex process that is influenced by several factors, including light and other environmental factors such as temperature and nutrient supply (Honda *et al*., 2002; Xu *et al*., 2012). There are two categories of genes that affect anthocyanin biosynthesis: The first category encodes enzymes required for pigment biosynthesis (structural or biosynthetic genes) (Honda *et al*., 2002); and the second category is comprised of transcription factors, which are regulatory genes that influence the intensity and pattern of anthocyanin expression (Telias *et al*., 2011). Honda *et al*. (2002) found that anthocyanin expression is polygenically controlled and that at least five genes are co-ordinately expressed during anthocyanin expression. Lin-Wang *et al*. (2010) found that three MYB activators of apple anthocyanin are alleles of each other and that groups of structural genes are thus tightly linked. The levels and expression of these five genes were found to be positively related to the degree of anthocyanin concentration (Espley *et al*., 2007). Structural genes that control anthocyanin synthesis are more easily expressed in red fruited genotypes compared to yellow and green genotypes (Ju *et al*., 1999), where anthocyanin transcription factors are altered (Kim *et al*., 2003). Yellow and green apples will thus accumulate red pigments in part of their peel upon exposure to sunlight (Telias *et al*., 2011).

King *et al.* (2000) showed the genetic contribution to fruit texture. These researchers used an 11-member trained sensory panel to determine the genetic variation in a large breeding population for attributes relating to apple texture, including first bite-texture and texture during chewing. A quantitative genetic analysis was conducted for two seasons on instrumentally measured attributes as well as sensory attributes that were measured on a scale ranging from 0-100, denoting zero to extreme. For this study, the overall genotypic estimates of penetrometer readings and sensory descriptors were analysed by PCA. Penetrometer measurements comprise more and different underlying genetic components than those involved in sensory descriptors, because relatively few quantitative trait loci (QTL) were detected for sensory textural attributes (King *et al.*, 2000). Sensory descriptors of fruit texture (crispness, juiciness, hardness) showed higher heritabilities than instrumentally measured attributes (penetrometer readings and stiffness as measured with acoustic resonance). G*E interaction was not significant for sensory textural attributes, but 43% of the variability for penetrometer data could be accounted for by environment, and 25% by G*E interactions.

Discrepancies on the heritability of sensory measured fruit texture recorded in the literature can partly be ascribed to the influence of maturity on textural attributes (Alspach & Oraguzie, 2002). Inappropriate harvest dates would lead to higher residual variances, lower within-family variances and lower heritability estimates (Alspach & Oraguzie, 2002). These authors recorded very low heritability estimates for crispness and juiciness, but relatively low heritability estimates for firmness (0.35), which were comparable to values reported by Durel *et al.* (1998) for juiciness and firmness, but generally lower than values reported by King *et al.* (2000). Alspach and Oraguzie (2002) specifically ascribed the higher heritability estimates obtained by King *et al.* (2000) to their ability to better determine the appropriate harvest date when working with a single cross of known parents, compared to when a diverse open-pollinated population is used.

Lower heritabilities for sensory measured attributes can further be ascribed to an important extra component attributable to assessors, which inflates the residual variance component (Oraguzie *et al.*, 2009). This component was higher in a two-member trained panel, compared to when the mean score of 11 trained panellists were used by King *et al.* (2000). The residual variance component can be reduced when variances attributed to judge differences are minimised in a larger trained panel (King *et al.*, 2000), and when sensory discrimination between genetic differences are maximised by the use of a 0-100 continuous scale (Hansche *et al.*, 1972). For the study by Alspach and Oraguzie (2002), variance components were determined on sensory data generated by two trained panellists using a 0-9 rating scale for two seasons. De Souza *et al.* (1998) found higher heritability estimates when a 0 to 9 scale was used, compared to when they used a 1 to 4 scale. Although objective measurements of taste such as TSS and TA should result in a reduced residual component compared to sensory analysis of sweet and sour tastes (Alspach & Oraguzie, 2002), TSS is not a good indicator of perceived sweetness (Harker *et al.*, 2002a).

Alspach and Oraguzie (2002) and Durel *et al.* (1998) found that the phenotypic and genetic correlations between several attributes were generally in agreement. Conversely, Kouassi *et al.* (2009) and Alspach and Oraguzie (2002) reported that the negative association between sweet and sour taste were stronger for phenotypic compared to genetic correlations. Positive correlations between sensory measurements of texture, such as crispness, juiciness and firmness have been reported in the literature (King *et al.*, 2000; Alspach & Oraguzie, 2002). Positive correlations between different sensory measures of texture and between sweet and sour taste could be related to human perception which tend to integrate these attributes, rather than to the inherent segregation of genes for these specific attributes *per se* (Alspach & Oraguzie, 2002). King *et al.* (2000) proposed that genetic factors may be masked by other genes which may overrule their expression in human perception, leading to perceptual interaction (linkage perception).

QTLs

A QTL is a genetic locus, with alleles that play a role in the outcome of genetic variation. Generally, quantitative attributes are multifactorial and are influenced by several polymorphic genes and environmental conditions, i.e., one or many QTLs can influence an attribute or a phenotype. The availability of molecular markers and genetic linkage maps allows the localisation of major genes and the dissection of complex, polygenic attributes into a number of QTLs. QTL analysis is used to unravel the mechanisms underlying the genetic control of important attributes in apple fruit quality and QTLs for attributes such as sugar level, acidity level and apple fruit texture have been identified (King *et al.*, 2000; Liebhard *et al.*, 2003; Kenis *et al.*, 2008). Liebhard *et al.* (2003) reported four QTLs for instrumentally measured fruit flesh firmness, eight QTLs for fruit weight and attributed sugar concentration (TSS) to five genomic regions. These results provided evidence for the polygenic mode of inheritance for these attributes suggested by other authors (Visser *et al.*, 1968; Janick *et al.*, 1996; King *et al.*, 2000).

4. EVALUATION OF FRUIT QUALITY ATTRIBUTES IN APPLE BREEDING PROGRAMMES

Fruit quality assessment forms an important part of any breeding programme (Laurens, 1999). The most important criteria for evaluation of eating quality that is commonly included in the assessment of breeding programmes relate to textural attributes such as crispness, firmness, juiciness and taste attributes such as sugar and acid concentration (Redalen, 1988; King *et al.*, 2000; Kouassi *et al.*, 2009). Although flavour is recognised as an important quality attribute, it is complex to quantify and therefore not always assessed. Apple appearance evaluation includes assessment of ground colour, over-colour, type of colour, fruit shape, size, lenticel conspicuousness and russet coverage (Ju *et al.*, 1999; Laurens, 1999; Hampson & Quamme, 2000; Alspach & Oraguzie, 2002).

Although instrumental measurements are available for the assessment of several eating quality attributes, only those for firmness, TSS and TA are generally considered practical for the assessment of a breeding population in the first phase. The postharvest evaluation and pre-release trials of apples have always relied on an element of sensory assessment, whether the assessors were the experimenters/breeders themselves or other participants (King *et al.*, 2000; Oraguzie *et al.*, 2009). The large amount of fruit that needs to be assessed within a short time after harvest limits the use of large assessor groups in the first selection phase (Oraguzie *et al.*, 2009). Breeding programmes therefore often rely on a single 'expert taster', or small teams of expert tasters (2-4), for sensory evaluation of the population (Brookfield *et al.*, 2011). The experience of the 'expert taster' can relate to: 1) Familiarity with a product class as the result of long term exposure to a wide variety of products in that specific class and 2) a clear understanding of the product's sensory attributes (Gawel, 1997). The term 'expert' in this case refers to individuals who are well-experienced in the sensory assessment of a breeding programme (Oraguzie *et al.*, 2009). In South Africa, the general tendency is to use the plant breeder for evaluating the eating quality and appearance attributes. Evaluation is conducted using a composite sample of three or five fruit per seedling for all the seedlings within the breeding programme. Sensory attributes can be categorised or measured on unstructured or structured line scales (Durel *et al.*, 1998; King *et al.*, 2000; Alspach & Oraguzie, 2002). Depending on the type of data, the data can be categorised using frequency distribution (Durel *et al.*, 1998), univariate ANOVA can be used to test for significant differences in families for continuous or interval data or a multivariate technique such as PCA can be used to test for association between seedlings and sensory attributes (Cantín *et al.*, 2010). Limited research information is available on the methodology of eating quality and visual assessment within breeding programmes.

Many breeders rely on their own judgement to quantify attributes relating to eating quality and appearance and thereby identify the most promising and tasty selections among the many generated by controlled crosses (Hampson *et al.*, 2000). Limited information is available from the literature on the viability of using expert tasters, who can either work individually or in small teams. However, use of these small teams of tasters from breeding programmes has continued to be the basis of germplasm evaluation (Oraguzie *et al.*, 2009). In a study conducted by Alspach and Oraguzie (2002), two trained assessors had to agree upon the intensity of sensory attributes, measured on a scale ranging from 0 (none) to 9 (extreme/severe). Gálvez-López *et al.* (2012) used four expert assessors who worked in two separate groups to rate sensory attributes. Sensory data generated by small teams can be analysed per individual assessor, mean scores can be computed from the group's assessment or assessors can generate an agreed score (Alspach & Oraguzie, 2002; Oraguzie *et al.*, 2009).

Oraguzie *et al.* (2009) investigated the effect of judge by comparing the correlations between two experts who assessed the same fruit for a variety of attributes. They also determined the difference between the highest and lowest mean for each of four experts for several sensory attributes. The correlations between the same expert's assessments of different fruit from the same tree were higher than the correlations between different experts' assessments of the same fruit. Furthermore, the correlations between assessors differed for different attributes, and were for example higher for firmness than for sweetness. These authors suggested that individual assessor scores should always be recorded and selection should be based on the data only after adjustments for assessor differences have been made. Hampson *et al.* (2000) performed a mean separation by judge to monitor assessor consistency for evaluation of sensory attributes. Variation between judges were attributed to differences in perception and personal preferences, differences in scale usage and differences among samples within a selection. Judges were used as blocks in the ANOVA, in order to remove the effect of judges using different parts of the scale. Judges who perceive differences among selections in magnitude or direction from the other judges can easily inflate the judge*selection interaction that is incorporated into the error term. Error term inflation reduces the sensitivity of measurement and it is vital to train judges sufficiently to reduce this tendency or to include sufficient control samples or reference standards throughout the experiment to ensure standardisation of the sensory methodology (Hampson *et al.*, 2000).

The problem of the assessor effect has been reduced by more advanced forms of sensory analyses in addition to the breeder's expert evaluation of apple selections. In recent years, the approaches to tasting of fruit have been greatly influenced by the development of formalised sensory evaluation techniques such as DSA. The maximum treatments (12) that can be analysed over a short time in DSA studies are much smaller than the number of fruit treatments that need to be analysed during a breeding programme (Oraguzie *et al.*, 2009). Furthermore, replicated measurements, according to an experimental design, are preferred for analysis of advanced selections (Lawless & Heymann, 2010). Although the use of a trained panel to evaluate large populations of fruit in a breeding programme is rare, it appears to be successful (Deslaures *et al.*, 1999; King *et al.*, 2000; Hampson *et al.*, 2000). Hampson *et al.* (2000) showed that the problem of large population sizes could be circumvented by pre-screening by three assessors for overall appearance, texture and flavour. In the DSA conducted thereafter by the trained panel on the selected seedlings, it was found that a panel size of minimum 11 trained assessors was sufficient to achieve a one point statistical discrimination on the 0 to 9 point intensity scale. King *et al.* (2000) used an 11-member trained panel for the sensory evaluation of fruit texture in a breeding programme. Significant panellist*selection interactions were found, but did not affect rank order. Deslaures *et al.* (1999) used DSA to describe the broad range of materials within an apple breeding programme. Rating scales of 0=none to 5=extreme were used for most of the nine flavour and texture attributes. The authors emphasised the importance of using material from a breeding programme to develop DSA methodology for assessing new varietal material, because commercial cultivars normally do not display such variation.

It would be unreasonable to argue that either expert or trained panels would be better suited to perceive and discriminate between flavour and texture intensities among products that they are familiar and have experience with (Oraguzie *et al.*, 2009). Chambers and Smith (1993) investigated the effect of testing experience in a specific food category on the performance of trained sensory panellists in DSA. Data obtained from inexperienced panellists did not differ significantly from experienced panellists that undertook intensive descriptive training. Although results from the wine literature suggested that there is little difference in the ability of either expert or trained panels to describe differences among wines (Gawel, 1997), no results could be found in the literature on the statistical variation between expert tasters and trained panels in a fruit breeding programme. The only reported comparison between an expert and trained panel was an indirect comparison made by Oraguzie *et al.* (2009) who compared correlations between their expert panel and instrumental measurements on advanced selections to similar correlations obtained by Harker *et al.* (2002a, b) on commercial cultivars. The sensory-instrumental correlations for expert assessors and trained panellists were in close agreement (Harker *et al.*, 2002a, b; Oraguzie *et al.*, 2009).

Expert and trained panels have also been used for preference testing in a breeding programme (Redalen, 1988), due to the limitations to use consumer preference tests for screening breeding selections in the first phase (Oraguzie *et al.*, 2009). Hampson *et al.* (2000) investigated the validity of using a single assessor to predict the preference of a larger group. Hedonic liking scores of each judge in the trained panel were correlated with that of the mean panel score, but poor correlations showed that one or two tasters do not provide a reliable estimate of the preference of a larger group. Liking differences between a trained and consumer panel were investigated, although data were not directly comparable due to scaling differences. Consumers were asked to rate taste and appearance liking using an 8 cm line scale, with anchors of 'dislike' and 'like very much', while the trained panel used 0 to 9 bipolar hedonic scales to rate overall liking for flavour and texture independently. Mean ratings of consumers' general taste liking were then compared to the trained panel's texture and flavour liking. Consumers' preferences for eating quality were generally in agreement with the trained panel's preference for texture and flavour. Preference for appearance showed bigger differences between these groups. Hampson *et al.* (2000) concluded that consumer tests are not viable for routine use in breeding selections, but that trained panels appear to be sufficiently indicative of consumer responses when screening large numbers of genotypes.

Decisions to commercialise an advanced selection from a breeding programme also need to be responsive to the impact of shape, colour and appearance on consumer acceptance of the product (Kappel *et al.*, 1995). Limited quantitative information is available from the literature regarding consumer preferences for visual attributes such as fruit shape. Hampson and Quamme (2000) used a 42-member consumer panel to establish tentative guidelines for screening apple breeding selections for visual attributes. Consumers' preference for fruit size was measured on the seven-point 'Just Right' scale, fruit shape was measured on the seven-point hedonic scale and the appearance of lenticels and stem bowl russet was measured on a seven-point acceptability scale. The results indicated that consumer preference tests seemed advisable just prior to the release of new cultivars.

5. SUMMARY

Apples are one of South Africa's most important agricultural commodities (DAFF, 2012). Although the export market has been characterised by higher volumes and financial revenues, approximately 30% of South Africa's total production is sold fresh on the local market at increasingly competitive prices (DFPT, 2011). An increase in consumer income resulted from rapid economic growth during the past decades (STASSA, 2006) and is expected to create a consumer segment that is willing to offer higher prices for high quality apple cultivars that meet their demands (Fick, 2011).

Consumers are increasingly interested in new, novel apple cultivars. These cultivars would gain competitive advantages and consequently price premiums for the supplier (Yue & Tong, 2011). Knowledge of the most efficient techniques for evaluation of the attributes that drive consumer preference and estimation of genetic gain that would result from selection for these attributes are required to meet consumers' high demands in new cultivar breeding. Consumer preference testing should be conducted from the early stages of the fruit breeding process to ensure successful new cultivar development (Hampson *et al.*, 2000), but is limited by the small amount of fruit usually available from a breeding family (Oraguzie *et al.*, 2009). Therefore, breeding programmes mainly rely on small groups of expert tasters to evaluate and identify the most promising selections (Hampson *et al.*, 2000). DSA by a trained panel could limit the variance contributed by small groups of assessors to lower heritability estimates (Hampson *et al.*, 2000), but the use of trained panels in the analysis of breeding programmes appears to be rare (King *et al.*, 2000).

Consumers are not always aware of the sensory attributes that drive their preference and should therefore not be asked to identify these attributes (Lawless & Heymann, 2010). DSA by a trained panel has been successful in identifying the sensory attributes that drive consumers' preference for apple eating quality (Daillant-Spinnler *et al.*, 1996). Sensory profiling generated by a trained panel can be projected onto preference dimensions generated by a consumer panel by using techniques of preference mapping (Jaeger *et al.*, 1998). Consumer preference is not only driven by direct perceivable sensory attributes, but also by the expectations that are indirectly created by appearance when it serves as an indication of the eating quality of the fruit (Shankar *et al.*, 2010).

Although consumers generally have a high preference for sweet and firm apples and dislike very sour and mealy apples (Jaeger *et al.*, 1998; Andani *et al.*, 2001), smaller consumer segments have been identified that prefer sour apples and have a higher tolerance towards mealiness (Carbonell *et al.*, 2008). Marketers are increasingly interested in consumer segments with similar preferences and how these preferences relate to socio-demographic factors (Richards, 2000). Techniques of consumer segmentation can be based on socio-demographic factors (Kühn & Thybo, 2001; Cliff *et al.*, 2002), visual clustering of consumers' preference on preference maps (Daillant-Spinnler *et al.*, 1996) or statistical clustering methods, such as Ward's clustering (Carbonell *et al.*, 2008).

Methodologies applied and results obtained in literature were examined to gain insight into optimal fruit quality and consumer analysis in a breeding programme.

Table 1 Summary of the most important sensory, consumer preference and quantitative genetic studies on apple cultivars and breeding populations

Authors	Plant material	Outcome	Limitations
<u>Quantitative genetic studies</u>			
Hampson *et al.*, 2000	Apple breeding population	Pre-screening of selections by thee expert assessors. A trained panel was later used to conduct DSA on the selections. Preference was also assessed by the trained panel.	Sensory attributes were rated on a unipolar 0 to 9 intensity scale. Trained judges were used to analyse preference.
King *et al.*, 2000	Apple breeding population	Successfully used a 11-member trained panel for DSA (on a 0-100 intensity scale) of fruit texture for genotypes harvested over two years. Assessments of instrumental and sensory attributes were compared.	Data were only collected over two years.
Alspach & Oraguzie, 2002	Four sublines of a breeding population	Variance components were computed for several sensory attributes in a breeding population that were harvested from three locations over two years.	Only two trained assessors were used. Sensory attributes were measured on nine-point category scales. Data were only collected over two years.
Gálvez-López *et al.*, 2012	Apple breeding population	Heritability estimates and phenotypic correlations were obtained for sensory and instrumental texture attributes in an apple breeding population that was harvested over two years.	Only four expert assessors were used, while 2 assessors generated two sensory scores for each attribute assessment per sample. Data were only collected over two years.

Sensory and consumer studies

Williams & Karter, 1977	Apple cultivar (Cox's Orange Pippen)	Development of lexicon and procedure for sensory profiling of apples.	List of sensory descriptors too extensive to be used for routine quality assessment.
Dhanaraj *et al.*, 1981	Apple cultivars	Development of a condensed list of sensory descriptors for apples.	Sensory attributes were measured on a unidimensional scale.
Redalen, 1988	Apple cultivars and selections	Sensory and instrumental analyses were combined with a basic consumer survey. Consumer socio-demographic information was collected.	General scale used for eating quality and appearance attributes (1=very poor to 10=excellent). Consumers were asked to indicate the most and least preferred apples presented to them. No hedonic scales were used.
Daillant-Spinnler *et al.*, 1996	Twelve apple cultivars from the Southern Hemisphere	Developed a highly successful method for the quantitative sensory analysis of apples. Consumer preference was tested with the hedonic scale and sensory and consumer preference data were analysed with multivariate statistical programmes.	Small consumer group (n=120). Visual clustering of consumer groups, this research only considered preferences on the first two preference dimensions.
Plotto *et al.*, 1997	Two commercial apple cultivars	Eating quality of apples from multiple harvests and storage durations was assessed sensorially and instrumentally.	An untrained consumer panel conducted DSA, as well as hedonic preference tests.
Jaeger *et al.*, 1998	Three apple cultivars from the Northern Hemisphere	Multivariate statistical analysis of consumer preference and sensory data for fresh and aged apples in a cross-cultural context (Danish and British consumers).	Visual clustering (thus grouping) of consumers on different preference maps for the two cultural groups.
Andani *et al.*, 2001	Three apple cultivars from the Northern Hemisphere	Multivariate statistical analysis of consumer preference and sensory data. A method and lexicon were developed to analyse mealiness in apples.	Although consumers from five different EU countries participated in the study, attention was not given to consumer clustering.

Kühn & Thybo, 2001	Six apple cultivars	Multivariate statistical analysis of consumer preference and sensory data. Children were used in the consumer preference study.	Although reference was made to the sensory analysis of apple appearance, no descriptions of the appearance attributes were reported.
Carbonell *et al.*, 2008	Three commercial apple cultivars that were stored for three different storage periods	Multivariate statistical analysis was used to visually group and statistically segment consumers with similar apple preferences. DSA was conducted by a trained panel and preference testing conducted by a consumer panel.	Limited sample variety (only three cultivars were used). Consumer preference for appearance was not analysed.

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CHAPTER 3

Preference patterns of different ethnic and age groups for apple eating quality and appearance

5. DISCUSSION

5.1 Ethnic groups

5.2 Age groups

6. CONCLUSIONS

7. REFERENCES

1. ABSTRACT

South Africa is a multicultural country that is characterised by high variation in age as well as population size of three ethnic groups, viz. black, coloured and white. In this study, consumers were selected to represent an approximately equal number of white, coloured and black consumers, differing in age (18-24, 25-35 or 36+), gender and socio-economic background in the Stellenbosch area, Western Cape, South Africa. Consumer preference for apple eating quality and appearance was analysed on a nine-point hedonic scale using nine commercial apple cultivars to attain variation in flavour and appearance parameters. Ethnic group and age group interacted with consumer preference for eating quality and appearance. Descriptive sensory analysis (DSA) using a trained panel was performed on all apple cultivars and projected onto consumers' preference dimensions using principal component analysis (PCA). Black and coloured consumers liked sweet taste and disliked sour taste. White consumers' preferences were not significantly driven by sensory attributes. Consumers from all three age groups had a high preference for sweet taste, while consumers from the second (25-35) and third (36+) age groups showed a strong aversion to sour taste. The appearance of full red 'Topred' was liked by consumers from all age and ethnic groups, while the white and youngest consumers also liked the appearance of 'Granny Smith' and 'Pink Lady®'. Consumers tended to prefer the appearance of cultivars that associated with the eating quality attributes that they liked.

Keywords Consumer groupings, consumer preference, *Malus x domestica* (Borkh.), principal component analysis.

2. INTRODUCTION

South Africa is a multicultural country with a heterogeneous socio-economic society that is characterised by a variety of ethnic groups who have different eating habits and food preferences (Viljoen & Gericke, 2001). Although ethnic group is one of the most important determinants of food choice (Prescott & Bell, 1995), the effect on food preference is poorly understood (Pangborn *et al.*, 1988). Limited information is available on the eating habits and food preferences of the different ethnic groups in South Africa, where white consumers' eating patterns are generally described as Western or European, but are traditionally perceived to differ from those of black consumers (Viljoen & Gericke, 2001).

Unequal national and provincial distribution of these ethnic groups are evident, viz. 79%, 9% and 9% black, coloured and white consumers in the country, respectively, but 30%, 50% and 18% in the Western Cape Province (STATSSA, 2011). Although the Group Areas Act of 1950 (Act No. 41 of 1950), which assigned different ethnic groups to different residential and business areas in urban regions, was repealed in 1991, the effects of this law have still not been completely eradicated. Black, white and coloured consumers still often reside in largely homogenous neighbourhoods and favour particular retailers and commercial districts. Breeders, marketers and distributers of apple cultivars need to understand how consumers' ethnic group relates to the sensory attributes that drive their apple preferences, mainly to identify the localities where higher concentrations of consumers would have a high preference for specific cultivars, thereby increasing consumer satisfaction and sales. Knowledge of the different ethnic groups' apple preferences would thus not only be valuable for the geographic distribution of apple cultivars, but also for the relative proportions in which these cultivars should be distributed. Since approximately 30% of South Africa's total apple production is sold fresh locally (DFPT, 2011), it is important to understand the eating quality and appearance preferences of local consumers. It is a general perception in the South African apple industry that black and coloured consumers have an aversion to sour and a preference for sweet apples (Fick, 2011), but the extent to which this is actually true for consumers in these ethnic groups has never been determined. Studies on apple preference have seldom found distinct cultural or ethnic preference differences among European apple consumers, who generally like juicy, crispy, crunchy and sweet apples with a high apple flavour, but dislike mealiness and a strongly acidic taste (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998; Andani *et al.*, 2001). Limited information is available on consumers' preference for apple appearance, especially now that the global export market is expanding. Research conducted in Europe showed that appearance attributes are major drivers of liking and that consumers prefer bi-coloured types with an attractive shiny red over-colour (Fischer & Fischer, 2008).

An understanding of the effect of age on consumers' apple preferences is also required. If consumers from different age groups respond differently to marketing stimuli, marketers of apple cultivars could create specific programmes aimed at the consumer group that has the highest preference for the specific cultivars. Although Jaeger *et al.* (1998) and Hampson *et al.* (2000) found no effect of age on apple preference scores, age-related differences in preferences for apple attributes and eating quality were reported by Racskó *et al.* (2009a, b). Since forty-five per cent of the consumers in the Western Cape Province of South Africa is younger than 24 (STATSSA, 2011), it is important to establish the effect of age on consumer preference.

Apple marketers and distributors in South Africa rely primarily on sales data in order to distribute apple cultivars to selling points. Cultivars that have shown higher sales in one season at a specific selling point would be distributed in high quantities to the same point during the next season. Relying on sales data to determine cultivar distribution has some drawbacks: Sales data are not a true reflection of the actual preferences of consumers who might purchase cultivars based on other factors, such as familiarity. Neither do sales data provide an accurate estimation of consumers' purchase decisions if they were to be presented with a wider variety of apple cultivars.

In view of the above, the aims of this research were to: 1) Determine if ethnic group and age significantly affect local Western Cape consumers' preferences for apple eating quality and appearance, and 2) establish the main drivers of liking for coloured, black and white consumers and for consumers from three different age groups.

3. MATERIALS AND METHODS

3.1 Plant material

Nine apple cultivars (*Malus x domestica* Borkh.), viz. Cripps' Pink, Cripps' Red, Fuji, Golden Delicious, Granny Smith, African Carmine, Starking, Topred and Royal Gala were used in this study. The selected cultivars were chosen to attain a variety in flavour and textural attributes, as well as colour and colouring patterns. 'Pink Lady®' is the trademark name reserved for 'Cripps' Pink' fruit with more than 40% blush coverage (Anon., 2000), while 'Sundowner®' is the trademark name given to 'Cripps' Red' apples. The 'Cripps' Pink' and 'Cripps' Red' apples that were used in this study met the required quality standards and will therefore be referred to by their trademark names.

First grade export quality apples were provided by local exporting companies: 'Topred', 'Starking', 'Sundowner®' and 'Fuji' by Ceres Fruit™ and 'Royal Gala', 'Granny Smith', 'Golden Delicious' and 'Pink Lady®' by Colors Fruit (SA) Pty Ltd. 'African Carmine' fruit were harvested from the Agricultural Research Council's (ARC) Drostersnes experimental farm in the Vyeboom area in the Western Cape (latitude 34°4'S; longitude 19°4'E). All fruit were kept in commercial storage, until it was relocated to the cold storage room at –0.5 ºC at the Department of Horticultural Science, Stellenbosch University, South Africa, approximately one month before testing commenced.

3.2 Descriptive sensory analysis

Descriptive sensory analysis (DSA) was carried out between 13 and 16 July 2010, in the sensory research laboratory at the Department of Food Science, Stellenbosch University. The sensory panel consisted of eight female judges. All judges were experienced in sensory analysis of apples and were therefore only subjected to two training sessions. Training was conducted using the consensus method and analyses were performed according to 'Generic Descriptive Analysis', as described by Lawless and Heymann (2010). Judges were tested for consistency. Samples of all nine cultivars were used in the training sessions to calibrate the panel on the sensory attributes typical for the cultivars to be tested. Unstructured line scales were used for attribute intensity analysis. The left hand side of the scale corresponded to the lowest intensity and the right hand side corresponded to the highest intensity. The judges agreed on a consensus list of attributes for describing the flavour and texture of the peeled apple samples, viz. sour taste, sweet taste, overall apple flavour, crispness, crunchiness, juiciness and mealiness. It was also decided to analyse the attributes 'astringency', 'bitterness' and 'toughness of the peel' of the unpeeled samples. The definitions used for the sensory attributes (Table 1) were similar to those used by Daillant-Spinnler *et al.* (1996).

The fruit were analysed during three replicate sessions. Each panellist assessed one fruit of all nine cultivars during a replicate session. Apples were cut lengthwise into eight slices so that the same apple was analysed by the entire panel during a replication. Slices of unpeeled fruit were presented on Petri dishes (Kimix, South Africa) and panellists were instructed to peel the samples prior to analysis of the flavour and texture attributes. Samples were coded with three digit random codes and presented in a randomised complete block design, balanced to minimise order and carryover effects. The latter design was based on the Williams Design presented by the Compusense® Five data collection software that collected the data electronically (Version 4.2, Compusense Inc., Guelph, Ontario, Canada). Distilled water and biscuits (Woolworths, South Africa) were provided as a palate cleanser between samples. Profiling was conducted in tasting booths with standardised artificial daylight lighting and temperature control (21 ºC). The average response over replicates and assessors for all attributes were computed and used in the multivariate data analyses (Johansen *et al.*, 2010).

3.3 Instrumental measurements

Instrumental analyses were conducted on nine fruit for each cultivar: Three fruit were analysed together as a replication set and three replications were conducted for each cultivar. Fruit were removed from cold storage and allowed to reach room temperature before instrumental analyses were conducted at the Department of Horticultural Science, Stellenbosch University on the same day. Different fruit from the same cultivars were used for DSA and for instrumental measurements.

Fruit firmness (N) was determined as the maximum force required to push an 11 mm diameter probe with a convex tip into the flesh, after peeling two equatorial sites, using a motorised penetrometer (Guss Instruments, Stellenbosch, South Africa). The remaining parts of the fruit from each three-fruit sample were juiced together and analysed for total soluble solids (TSS) concentration with a digital refractometer (TSS 0-32%, Model N1, Atago, Tokyo, Japan) and titratable acidity (TA) (719S Titrino autotitrator, Metrohm 50, Herisau, Switzerland) by titration with 0.1 M NaOH to an endpoint of 8.2. TA results were expressed in gram-equivalents of malic acid per litre of juice. The TA/TSS ratio was calculated for all samples. Average values were calculated for each three-fruit replication set and used for further statistical analysis.

3.4 Consumer analysis

3.4.1 Consumer recruitment

Consumer preference analyses were conducted in the sensory research laboratory of the Department of Food Science, Stellenbosch University on 23 and 30 July 2010. Consumers were recruited on the basis that they regularly consume apples. External recruiters were used to recruit approximately equal numbers of consumers from different ages, ethnic groups (black, coloured and white) and socio-demographic backgrounds. White consumers were mainly recruited from Stellenbosch University, and were either students or staff. Coloured and black students and staff from Stellenbosch University also participated in this study, but in order to include a representative sample from the larger Stellenbosch area, coloured consumers were further recruited from Cloetesville, and black consumers from Kayamandi (an informal settlement) and Jonkershoek. Care was taken to apply the principle of representative demographic sourcing for the latter three areas.

The 431 consumers recruited were asked to complete a questionnaire that consisted of four subsets (Q1-Q4). Socio-demographic information collected in Q1 (Appendix 2) included gender, age, ethnic group, income and education. Preferences for eating quality and appearance were assessed in Q2 (Appendix 3) and Q3, respectively. General information on consumers' conceptual apple preferences and the factors that influence their apple purchase patterns were collected in Q4 (Appendix 4).

3.4.2 Preference for eating quality

Eating quality preference tests were conducted in 2009 on nine cultivars that were presented peeled and unpeeled. ANOVA showed that although preference was generally affected by peeling, this effect was not cultivar specific ($P>0.0005$) and consequently did not influence preference patterns (Appendix 1). It was therefore decided to limit the consumer preference analysis in 2010 to the analysis of unpeeled samples due to practical problems relating to oxidative browning of cut samples.

Consumers were presented with unpeeled samples of all nine cultivars in Q1. A randomised complete block design was used, balanced for order and carry-over effects and similar to the design used for the descriptive sensory analysis. A sample consisted of a sixth of an apple, sliced from stem end to calyx end. Consequently, every six consumers received a sample set of the exact same fruit, while different fruit from the same cultivars were given to the next set of six consumers. Consumers rated each sample for liking on a nine-point hedonic scale from "dislike extremely" to "like extremely". In this test, consumers are asked to indicate which term best describe their attitude towards the products being tasted (Lawless & Heymann, 2010). Consumers were instructed to indicate their preference for the total eating experience, including texture and flavour. Samples were presented with three-digit random codes in Petri dishes on white trays in a room with standardised artificial daylight lighting and temperature control (21 ºC). Consumers were requested to drink water between samples.

3.4.3 Preference for appearance

Consumers were presented with photograph booklets for Q3 that contained photographs of one representative apple of each of the nine cultivars that were assessed in the eating quality test (Appendix 5). Consumers were again requested to use the nine-point hedonic scale to indicate their liking for the overall appearance of the cultivars on the photographs provided. A randomised complete block design was again used, where all consumers analysed all nine photographs. Four sets (A, B, C & D), consisting of four booklets each, were created to ensure that photographs were presented to consumers in different orders. The photograph order between sets was randomised, but was identical within sets. Three digit random numbers were assigned to the photographs and were again randomised between sets but identical within sets. The booklets were bound with a ring binder along the top border. Each of the four sets was colour coded to match the corresponding questionnaire for that particular set (A–D), in order to ensure that every consumer paired the correct booklet with the corresponding questionnaire.

3.4.4 Conceptual preference and purchase factors

For Q4, consumers were asked to indicate their degree of liking for the apple cultivars presented in Q2 and Q3, as well as their preference for certain apple sensory attributes and apple peel appearances on the nine-point hedonic scale. The importance of several aspects considered when purchasing apples were also rated on a nine-point structured scale. No taste samples were provided in Q4 and preference analysed in this part of the study will be referred to as "conceptual preference".

3.5 Statistical procedures

The purpose of the study was to analyse the interaction between consumers' ethnic/age group and their preference for apple attributes relating to appearance and eating quality. Furthermore, the effects of additional factors (i.e. gender, income, etc.) that contribute significantly to the intrinsic (i.e. eating quality and appearance) and extrinsic (i.e. price, cultivar indication on the packaging, etc.) drivers of consumer liking were also analysed. Instrumental and sensory data were included in this study to serve as an external data set to further explain the intrinsic factors that drive consumers' apple preferences.

The sensory data for each attribute were subjected to a three factor analysis of variance (ANOVA) using cultivars, panellists and replications as main effects. No significant interaction (P>0.05) was found, indicating that the mean scores gave a reliable estimate of the samples' sensory attributes. Cultivar attributes were therefore averaged across replicates and panellists. Instrumental data for firmness, TSS, TA and TSS/TA were subjected to one-way analysis of variance, with cultivar as main effect.

In order to compare the consumer characteristics that contributed to consumers' preference for the nine apple cultivars, these characteristics were subjected to a 9 x 3 x 3 x 3 x 5 factorial ANOVA, with factors cultivar, ethnic group, age group (18-25, 26-35, 36+), education (lower than final school year, final school year and tertiary education) and employment (student, labourer, administrative, professional and retired). SAS statistical software (SAS, version 9, 1999, Cary, North Carolina, USA) was used for the analyses. Statistical significance was defined at P≤0.05. Non-significant main factors and interaction factors were removed from the model, and a 9 x 3 x 3 ANOVA was redone with factors cultivar, ethnic group and age group. This three factor ANOVA model was also applied to the analyses of appearance preference and conceptual preference, where consumer liking for actual apple appearance and conceptually tested cultivars and attributes were taken as the dependent variables. Student's t-LSD's (Least Significant Difference) were calculated at a 5% significance level and used to determine whether preference for eating quality and appearance differed significantly between different age and ethnic groups.

Principal component analysis (PCA) was performed in order to study the data structure and the association between the sensory attributes, consumer preference and consumer characteristics (age and ethnic group) that contributed significantly to consumer preference. In order to reduce variation and the number of points on the corresponding figures, mean values of the liking scores were calculated for combinations of ethnic_group*cultivar and age_group*cultivar. These means, together with the sensory means and the corresponding number of observations, were taken as input to a weighed PCA of the correlation matrix. Means for ethnic_group*cultivar and age_group*cultivar were projected onto separate PCA spaces. To measure the linear relationship between the sensory attributes and consumer liking, Pearson's correlation coefficients were calculated with XLSTAT software for each of the different age and ethnic groups (Addinsoft, Version 2007, Paris, France) (Pèneau *et al.*, 2006). Similar PCA was performed in order to study the effect of ethnic and age group on consumers' preference for apple appearance. Consumers' age and ethnic group (Y-variables) were also related to the residuals of importance ratings given to purchase factors (X-variables) in a PLS regression plot, where dummy variables were created for consumers' age or ethnic group (Johansen *et al.*, 2010).

4. RESULTS

For the purpose of this part of the study and in order to refrain from vague terms for reporting, "preference for eating quality" indicates a consumer's degree of liking for the overall texture and flavour of apples, where the term "flavour" includes sweet taste, sour taste and flavour volatiles (Rowan *et al.*, 2009). "Preference for appearance" indicates how consumers liked the overall colour and shape of the fruit. Consumers tasted all apple samples to give an indication of "preference for eating quality" and viewed life-size colour photographs of representative apples to indicate "preference for appearance", which will be referred to as "actual evaluation". Preference for specific aspects of eating quality (e.g. juiciness, crispness, etc.) and appearance (e.g. pink blush, red bi-colour, etc.) was also evaluated conceptually.

4.1 Sample attributes

For the sake of readability and brevity, only the most important differences in sensory and instrumental sample attributes will be reported here.

4.1.1 Sensory profiles

Mean sourness of Granny Smith and Sundowner® were significantly higher than in other cultivars (Fig. 1). Pink Lady® was significantly more sour or acidic than the remaining cultivars. African Carmine and Topred had the lowest sourness values, but not significantly lower than all other cultivars. 'Topred', 'Pink Lady®', 'African Carmine', 'Royal Gala' and 'Starking' had the highest mean sweetness and were significantly sweeter than 'Granny Smith', which received the lowest sweetness score. Apart from Sundowner® and Granny Smith, Pink Lady® had a significantly higher apple flavour than other cultivars. Fuji had the significantly lowest apple flavour. Granny Smith and Sundowner® were the only astringent cultivars (>2.0), although only slightly astringent and not significantly more than Topred and Fuji.

Fuji was perceived as the crispiest, crunchiest and juiciest cultivar, although it was not crispier than Granny Smith or crunchier than Pink Lady® and it was only juicier than Golden Delicious and African Carmine (Fig 2). African Carmine and Golden Delicious were less crispy and crunchy than other cultivars, but not significantly less than Royal Gala, Starking and Topred. Only 'African Carmine' was perceived as slightly mealy (>5.0), although not significantly mealier than 'Starking'. Peel toughness and bitterness were considerably low for all samples and are not shown.

4.1.2 Instrumental measurements

Topred and Starking had a significantly higher TSS concentration than all other cultivars (Table 2). 'Granny Smith' had the lowest TSS, but was not significantly lower than 'Fuji', 'Sundowner®' and 'Golden Delicious'. 'Granny Smith' had a significantly higher TA than all other cultivars and Sundowner® and Pink Lady® higher than the remaining cultivars. 'African Carmine' had the lowest TA. TSS/TA was significantly higher in African Carmine and lower in Sundowner® and Granny Smith compared to other cultivars. 'Pink Lady®' also had low TSS/TA levels. Firmness was significantly higher in Pink Lady® than in other cultivars, except for Granny Smith, Fuji and Sundowner®. Firmness for Golden Delicious and African Carmine was comparable to Royal Gala, but was significantly lower than all other cultivars.

4.2 Consumer characteristics

The black, white and coloured consumer groups constituted 37%, 34% and 29% of the total consumer group (n=431), respectively (Table 3). Forty-three per cent of the consumers were aged between 18 and 25 (first age group), 23% were between 26 and 35 (second age group) and 34% were 36 years or older (third age group). White consumers in the second age group, black consumers in the third age group and coloured consumers in the second and third age groups were underrepresented. Male consumers in general, but especially white males, were underrepresented. Seventy-eight per cent of the consumers were frequent apple eaters who consumed apples three times or more weekly, while only 22% of consumers seldom ate apples.

White consumers were generally more familiar with most cultivars than the coloured consumers, who we more familiar than the black consumers (Table 4). Consumers from all age and ethnic groups were more familiar with Granny Smith and Golden Delicious, although a larger percentage of the white and coloured consumers were familiar with these cultivars compared to the black consumers. Ninety per cent of the white consumers were familiar with Pink Lady®, while only 52% of the coloured and 44% of the black consumers knew this cultivar. Consumers were mostly unfamiliar with 'African Carmine', 'Sundowner®' and 'Fuji'. More consumers from the third age group were familiar with 'Starking' and 'Topred' compared to consumers from the second and first age groups. 'Pink Lady®' was equally familiar among the three age groups (Table 4).

4.3 Consumer grouping

Both ethnic group and age group interacted significantly with consumers' liking for cultivar eating quality and appearance (Table 5). The three way interaction between age group, ethnic group and cultivar liking was not significant.

4.3.1 Grouping based on ethnicity

4.3.1.1 Actual preference for eating quality

When PCA was conducted on the sensory profiles and hedonic preferences for eating quality obtained for each of the three ethnic groups, the first (PC1) and second principal components (PC2) accounted for 49.9% and 22.6%, respectively, of the variability in consumer response (Fig. 3). The preferences of the black and coloured consumers were similar and showed a close association on PC1, but differed from those of the white consumers on PC1 and PC2. Differences in preference for mealiness, crunchiness and juiciness explained the largest part of the variation on PC1 and juiciness, peel toughness, sweetness, bitterness and mealiness on PC2 (Fig. 3). The positioning of African Carmine and Granny Smith on opposite sides of PC1 showed preference differences among the three ethnic groups for these cultivars, which differed from Topred on PC2. The preference of the black and coloured consumers associated positively with sweetness (r=0.80; P=0.0090 for black and r=0.78; P=0.0133 for coloured consumers) and negatively with sourness (r=−0.75, P=0.0188 for black and r=−0.86, P=0.0027 for coloured consumers) (Fig. 3). Astringency was negatively correlated with the preference of the coloured consumers (r=−0.84; P=0.0051). Sweetness and sourness were not significant drivers of preference for the white consumers. Although crispness, crunchiness and juiciness did not correlate significantly with the preference of any ethnic group, these attributes did show a stronger positive association and mealiness a stronger negative association with the preference of white consumers relative to the preference of the coloured and black consumers (Fig. 3). The preferences of the coloured and black consumers associated with cultivars situated on the top right part of the plot, such as Royal Gala, Starking and Topred, while the white consumers' preferences were clearly situated between the latter two cultivars in the right quadrant, and Pink Lady® and Fuji in the left quadrant (Fig. 3).

Black and coloured consumers liked 'Topred' and 'African Carmine' significantly more and 'Pink Lady®' significantly less than white consumers (Fig. 4). Coloured and white consumers liked 'Granny Smith' significantly more than the black consumers. Coloured consumers liked 'Golden Delicious' significantly more and 'Sundowner®' significantly less than the black and white consumers. Black consumers liked Topred significantly more and Granny Smith significantly less than other cultivars, apart from similar preferences for Topred and Starking. Topred, Golden Delicious and Starking were comparably and highly liked by the coloured consumers, who liked Sundowner® and Granny Smith significantly less than other cultivars. Pink Lady® was the most preferred cultivar among the white consumers, who liked it equally to Topred, Starking and Royal Gala. White consumers gave the lowest preference score to 'Granny Smith', but did not like it significantly less than 'African Carmine'.

4.3.1.2 Conceptual preference for eating quality attributes and cultivars

When tested conceptually, consumers from all three ethnic groups indicated that they liked sweetness and juiciness comparably and also more than other attributes, although the white consumers gave similar preference scores (>7.0) to apple flavour (Fig. 5). Coloured and black consumers indicated a significantly lower aversion to mealiness than the white consumers and a lower tolerance to sour taste.

Coloured consumers indicated a significantly greater liking for 'Starking' and 'Topred' than the black and white consumers (Fig. 6). Coloured and black consumers indicated a significantly greater liking for Golden Delicious than for other cultivars, and also than the white consumers. Apart from Fuji, white consumers indicated a greater liking for Pink Lady® compared to other cultivars and to other ethnic groups. Coloured consumers indicated lower liking for African Carmine compared to other cultivars, but not lower than the other ethnic groups. 'Royal Gala', 'Sundowner®' and 'Granny Smith' received intermediate preference scores from all three ethnic groups.

4.3.1.3 Preference for appearance

PC1 and PC2 accounted for 64.0% and 33.7%, respectively, of the variability in preference responses of consumers from the three ethnic groups (Fig. 7). Preference differences for 'Golden Delicious', 'Topred' and 'Granny Smith' explained the largest part of the variation on PC1, and in addition to 'Starking' explained the variation on PC2. The appearance preferences of the black and coloured consumers grouped together and were situated further from the preference of the white consumers. Golden Delicious and Topred were important drivers of liking for the coloured and black consumers, shown by its position on the far right side of PC1 (Fig. 7). The white consumers' preference was situated between Topred in the top right and Granny Smith in the top left quadrant of PC1.

Consumers from all three ethnic groups expressed a similarly high preference for 'African Carmine' (Fig. 8) and also for striped red and full red apples (>6.0), apart from higher scores given by the coloured compared to the black consumers for full red apples (Fig. 9). 'Sundowner®' and 'Fuji' were comparably liked by consumers from the three ethnic groups (Fig. 8). Coloured consumers indicated a greater liking for 'Golden Delicious' and 'Topred' compared to other consumers, apart from similar preferences for 'Topred' by the white consumers. In addition to black consumers who liked African Carmine comparably, coloured consumers also liked Golden Delicious and Topred more than other cultivars (Fig. 8). Coloured consumers indicated a significantly greater liking for full red and full yellow apples compared to other colours and colour patterns, but also compared to the black consumers (Fig. 9). Similar scores given by coloured consumers to 'Starking', 'Sundowner®', 'Fuji', 'Pink Lady®' and 'Granny Smith' were higher than for 'Royal Gala'. Coloured and black consumers gave similar preference scores to red and pink bi-coloured apples, but black consumers gave significantly lower scores for green apples than coloured consumers. The coloured consumers gave higher preference scores to most cultivars (Fig. 8), but this could be attributed to differences in scale usage, which is accounted for in the PCA plot (Fig. 7).

White consumers liked Topred more than other cultivars except for Granny Smith, which they liked more than the coloured and black consumers. White consumers gave comparably high preference scores to 'Royal Gala', 'Sundowner®', 'Fuji' and 'Starking', of which they liked 'Royal Gala' and 'Starking' less than the coloured consumers, but similarly to the black consumers (Fig. 8). White consumers indicated a significantly greater liking for 'Pink Lady®' compared to the black consumers and also for pink blushed and red blushed apples compared to the coloured and black consumers (Fig. 9). Apart from Starking, white consumers indicated lower liking for Golden Delicious compared to other cultivars (Fig. 8) and also for yellow apples compared to other ethnicities and appearances (Fig. 9). Full red, pink bi-colour, full green and red bi-coloured apples were comparably and highly liked by the white consumers who expressed significantly greater liking for the latter three appearances compared to the other ethnic groups.

4.3.1.4 Factors relating to apple purchase decisions

The factors that influenced the purchase patterns of the black and coloured consumers grouped together and differed from those of the white consumers on the first component (Fig. 10). The coloured and black consumers' importance ratings showed a closer association with size of the fruit and purchase price, while the importance ratings given by the white consumers associated with cultivar loyalty and cultivar name indication on the packaging. The colour of apples was of equal high importance to consumers from all three ethnic groups and, except for black consumers for whom size was of similar importance, it was considered significantly more important than other factors (Fig. 11). Cultivar indication was more important to the white than the black consumers and cultivar loyalty was more important to the coloured and white than the black consumers. Coloured consumers regarded purchasing price more important than the black and white consumers and apple size more important than the white consumers. No significant differences were detected among the importance scores given to familiarity with the cultivars. White consumers rated cultivar indication significantly more important than price, while the coloured and black consumers gave similar importance ratings to these factors.

4.3.2 Grouping based on age

4.3.2.1 Actual preference for eating quality

PC1 and PC2 accounted for 50.1% and 23.2%, respectively, of the variability in consumer response (Fig. 12). Sweet taste, mealiness, sour taste, astringency, crunchiness, crispness and juiciness explained the largest part of the variance on PC1, and juiciness, mealiness, bitterness and peel toughness on PC2. Preference of consumers from the third age group (AG3) (36+) were better explained on PC1, while PC2 explained a larger part of the variability in preference for the first (AG1) (18-25) and second (AG2) (26-35) age groups. Granny Smith and African Carmine explained preference differences on PC1, while the latter cultivar also explained variability on PC2.

Sweet taste was the most important driver of liking and was increasingly important for AG1 (r=0.70; P=0.0351), AG2 (r=0.72; P=0.0294) and AG3 (r=0.85; P=0.0039), as also evident from Figure 12. Sour taste and astringency were disliked by AG2 (r=−0.78; P=0.0142 and r=−0.73; P=0.0286) and AG3 (r=−0.86; P=0.0035 and r=−0.79; P=0.0126), but did not correlate with the preference of AG1. Figures 12 and 13 should be studied together, considering that consumers in AG1 generally gave lower preference scores for the eating quality of all cultivars. Granny Smith was the least liked cultivar among consumers from all age groups, but AG3 gave a comparably low preference score to Sundowner® and AG1 to African Carmine, which they liked significantly less than AG2 and AG3 (Fig. 13). AG1 indicated a lower liking for 'Topred', 'Starking' and 'Golden Delicious' than AG3, who liked it comparably to AG2. No significant preference differences for 'Sundowner®', 'Granny Smith' and 'Royal Gala' were detected between the different age groups. AG2 and AG3 indicated a significantly greater liking for Topred compared to other cultivars, although not significantly greater than Starking (Fig. 13).

4.3.2.2 Conceptual preference for eating quality attributes and cultivars

When probed conceptually on the preference for eating quality, consumers from all age groups expressed a similarly high preference for juiciness, which they liked comparably to sweetness (Fig. 14). AG2 indicated a significant greater liking for sweetness compared to AG1. AG3 indicated a significantly higher liking for apple flavour compared to AG1 and AG2. AG1 indicated higher aversion to mealiness and tolerance of sour taste compared to the older consumers. Consumers from all three age groups indicated significantly greater liking for sweetness, apple flavour and juiciness compared to sourness and mealiness (Fig. 14).

'Golden Delicious' was highly and comparably liked by consumers from all age groups and was the most preferred cultivar for AG2 and AG3, except for similar preference scores given by AG3 to Starking, Pink Lady® and Royal Gala (Fig. 15). AG1 indicated greater liking for Pink Lady® compared to the other cultivars, apart from a comparable preference for Golden Delicious. AG3 indicated a significantly greater liking for 'Starking' compared to AG1. The older consumer groups indicated a great liking for 'Topred' and AG3 for 'Royal Gala' compared to AG1. No significant differences were detected between the preference of consumers from the three age groups for 'African Carmine', 'Sundowner®', 'Fuji' and 'Pink Lady®'. Consumers from all three age groups indicated the lowest liking for African Carmine, but not significantly lower than for all other cultivars. AG2 and AG3 gave significantly lower preference scores for 'Granny Smith' compared to AG1.

4.3.2.3 Preference for appearance

PC1 and PC2 accounted for 66.3% and 27.4%, respectively, of the variability in consumers' appearance preference (Fig. 16). The preference for appearance of the older consumers grouped together and differed from that of the youngest consumer group on PC2. Preference differences for 'Topred', 'Granny Smith' and 'Starking' explained the largest part of the variance on PC1, while 'Granny Smith' explained the variance on PC2.

AG2 and AG3 generally gave higher preference scores than AG1, probably as a result of different scale usage (Fig. 17). Figure 16 should therefore be considered in relation to Figure 17, as it depicts the relative preference differences between groups. AG1 indicated a significantly greater liking for Topred and Granny Smith compared to other cultivars and also for Granny Smith compared to AG2 (Fig. 17) and for green apples compared to AG2 and AG3 (Fig. 18). Apart from similar preference scores for 'Fuji' and 'Royal Gala', AG1 indicated the lowest preference for 'Starking' (Fig. 17).

AG3 gave the highest liking scores for the red cultivars Topred, Royal Gala and African Carmine. They indicated a greater liking for African Carmine, Royal Gala and Starking compared to AG1 and AG2. Consumers from AG2 and AG3 gave significantly higher scores to 'Topred' compared to AG1, while in addition to 'Topred', AG2 indicated the highest preference for 'Golden Delicious' (Fig. 17). The two older consumer groups indicated a greater liking for full red apples compared to AG1 and also greater than for other appearances, with the exception of red striped apples in the case of AG3 (Fig. 18). AG3 indicated significantly greater liking for red striped and red bi-coloured apples compared to AG1. AG2 and AG3 indicated a greater liking for the appearance of yellow apples compared to AG1. No significant preference differences were detected between pink bi-coloured, pink blushed and red blushed apples for consumers from the three age groups. AG3 gave the lowest scores for 'Granny Smith', but not significantly lower than for 'Pink Lady®', 'Fuji' and 'Sundowner®'. AG2 indicated a significantly lower preference for Granny Smith than for other cultivars, except for Starking (Fig. 17).

4.3.2.4 Factors relating to apple purchase decisions

The youngest consumers' importance ratings associated with colour and size, while older consumers showed a closer association with price and cultivar loyalty (Fig. 19). Since differences in scale usage are evident from Figure 20, it should be studied together with the PLS plot (Fig. 19). Consumers from all three age groups expressed similarly high importance ratings to colour and rated it significantly more important than other factors (Fig. 20). Size was also rated equally important by consumers from all three age groups. Name indication and price were comparably important to size for AG2 and in addition to cultivar loyalty, also for AG3. AG3 rated cultivar name indication more important than AG1, but both these groups rated it similarly important to AG2.

Cultivar loyalty and familiarity with the cultivar were of least importance to AG1 and, together with price, they rated these factors significantly lower than AG2 and AG3. Cultivar familiarity was the least important factor for AG3, although not less important than cultivar loyalty, while these factors were of least importance to AG2.

5. DISCUSSION

5.1 Ethnic groups

Clear preference differences for eating quality and appearance were illustrated for white, coloured and black consumers in the Western Cape. Multivariate analyses revealed that Granny Smith and African Carmine were the most important cultivars that distinguished between the eating quality preferences of consumers from these ethnic groups, which could be explained by different preferences for firm and sour (e.g. Granny Smith) or sweet and slightly soft (e.g. African Carmine) apples. In accordance with results obtained by Symoneaux *et al.* (2012), sour cultivars that were used in our study were firmer than sweeter, mealier cultivars. Consumer response to sour taste and firmness, and also sweetness and mealiness, could therefore not be studied in isolation (the combination of sensory attributes that are nested in a specific cultivar and the consequent effect on consumer preference is discussed in more detail in Chapter 4). It should be noted that the use of only three fruit for QDA in the current study could have lead to unrepresentative sensory profiling, if the eating quality of one of the fruit that were used would have been unrepresentative of the eating quality of the specific cultivar.

Flavour attributes were important drivers of liking for the coloured and black consumers, whose preferences differed from those of white consumers on average. Coloured and black consumers' preference for sweetness manifested in high liking scores for sweet cultivars, such as Topred, Golden Delicious, African Carmine and Starking. Their aversion to sour taste was clear from the low preference scores for sour 'Granny Smith' and 'Sundowner®'. Coloured and black consumers' greater preference for cultivars with high sweetness and low sour taste, such as Topred and Golden Delicious, compared to cultivars with low TSS/TA ratios, such as Pink Lady® (despite high sweetness), Granny Smith and Sundowner®, could be ascribed to linkage perception, i.e., the integrated effect of sweet and sour taste on overall taste perception. These consumers' preference for sweet taste and aversion to sour taste were again shown by higher conceptual preference scores for sweet taste and 'Golden Delicious' and low preference scores for sour taste and 'Granny Smith'. Familiarity with these cultivars did not greatly impact conceptual preference scores, considering that consumers were mostly equally familiar with sweet Golden Delicious and sour Granny Smith, which are the most grown cultivars in South Africa (DFPT, 2011).

Black and coloured consumers' preference for sweet apples could be explained by reduced taste sensitivity to sucrose among Sub-Saharan African populations (Fushan *et al.*, 2009) and a predisposition to prefer higher levels of sweetness, which is genetically controlled and culturally determined (Bretz *et al.*, 2006; Keskitalo *et al.*, 2007). Their closer association with mealiness probably resulted from their preference for the sweet taste of 'African Carmine', which was only slightly mealy, but had the mealiest fruit that were used in the study. 'African Carmine', a relatively new cultivar released to the South African industry in 1999 by the ARC Infruitec-Nietvoorbij breeding programme (Halgryn *et al.*, 2000), could gain market share due to repeated purchases in regions with a higher concentration of black and coloured consumers.

Average preference scores computed for the white consumer group as a whole did not correlate significantly with sweet or sour taste. White consumers gave similar preference scores to sweet cultivars (Topred) and sour cultivars with high TA (Sundowner®). Although their preference did not correlate significantly with firmness or mealiness, they tended to have a higher and lower preference for these attributes, respectively, compared to the coloured and black consumers. White consumers' higher tolerance to sour taste compared to black and coloured consumers possibly resulted from this tendency to like firmness, i.e. higher preference scores were given for firm 'Fuji' with low levels of sourness compared to firm, highly sour 'Granny Smith'. Higher mealiness in African Carmine compared to other cultivars probably caused lower preference scores for this cultivar, considering that white consumers indicated a strong dislike of mealiness in the conceptual evaluation.

In addition to high preference for sour as well as sweet fruit, white consumers' non-significant correlation with taste attributes might be ascribed to individual preference differences within the white consumer group as a whole. This group possibly consisted of sub-groups who preferred either a sweet or a sour taste, an occurrence that has been reported by Daillant-Spinnler *et al.* (1996) and Carbonell *et al.* (2008) among British and Spanish consumers, respectively. A possible reason for the resemblance between apple preference patterns of white consumers in the Western Cape (mostly from European ancestry) and European consumers, who mostly like firmness and dislike mealiness (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998), could be ascribed to the Western or European eating patterns of white South African consumers (Viljoen & Gericke, 2001). The preference of white South African consumers for the eating quality of pears has proven similar to the preferences reported for European consumers (Manning, 2009).

Granny Smith, Golden Delicious and Topred were the most important cultivars to explain appearance preference differences between the three ethnic groups. Black and coloured consumers indicated that they generally liked the appearance of full and striped red apples such as 'Topred', 'African Carmine' and 'Royal Gala'. Consumers are known to associate red colour with sweet taste (Clydesdale, 1993). This association probably relates to the development of red colour and sweetening of fruit during ripening (Steyn, 2012). The redder fruit from the outer canopy of red cultivars have higher sugar levels and sweetness compared to inner canopy fruit due to differences in light exposure (Hamadziripi, unpublished data). Similarly, the blush sides of apple fruit are sweeter than the non-blush sides (Dever *et al.*, 1995). It is therefore suggested that the black and coloured consumers' preference for red apples was driven by their preference for sweet taste. The low preference scores given by the coloured and black consumers to green 'Granny Smith' could be ascribed to their aversion to sourness and learned association between green colour and sour taste (Clydesdale, 1993; Shankar *et al.*, 2010). Coloured consumers' higher preference for 'Royal Gala' fruit with a yellow background compared to the particular 'Starking' photograph that depicted a green background suggested that they associated the greenish background with immaturity and sourness, considering that physiological maturity is related to the background colour of apples. Richardson-Harman *et al.* (1998) showed that consumers perceived 'Royal Gala' fruit with a yellower background to be riper than fruit with a greener background.

White consumers' appearance preferences also seemed to be driven by their preference for the eating quality typically associated with the cultivar's appearance, as evidenced by their preference for the appearance of firmer fruit such as Pink Lady® and Granny Smith. White consumers, who were mostly familiar with Granny Smith, indicated that they liked the appearance of this cultivar, probably because they associated Granny Smith with its familiar sour taste and firm texture. The appearance of Golden Delicious was possibly associated with the mealy texture that may develop during storage (Abbott *et al.*, 2004) and could explain why white consumers liked the appearance of this cultivar less compared to black and coloured consumers. Although consumers' preference for eating quality may have been influenced subconsciously by the peel revealed in the eating quality samples, this effect should be minimal, considering that consumers received a sixth of each cultivar. It would have been difficult to deduce the cultivar identity from such a small sample.

Cross-cultural studies have been conducted on consumers' preference for apples, where consumers from different nationalities were regarded as different cultures (Jaeger *et al.*, 1998; Jaeger, 2001). Preference mapping methodology used by Jaeger *et al.* (1998) showed similar preference patterns for apple eating quality between British and Danish consumers. Spanish and Norwegian consumers had similar preferences for apple juice (Rødbotten *et al.*, 2009). Preference for apple flavour and texture among consumers from different regions in Canada (Nova Scotia and British Columbia) did not differ significantly (Cliff *et al.*, 1999). Cross-cultural preference differences for food flavours were previously ascribed to differences in familiarity with sensory attributes or food products (Bertino *et al.*, 1983; Shankar *et al.*, 2010). Clear regional differences in preference for apple appearance reported by Cliff *et al.* (1999; 2002) were ascribed to varying familiarity with the cultivars used in these studies. Consumers preferred the visual attributes of the apples that they were more familiar with. In a similar study on pears, Gamble *et al.* (2006) found that Australian and New Zealand consumers preferred the appearance of familiar pear cultivars.

The present study showed that consumers from different ethnic groups did not necessarily indicate a greater liking for the sensory attributes of familiar cultivars, i.e. coloured and black consumers were mostly and equally familiar with 'Golden Delicious' and 'Granny Smith', but liked 'Granny Smith' significantly less than 'Golden Delicious' and also less than the white consumers. Black and coloured consumers' preference for sweet taste resulted in greater liking for 'Golden Delicious' in the eating quality, appearance and conceptual evaluations. Consumers' appearance preferences were rather driven by their eating quality expectations of fruit of a particular colour based on the association between the colour and taste of well-known cultivars such as Golden Delicious, Granny Smith and Starking. In a study conducted among Canadian and New Zealand consumers, Cliff *et al.* (2002) ascribed New Zealand consumers' preference for the green background colour of a red striped apple to their familiarity and eating quality preference of apple cultivars with similar appearance characteristics.

5.2 Age groups

Differences in consumer preference for apple eating quality and appearance could be related to age group, although it was less pronounced than preference differences between ethnic groups. Sweet taste was the most important driver of liking for eating quality for consumers from all three age groups. Consumers from the second (26-35) and third (36+) age groups had a strong aversion to sour taste, while the youngest age group's (18-25) aversion to sour taste was non-significant, as affirmed by their conceptual evaluation of taste attributes. The youngest consumers had a higher preference for sour, firm cultivars such as Pink Lady®, Sundowner® and Granny Smith compared to the older consumer groups. However, they liked sweet and low acid cultivars with high firmness such as Topred, but also less sweet Fuji significantly more than Granny Smith. Therefore it appears that young consumers do not have a higher preference for sour taste *per se*, but that their lower aversion to sour taste is due to their higher preference for the firmness of sour cultivars. Children and young consumers' preference for firmer cultivars was shown in a study conducted among Hungarian consumers by Racskó *et al.* (2009a). On the contrary, there is a general tendency among younger European consumers to prefer sweeter fruit (Labuschagnè, 2012).

The eating quality preference of older consumers (36+) associated strongly with sweet cultivars such as Topred, Royal Gala, Golden Delicious and Starking. Zandstra and De Graaf (1998) found that older consumers had a higher preference for sweetness in orange juice compared to younger consumers. It is generally assumed that consumers' taste sensitivity remains unimpaired until the late fifties, when a decline in sensitivity occurs (Mojet *et al.*, 2001). These authors reported a trend

(P<0.10) among older consumers (≥60) to have a higher sucrose threshold than younger consumers. Preference for higher sweetness of the older compared to the younger consumers could be ascribed to the high sweetness required by older consumers to perceive similar levels of sweetness. Consumers from the oldest age group who partook in the current study showed only a slightly stronger correlation with sweetness compared to the youngest consumers. The oldest consumer group in the current study were mostly younger than the oldest consumer groups in other studies, considering that AG3 included all consumers older than 36 of which only a small percentage was older than 60.

Appearance preference did not resemble eating quality preference of consumers from the three age groups to the same extent as was found for the ethnic groups. On average, consumers from all age groups preferred a full red peel colour. Higher preference for the appearance of 'Topred' probably relates to the association between full red peel colour and sweet taste. Older consumers, who had a higher preference for sweet taste, also preferred the appearance of red striped ‘Royal Gala’ and the yellow ‘Golden Delicious’ that are traditionally considered to be sweet. The youngest consumers showed a similar preference for Topred and Granny Smith, which were the most important cultivars in explaining preference differences between consumers from different age groups. Their high preference for the appearance of 'Granny Smith' was in accordance with their higher tolerance to sourness compared to the older consumer groups.

Consumers from all three age groups were more familiar with older cultivars such as Golden Delicious, Granny Smith, Starking, Royal Gala and Topred compared to newer cultivars such as Sundowner® and Fuji. Older consumers were more familiar with older red cultivars such as Royal Gala, Starking and Topred compared to younger consumers and also showed a high preference for these cultivars. Granny Smith was equally familiar to older consumers, who showed a lower conceptual preference for this cultivar because they were aware that they disliked the eating quality. Older consumers want to know what cultivars they are purchasing and are more loyal to familiar cultivars. Considering these requirements of older consumers, marketers of apple cultivars should pay attention to informative labelling if the apples are destined for a predominantly older consumer group. They should put emphasis on the sweetness of an apple cultivar, especially if it is expected that these older consumers would not be familiar with a specific cultivar. Racskó *et al.* (2009b) ascribed older consumers’ higher importance ratings for price to lower income levels among this group, but no effect of age group on income level was observed in the current study. It is therefore not clear why younger consumers would have indicated a lower importance rating to the price of apples. Although the youngest consumers liked the eating quality and appearance of Topred, their eating quality and to a lesser extent, appearance preferences, showed closer associations with newer cultivars such as Pink Lady®, Fuji and Sundowner®, compared to the preference of older consumers. Similar to findings by Racskó *et al.* (2009b) that Hungarian consumers under the age of 25 regard cultivar loyalty less important than older consumers (25-50), younger consumers in the current study also indicated lower importance for cultivar loyalty and cultivar indication on the packaging. Young consumers' willingness to experiment with new cultivars can be used by marketers to predict the success of new cultivars by monitoring its sales in stores where especially young consumers purchase food, i.e. small food stores that are open through the night.

6. CONCLUSIONS

It is clear that the ethnic and age group of consumers in the Western Cape have a significant effect on their preference for apple eating quality and appearance. The assumption in the apple industry that coloured and black consumers generally like sweet apples and dislike sour apples was confirmed. Local marketers and distributers should thus target geographic regions with a higher concentration of black and coloured consumers with sweet fruit of cultivars such as Topred, Starking and Golden Delicious. None of the sensory attributes correlated significantly with the preference of the white consumer group as a whole, probably because mean preference scores were computed from consumer groups who either liked sweet or sour apples. White consumers also liked both sweet and sour tastes if these attributes were present in cultivars with a firm texture. In order to account for preference differences within the same ethnic group, further statistical clustering should be applied to identify consumer groups with similar preferences.

Consumers from all three age groups had a high preference for sweet cultivars, but consumers from the youngest age group had a lower aversion to sour, firm cultivars such as Granny Smith. It is not known from this study how the preferences of younger consumers might change in the future to adapt to the sensory profiles of new apple cultivars or whether the preference differences between the three ethnic groups would decline. Therefore it might be necessary to conduct a follow-up study in a few years to validate the consumer preferences currently reported. All consumers in the current study older than 36 were grouped together, which did not allow accurate comparisons with results from the literature, where separate age groups are often reported for consumers older than 50 or 60 years. Narrower age groups would provide valuable information for consumer driven marketing, because not all consumers older than 36 are expected to respond similarly to marketing stimuli.

It was shown that consumers from all age and ethnic groups had a high preference for the appearance of a full red cultivar such as Topred. Their appearance preferences were driven by their preference for the expected eating quality that was associated with the specific appearance. Younger and white consumers showed a higher relative preference for the appearance of sour, firm cultivars such as Granny Smith and Pink Lady®.

Consumers' preference for eating quality was driven by flavour and textural attributes that varied concomitantly between the cultivars used for this study, such as a high sweetness and softer texture, and high sour taste and firmer flesh. In order to gain a better understanding of the individual sensory attributes that drove the preference of consumers from the three age and ethnic groups, it is necessary to include cultivars with a range of sensory profiles. Examples include juicy, crisp cultivars with a high sweetness (a higher sweetness is required than in the Fuji apples used for the present study) or apples with a high sour taste and softer texture. Since none of the cultivars had a tough peel or were particularly mealy, apples with a high degree of mealiness and peel toughness should be included in order to understand consumers' preference for these attributes.

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Table 1 Descriptors of sensory attributes used for the sensory analysis of apple fruit (adapted from Daillant-Spinnler *et al.*, 1996)

Attribute	Description	Scale
Sweet taste	One of basic tastes, e.g. sucrose	0 = None 100 = Prominent sweet taste
Sour taste	One of basic tastes, e.g. citric acid	0 = None 100 = Prominent sour taste
Apple flavour	Associated with typical apple flavour	0 = None 100 = Prominent apple flavour
Astringency	Dries the surface of the mouth, i.e. tannic acid	0 = None 100 = Prominent astringency
Crispness	Noise generated when chewing	0 = None 100 = Prominent crispness
Crunchiness	Ease of disintegration while chewing	0 = None 100 = Prominent crunchiness
Juiciness	Amount of juice released by sample during chewing	0 = None 100 = Extremely juicy
Mealiness	Over-mature soft, dry texture	0 = None 100 = Prominent mealiness

Table 2 Means of measured total soluble solids (TSS), titratable acidity (TA), calculated ratio of total TSS and TA (TSS/TA) and maturity indexes (firmness) for the nine apple cultivars. Means ± standard deviation (SD) with different alphabetical letters differ significantly. Means were separated by least significant difference (LSD) (5%)

Cultivar	TSS (ºBrix)	TA	TSS/TA	Firmness (N)
African Carmine	14.4 ± 0.31[bc]	0.14 ± 0.00[f]	103.2 ± 2.18[a]	57.8 ± 0.57[e]
Pink Lady®	15.0 ± 0.31[b]	0.51 ± 0.02[b]	29.4 ± 0.90[f]	74.5 ± 0.17[a]
Sundowner®	13.3 ± 0.45[cd]	0.52 ± 0.05[b]	24.5 ± 3.48[g]	69.6 ± 0.39[abc]
Fuji	13.6 ± 0.81[cd]	0.33 ± 0.02[c]	40.8 ± 3.26[e]	72.5 ± 0.11[ab]
Golden Delicious	13.3 ± 1.42[cd]	0.28 ± 0.04[d]	47.1 ± 4.16[d]	58.8 ± 0.13[e]
Granny Smith	12.3 ± 0.30[d]	0.59 ± 0.02[a]	20.9 ± 0.64[g]	72.5 ± 0.17[ab]
Royal Gala	14.0 ± 0.38[bc]	0.34 ± 0.01[c]	41.1 ± 1.50[e]	61.7 ± 0.48[de]
Starking	16.6 ± 1.15[a]	0.26 ± 0.02[de]	67.6 ± 1.84[c]	68.6 ± 0.21[bc]
Topred	16.6 ± 1.00[a]	0.23 ± 0.01[e]	73.1 ± 1.08[b]	65.7 ± 0.31[cd]
P-value	<0.0001	<0.0001	<0.0001	<0.0001

Table 3 Characteristics of the consumers expressed as percentage of the total consumer group (n=431) for black, coloured and white consumers

Characteristics	Black	Coloured	White	Total
Age				
18-25	16	9	18	43
26-35	13	7	3	23
36+	8	13	13	34
Gender				
Male	21	13	9	43
Female	16	17	24	57
Consumption of apples				
Daily	12	8	10	30
2-3 x week	18	13	17	48
≤ 2 x month	6	8	8	22
Total	37	29	34	100

Table 4 Familiarity with the nine apple cultivars by consumers from the different ethnic and age groups, expressed as percentage of total consumers

Cultivar	Black	Coloured	White	18-25	26-35	36+
African Carmine	26	26	15	15	28	27
Pink Lady®	44	52	90	63	58	63
Sundowner®	29	34	22	22	34	31
Fuji	28	31	39	24	39	38
Golden Delicious	59	71	92	76	72	73
Granny Smith	49	75	97	75	69	73
Royal Gala	46	45	61	47	53	53
Starking	40	54	66	42	52	66
Topred	35	45	49	33	44	53

Table 5 ANOVA (Analysis of variance) table with main and interaction effects for age and ethnic group with actual preference of apple eating quality and cultivar appearance, conceptual preference of sensory attributes and apple peel appearance, conceptual preference for apple cultivars and importance of purchase factors

Factor	**DF**	**Pr>F**	**Factor**	**DF**	**Pr>F**
Actual preference for eating quality			*Actual preference for appearance*		
Ethnic group	2	0.1778	Ethnic group	2	**<0.0001**
Age	2	**<0.0001**	Age	2	**<0.0001**
Ethnic group*Age	4	**0.0429**	Ethnic group*Age	4	**0.0406**
Ethnic group*Age(consumer)	430	**<0.0001**	Ethnic group*Age(consumer)	426	**<0.0001**
Cultivar	8	**<0.0001**	Cultivar	8	**<0.0001**
Ethnic group*Cultivar preference	16	**<0.0001**	Ethnic group*Cultivar preference	16	**<0.0001**
Age*Cultivar preference	16	**0.0005**	Age*Cultivar preference	16	**<0.0001**
Ethnic group*Age*Cultivar preference	32	0.2193	Ethnic group*Age*Cultivar preference	32	0.8662
Conceptual preference for sensory attributes			*Conceptual preference for peel appearance*		
Ethnic group	2	**0.0075**	Ethnic group	2	**<0.0001**
Age	2	**0.0111**	Age	2	**<0.0001**
Ethnic group*Age	4	**0.0006**	Ethnic group*Age	4	**0.0206**
Ethnic group*Age(consumer)	418	**0.0082**	Ethnic group*Age(consumer)	415	**<0.0001**
Sensory attributes	4	**<0.0001**	Peel appearance	7	**<0.0001**
Ethnic group*Sensory attributes	8	**<0.0001**	Ethnic group*Peel appearance	14	**<0.0001**
Age*Sensory attributes	8	**<0.0001**	Age*Peel appearance	14	**<0.0001**
Ethnic group*Age*Sensory attributes	16	0.6128	Ethnic group*Age*Peel appearance	28	0.2193
Conceptual preference for cultivars			*Importance of purchase factors*		
Ethnic group	2	0.0585	Ethnic group	2	**0.0016**
Age	2	0.3406	Age	2	**<0.0001**
Ethnic group*Age	4	**0.0224**	Ethnic group*Age	4	0.0781
Ethnic group*Age(consumer)	267	**<0.0001**	Ethnic group*Age(consumer)	418	**<0.0001**
Cultivar preference	8	**<0.0001**	Purchase factors	6	**<0.0001**
Ethnic group*Cultivar preference	16	**<0.0001**	Ethnic group*Purchase factors	12	**<0.0001**
Age*Cultivar preference	16	**<0.0001**	Age*Purchase factors	12	**0.0003**
Ethnic group*Age*Cultivar preference	32	0.0774	Ethnic group*Age*Purchase factors	24	0.2597

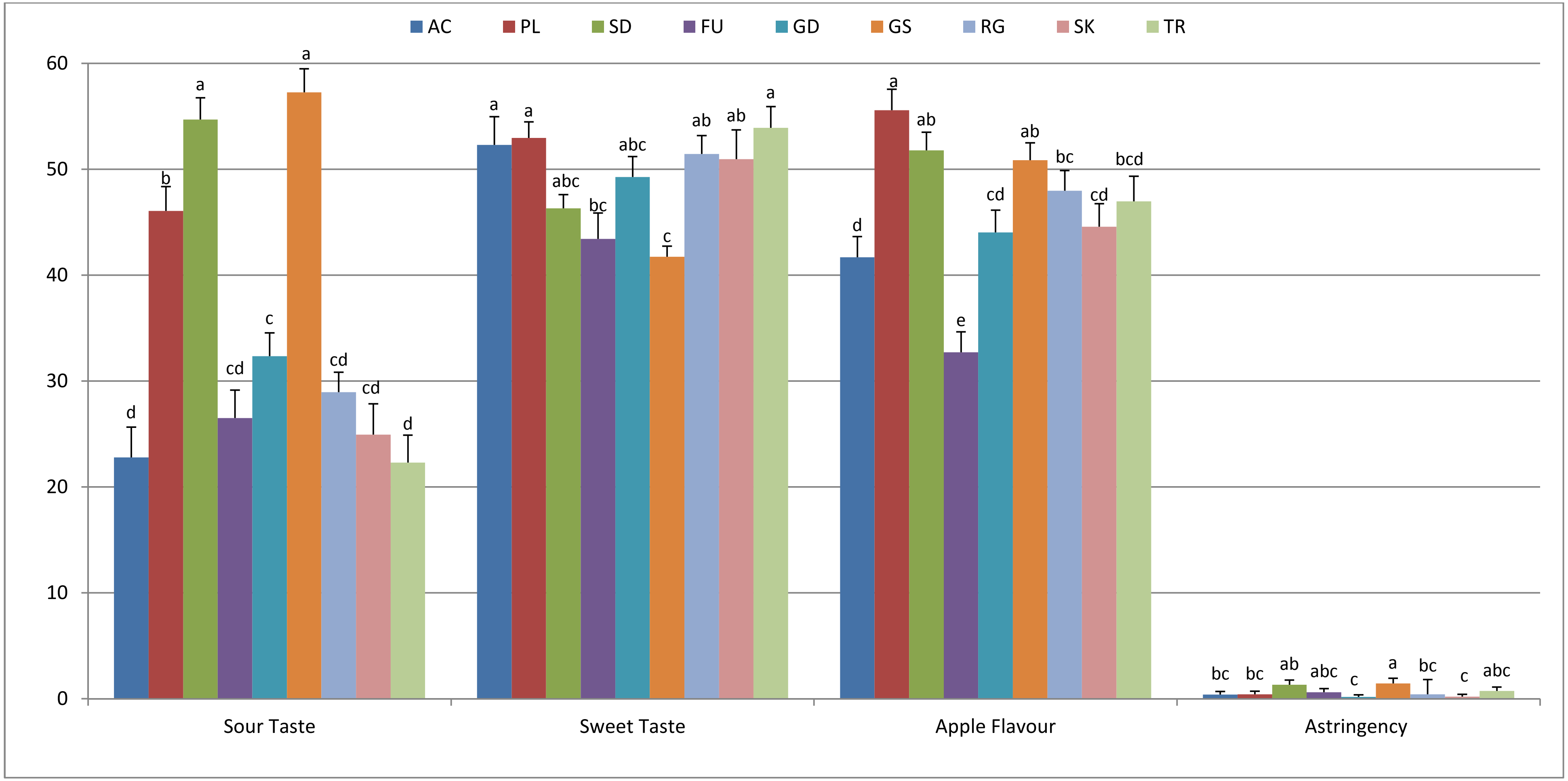

Figure 1 Overall means of sensory flavour and mouthfeel attributes measured on a 100 mm line scale during descriptive sensory analysis of nine apple cultivars, i.e., African Carmine (AC), Pink Lady® (PL), Sundowner® (SD), Fuji (FU), Golden Delicious (GD), Granny Smith (GS), Royal Gala (RG), Starking (SK) and Topred (TR). Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

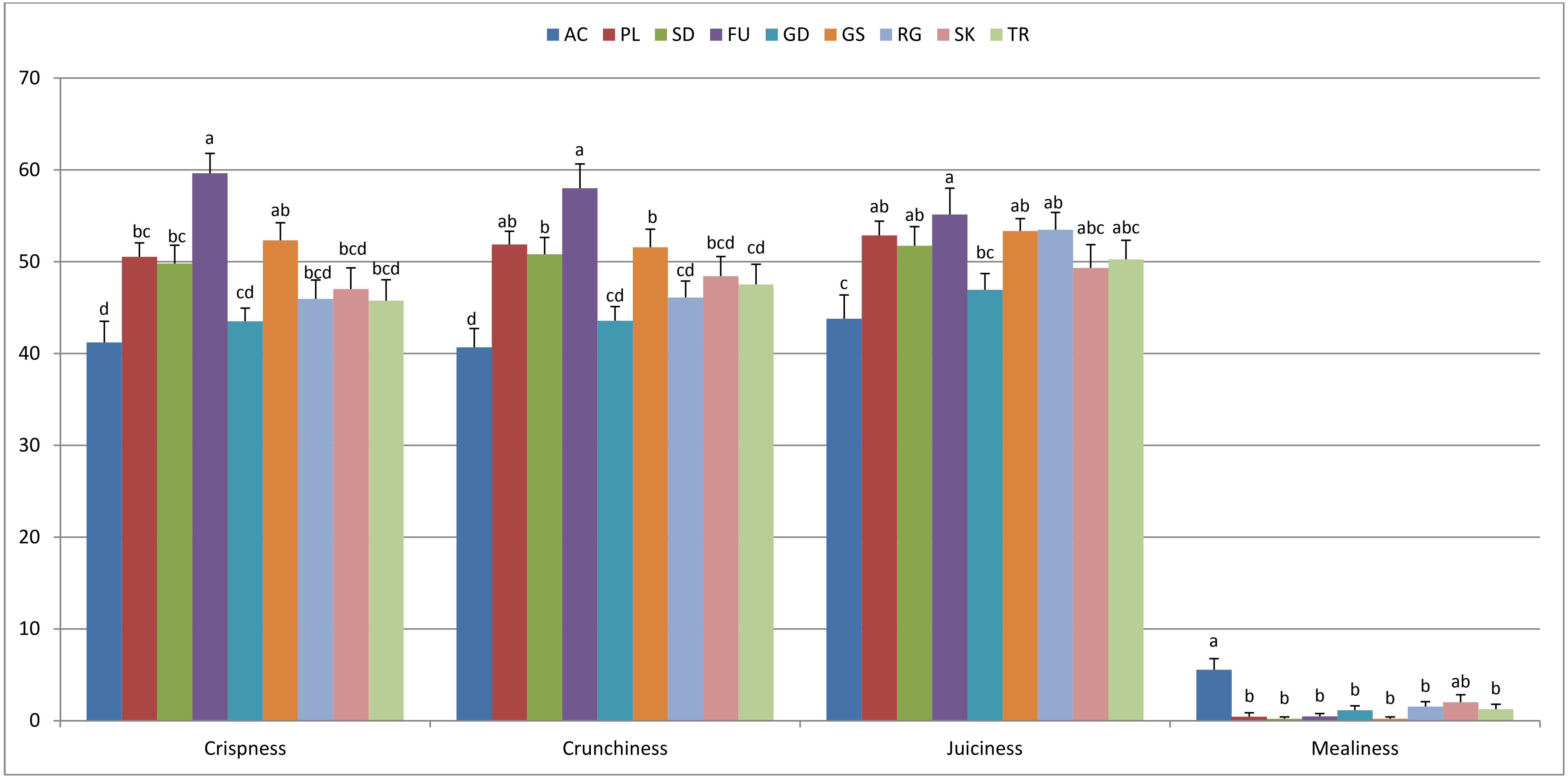

Figure 2 Overall means of sensory textural attributes measured on a 100 mm line scale during descriptive sensory analysis of nine apple cultivars, i.e., African Carmine (AC), Pink Lady® (PL), Sundowner® (SD), Fuji (FU), Golden Delicious (GD), Granny Smith (GS), Royal Gala (RG), Starking (SK) and Topred (TR). Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

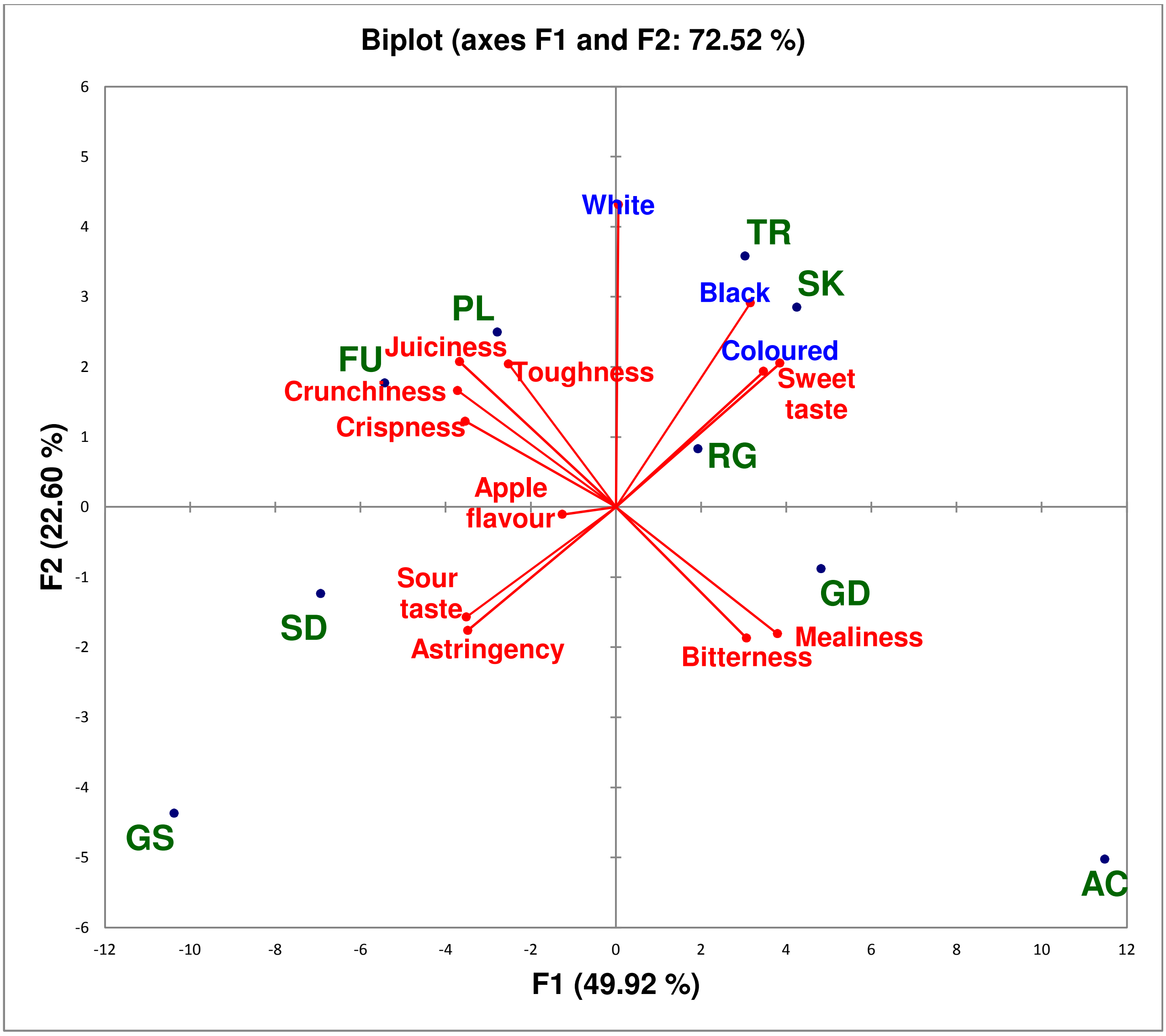

Figure 3 Principal component analysis bi-plot indicating the position of the consumer preference for overall eating quality for white, coloured and black consumers in relation to sensory attributes of apple fruit from nine cultivars, i.e., African Carmine (AC), Starking (SK), Pink Lady® (PL), Golden Delicious (GD), Granny Smith (GS), Royal Gala (RG), Fuji (FU), Topred (TR) and Sundowner® (SD).

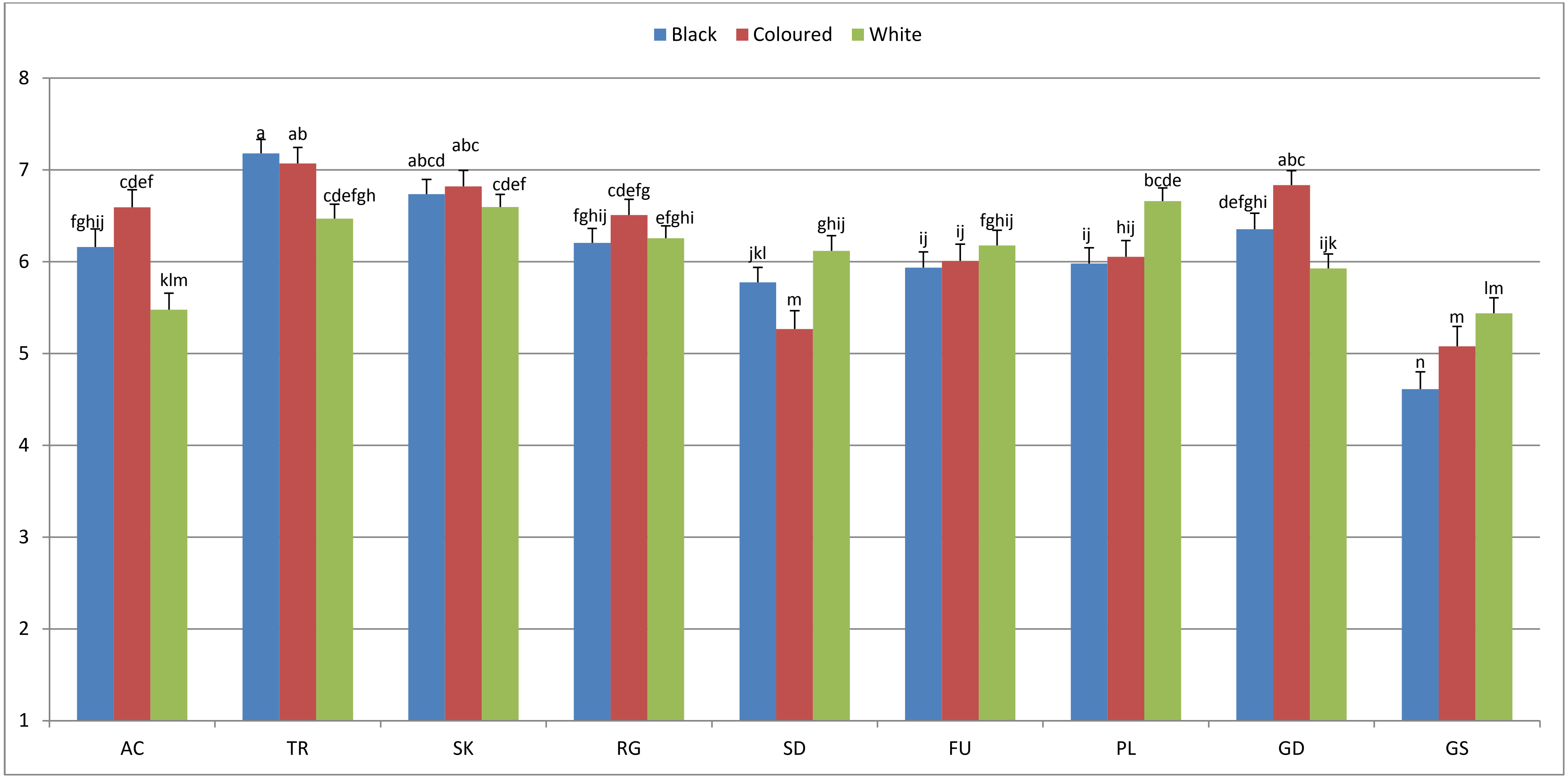

Figure 4 Mean preference scores for the nine apple cultivars in the actual eating quality evaluation, i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS) by the black, coloured and white consumers. Means +standard error with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

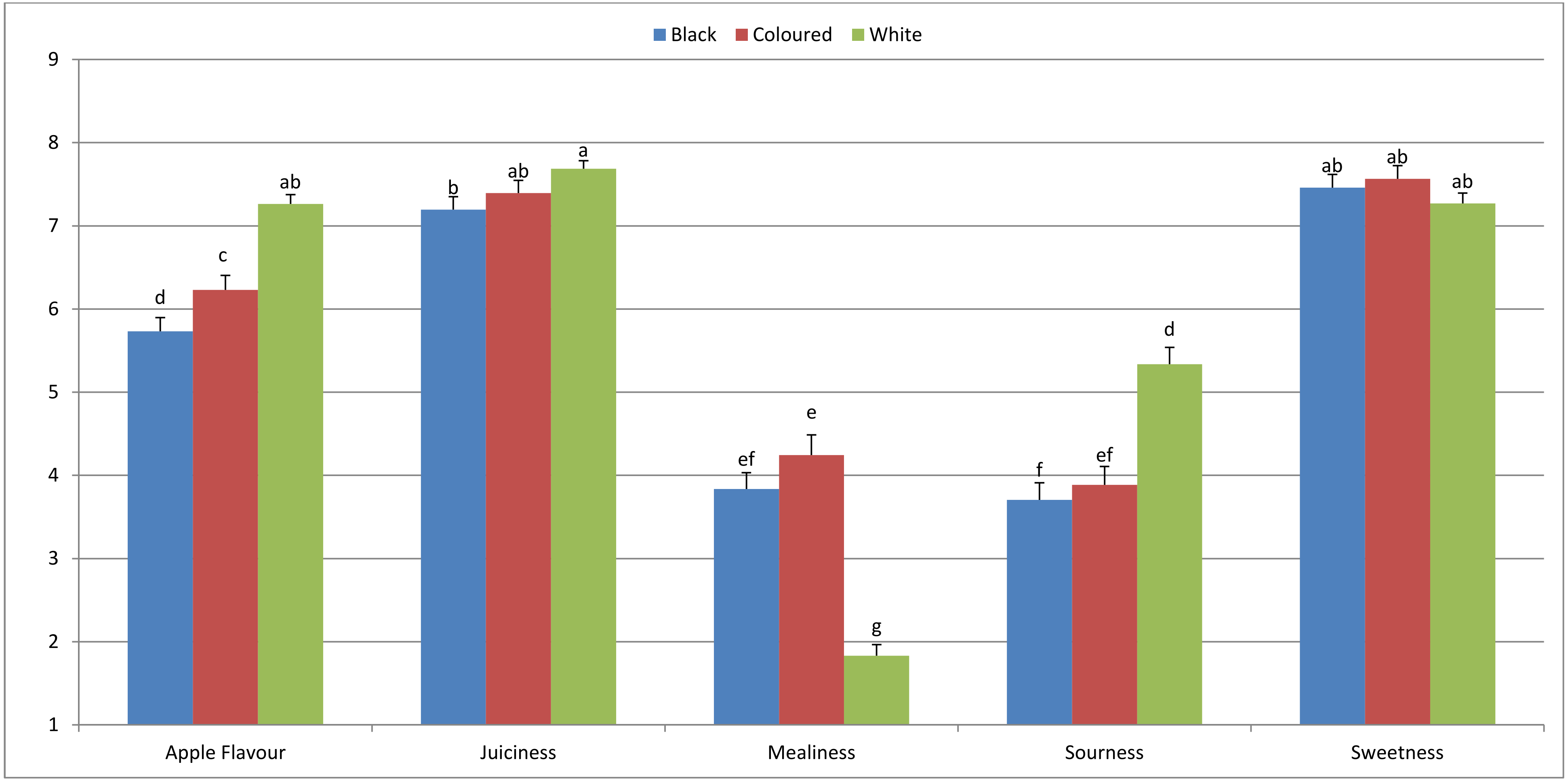

Figure 5 Mean preference scores for general sensory attributes of apples in the conceptual evaluation, rated by the black, coloured and white consumers. Means +standard error with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

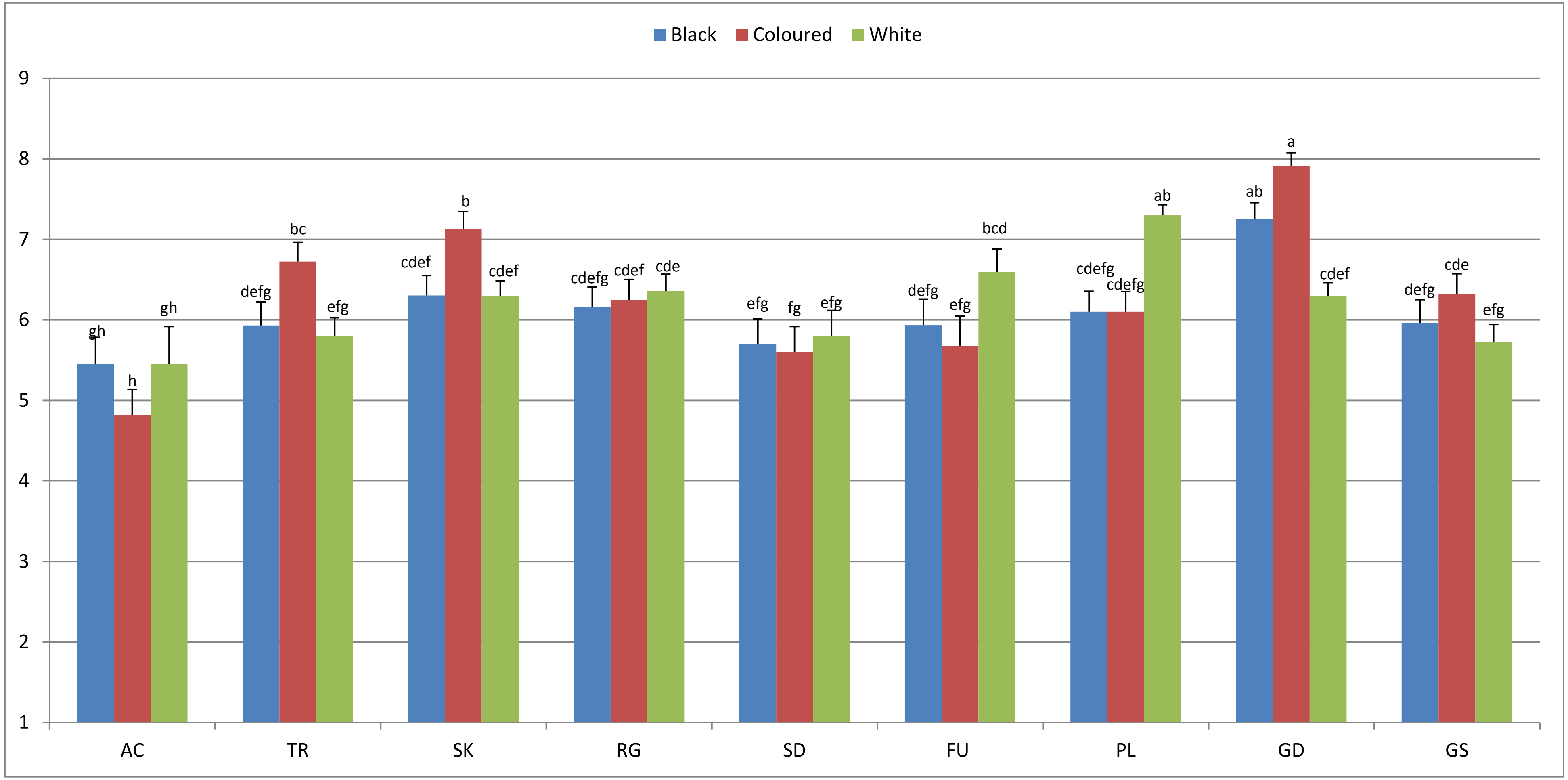

Figure 6 Mean preference scores for the nine apple cultivars in the conceptual evaluation, i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS) by the black, coloured and white consumers. Means +standard error with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

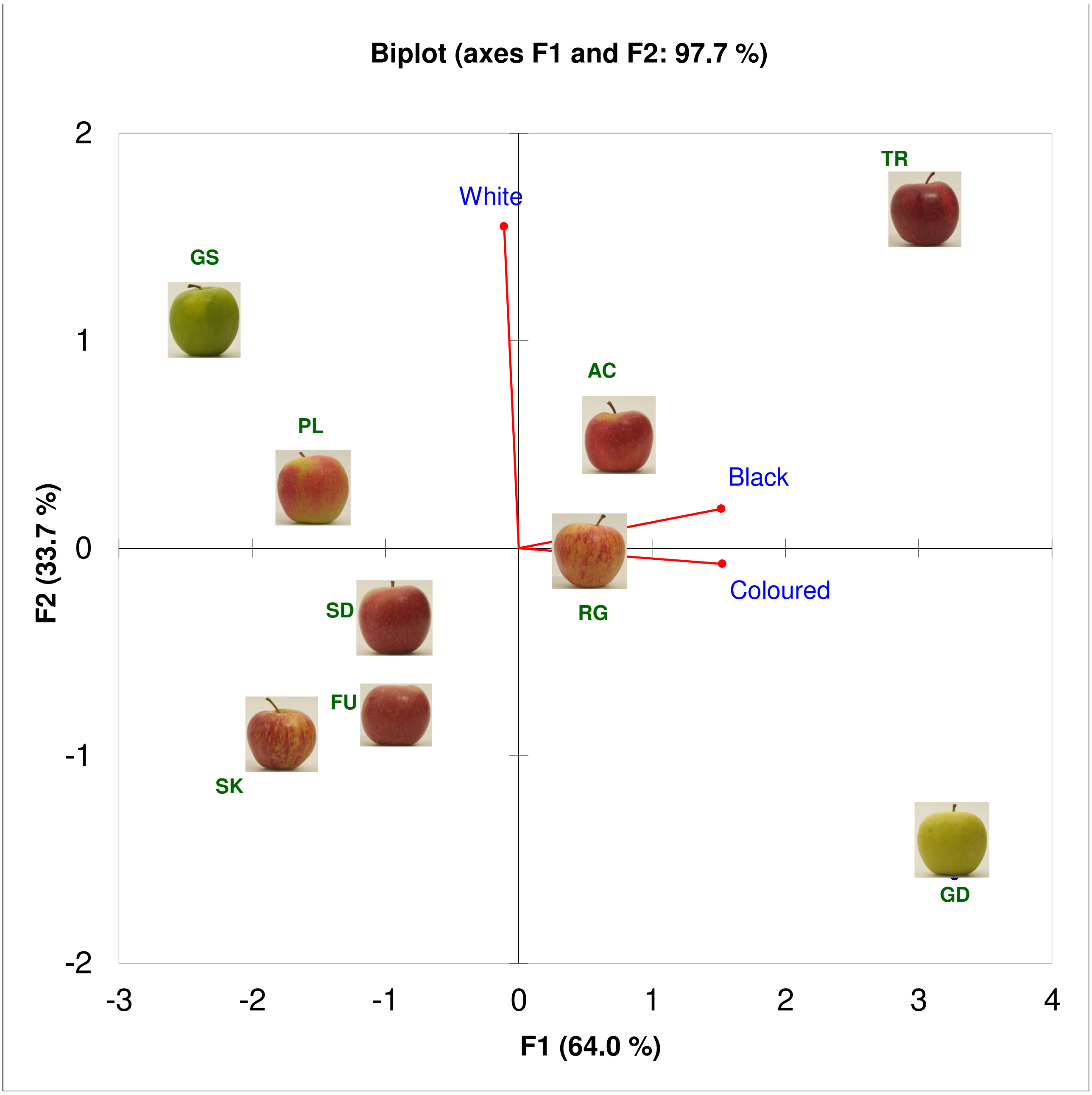

Figure 7 Principal component analysis bi-plot indicating the preference for appearance of the three ethnic groups (black, coloured and white) for the nine apple cultivars, i.e., African Carmine (AC), Starking (SK), Pink Lady® (PL), Golden Delicious (GD), Granny Smith (GS), Royal Gala (RG), Fuji (FU), Topred (TR) and Sundowner® (SD). The photographs used for the study are displayed in the plot.

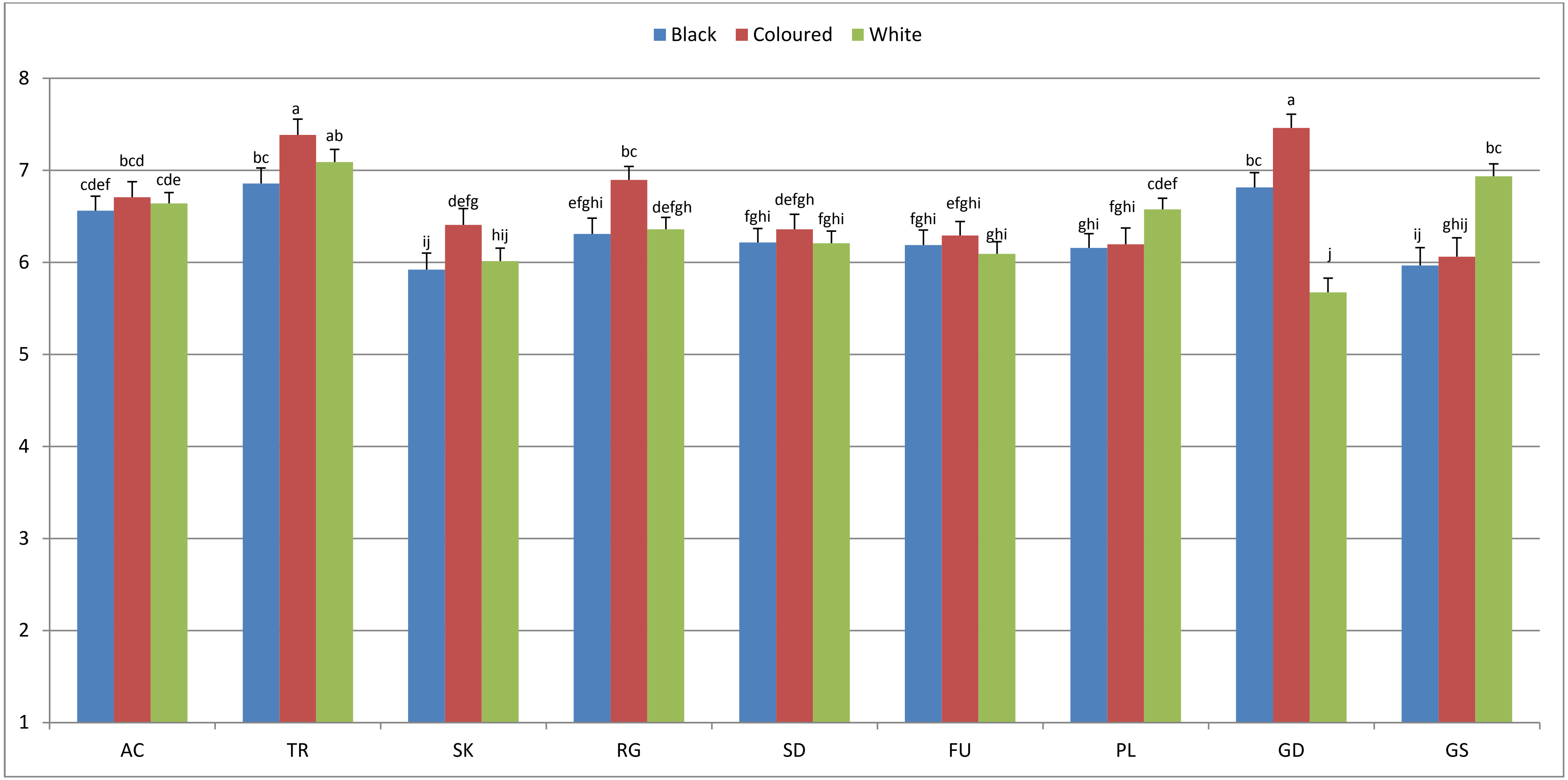

Figure 8 Mean appearance preference scores for the nine apple cultivars, i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS) by the black, coloured and white consumers. Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

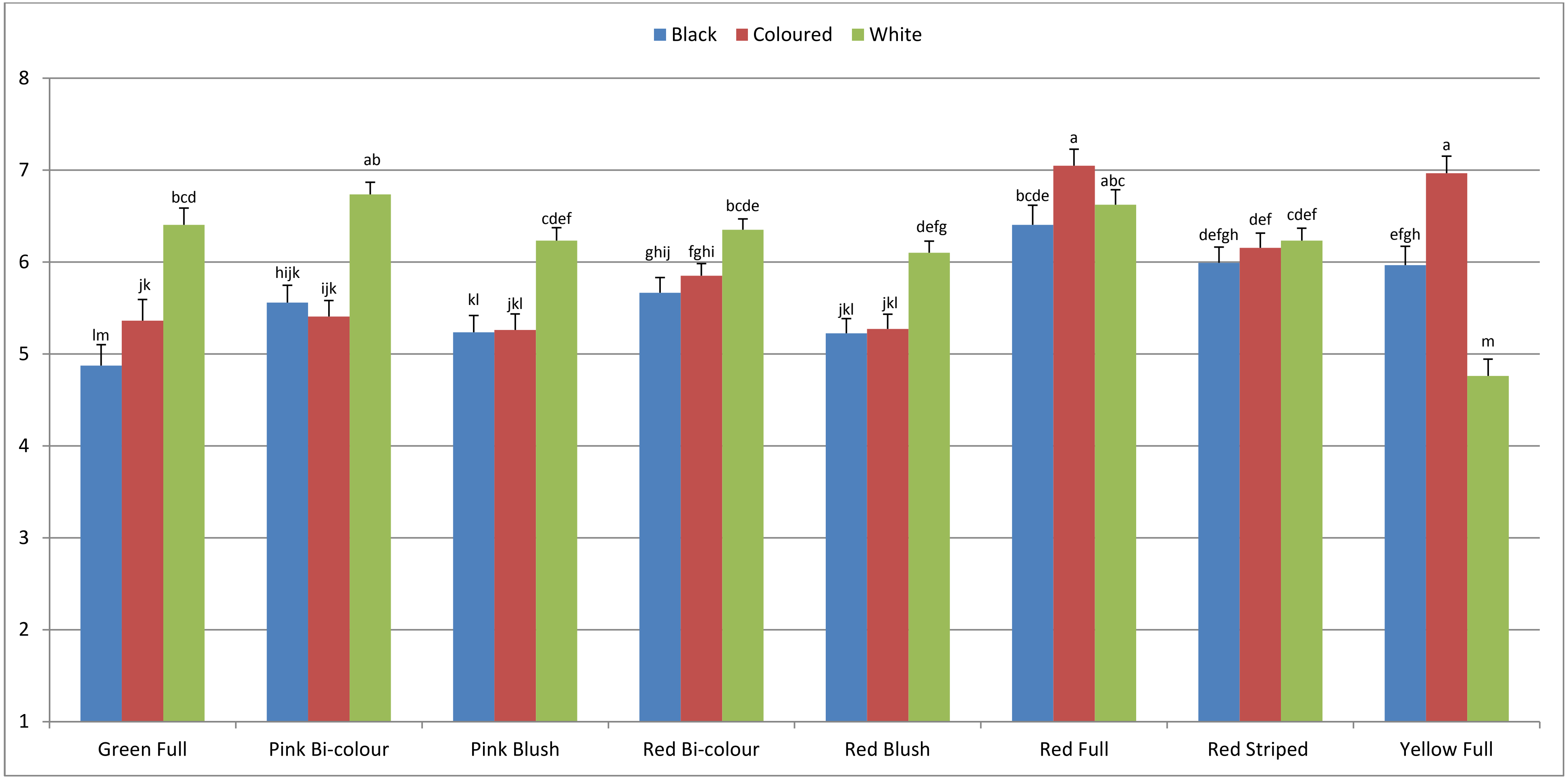

Figure 9 Mean preference scores for apple colours and colouring patterns as evaluated conceptually by black, coloured and white consumers. Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

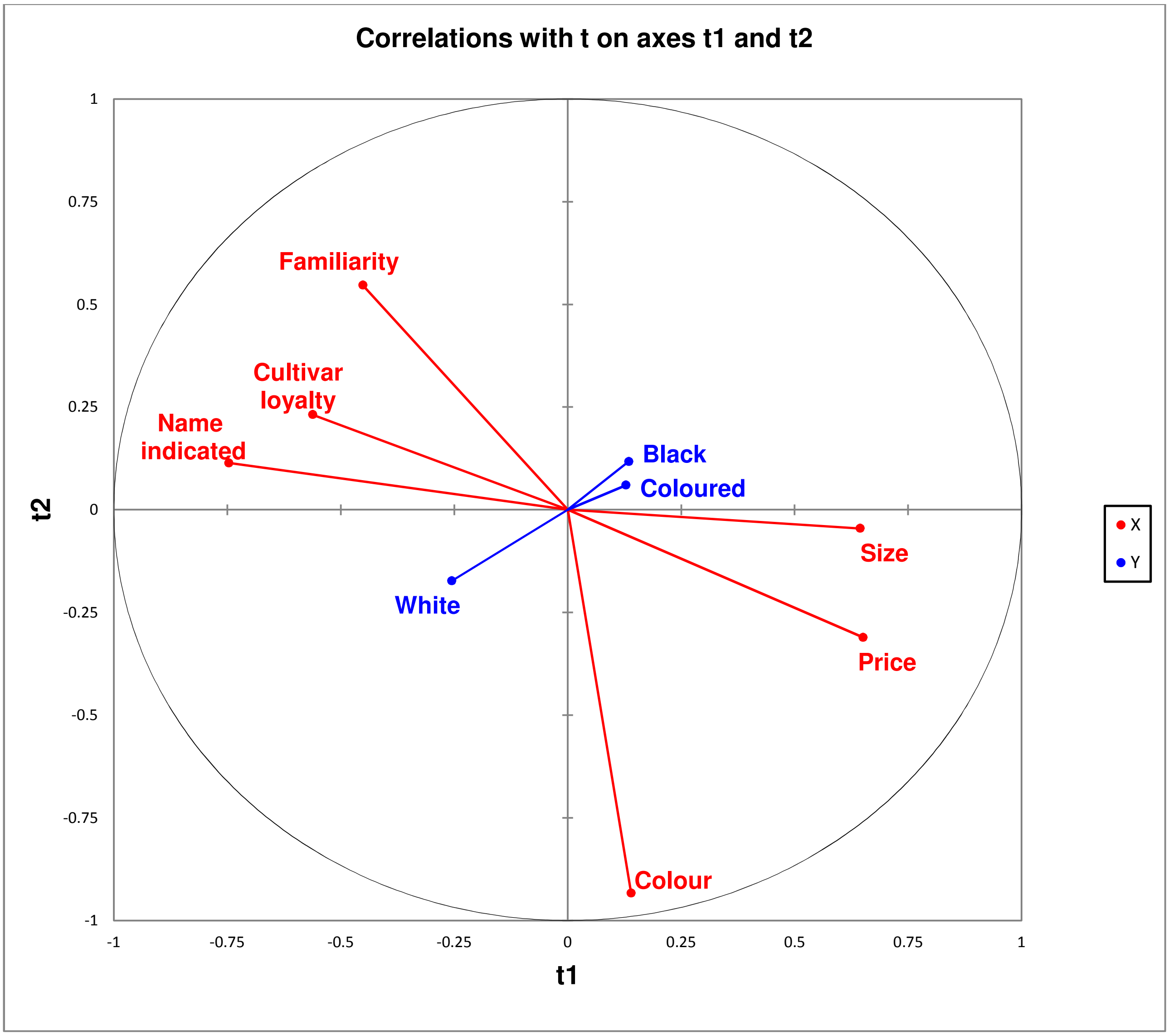

Figure 10 Partial least squares plot indicating the importance to white, coloured and black consumers of several purchase factors, i.e., colour of the apple (colour), loyalty to specific cultivars (cultivar loyalty), familiarity with cultivar (familiarity), cultivar name indication on the packaging (name indicated), price and size of the apples.

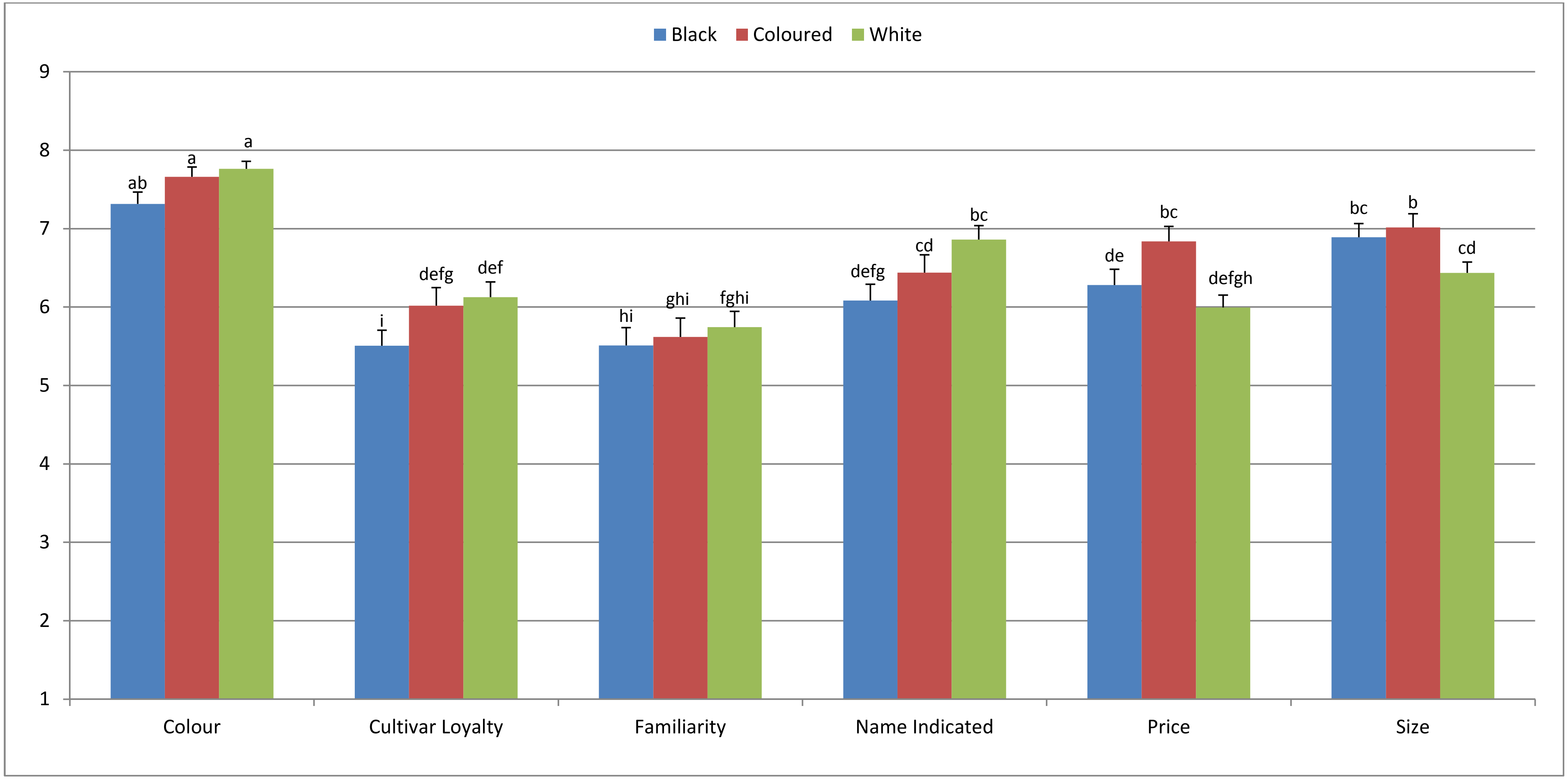

Figure 11 Importance ratings given to factors that influence purchase decisions for coloured, black and white consumers, i.e., colour of the apple (colour), loyalty to specific cultivars (cultivar loyalty), familiarity with cultivar (familiarity), cultivar name indication on the packaging (name indicated), price and size of the apples. Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

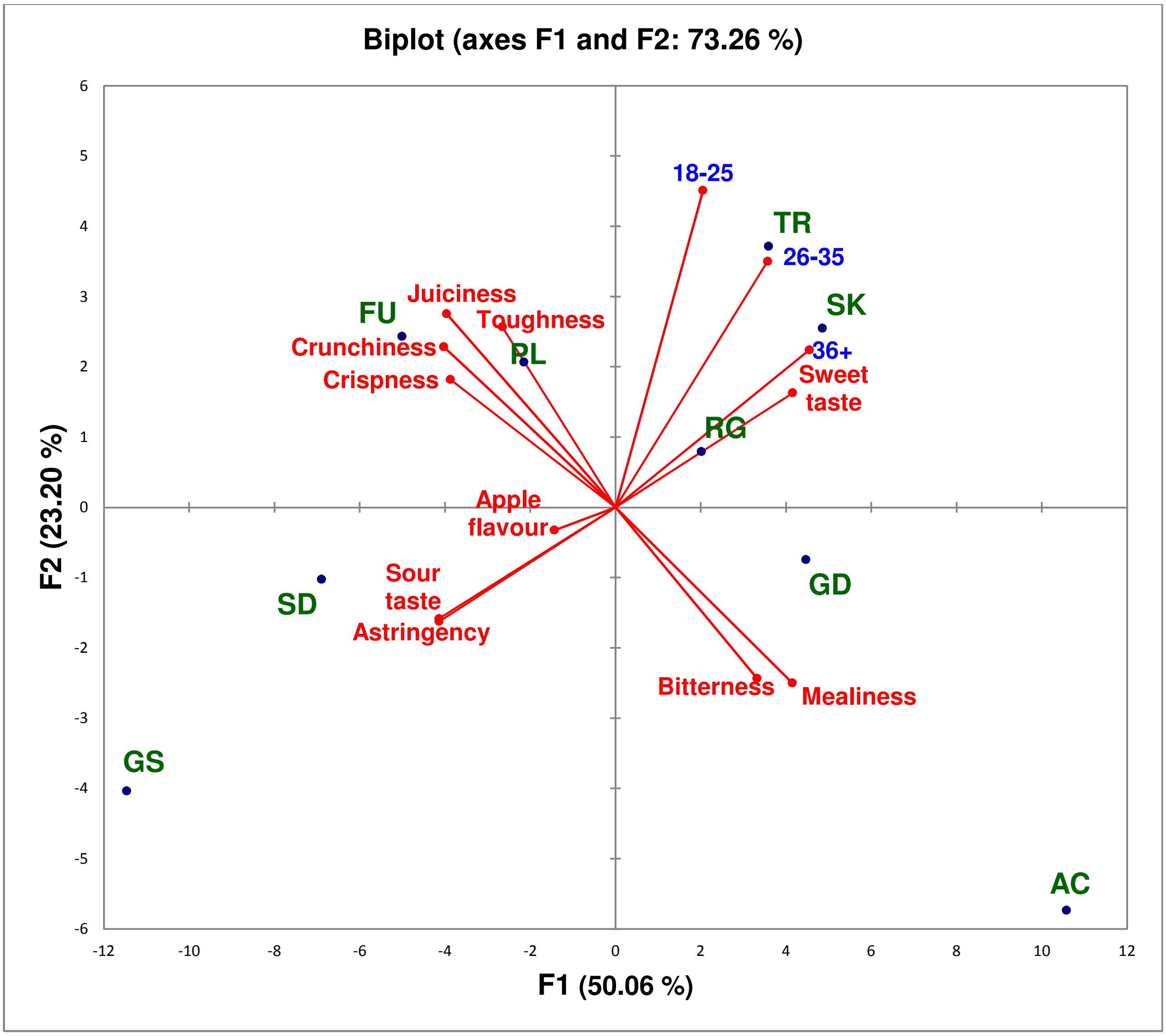

Figure 12 Principal component analysis bi-plot indicating the position of the consumer preference for overall eating quality for consumers from the three age groups (18-25, 26-35, 36+) in relation to sensory attributes of apple fruit from nine cultivars, i.e., African Carmine (AC), Starking (SK), Pink Lady® (PL), Golden Delicious (GD), Granny Smith (GS), Royal Gala (RG), Fuji (FU), Topred (TR) and Sundowner® (SD).

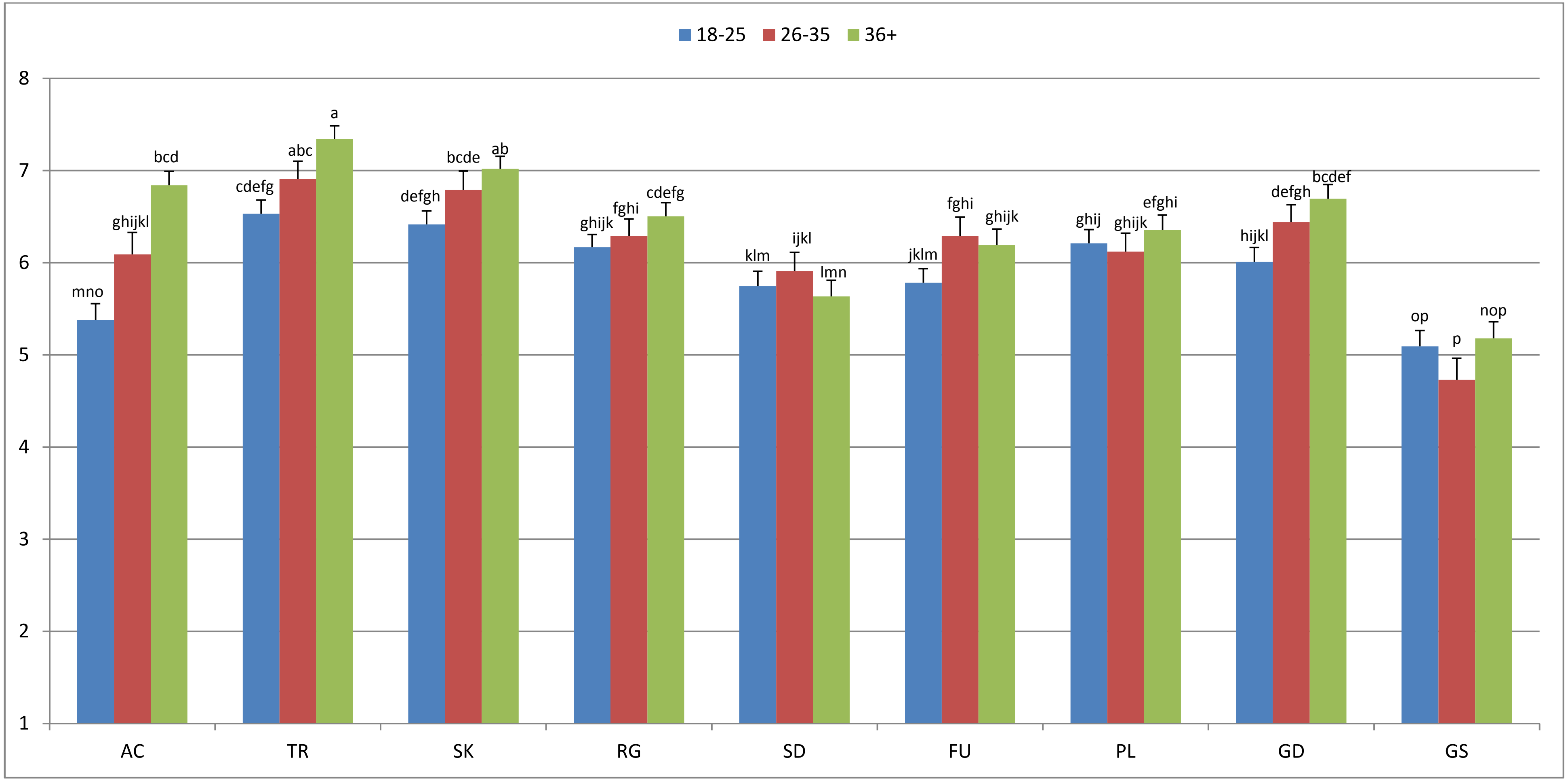

Figure 13 Mean preference scores for the nine apple cultivars in the actual eating quality evaluation, i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS) by consumers from three different age groups. Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

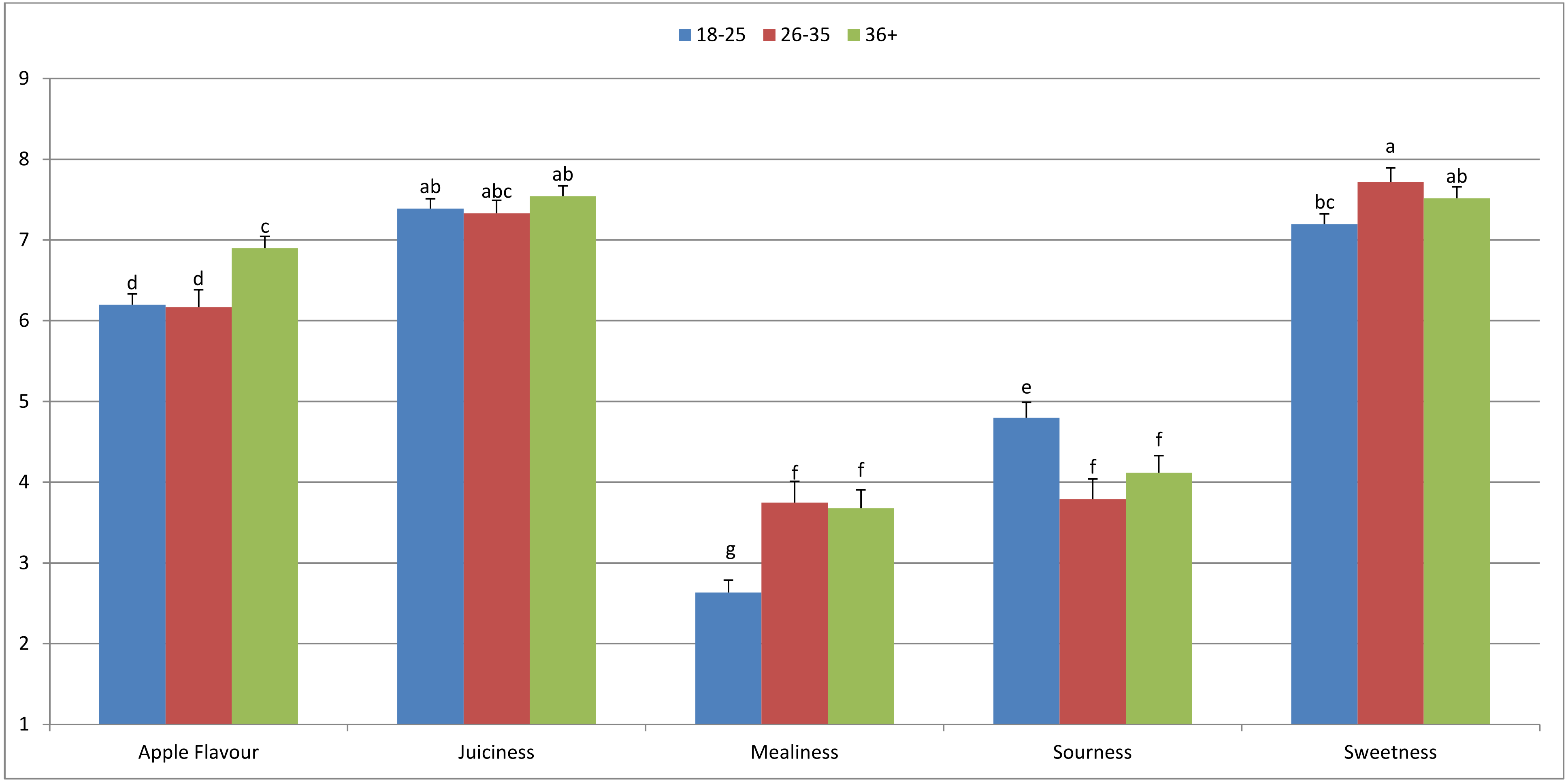

Figure 14 Mean preference scores for sensory attributes in the conceptual evaluation of consumers from different age groups, i.e., 18-25, 26-35 and 36+. Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

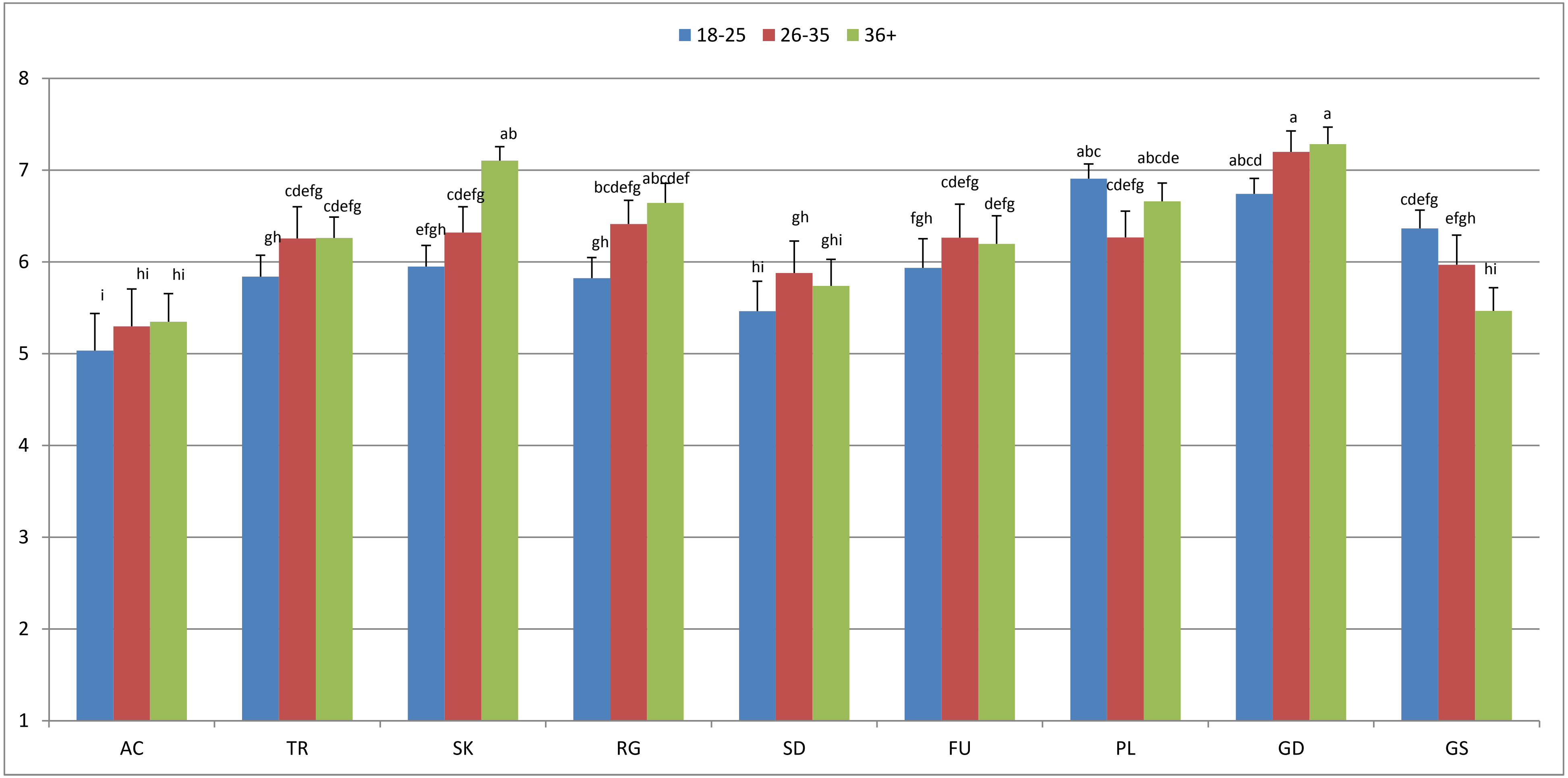

Figure 15 Mean preference scores for the nine apple cultivars in the conceptual evaluation, i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS) by the consumers from three age groups. Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

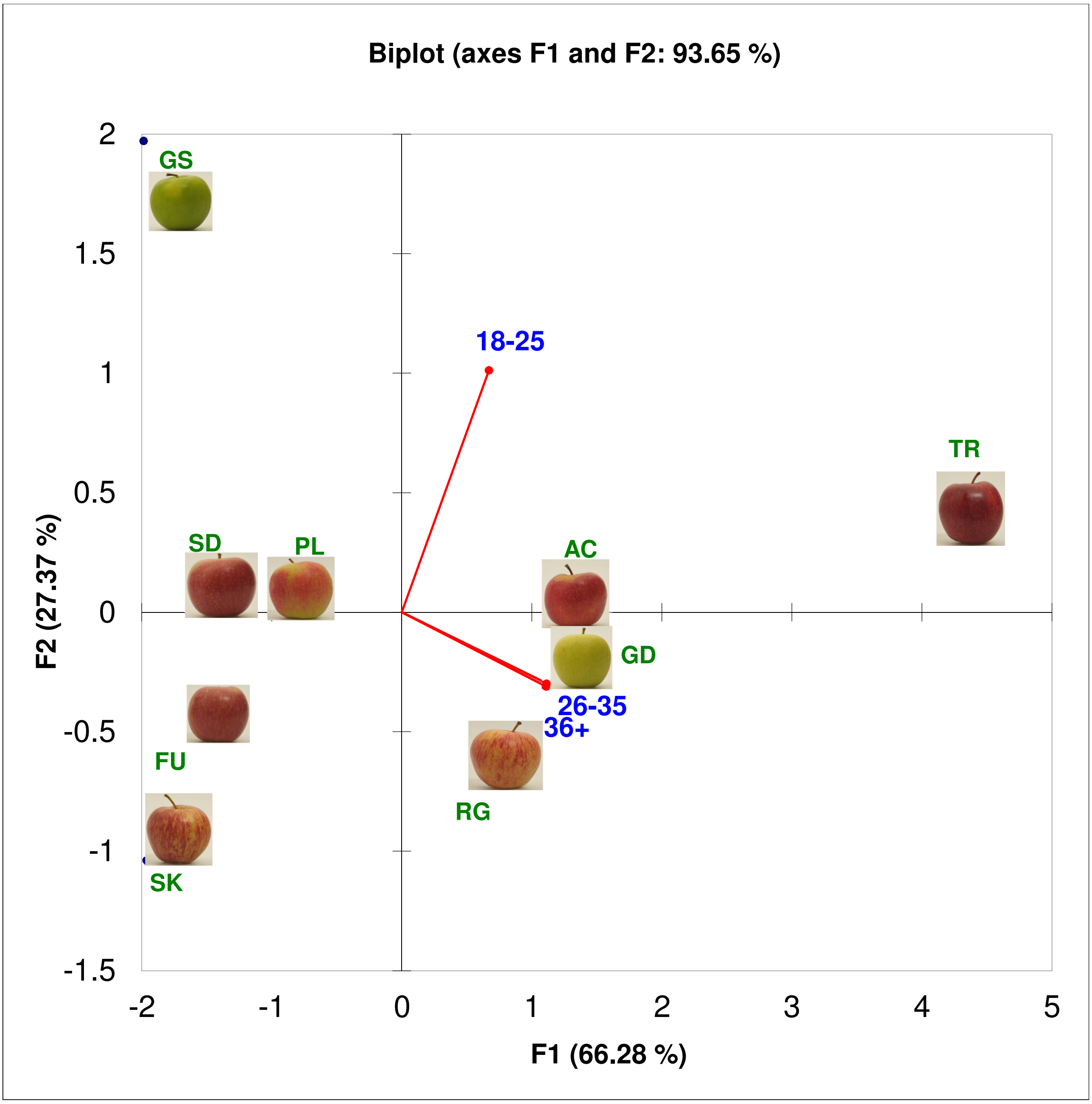

Figure 16 Principal component analysis bi-plot indicating the preference for appearance of the three age groups (18-25, 26-35, 36+) for the nine apple cultivars, i.e., African Carmine (AC), Starking (SK), Pink Lady® (PL), Golden Delicious (GD), Granny Smith (GS), Royal Gala (RG), Fuji (FU), Topred (TR) and Sundowner® (SD). The photographs used for the study are displayed in the plot.

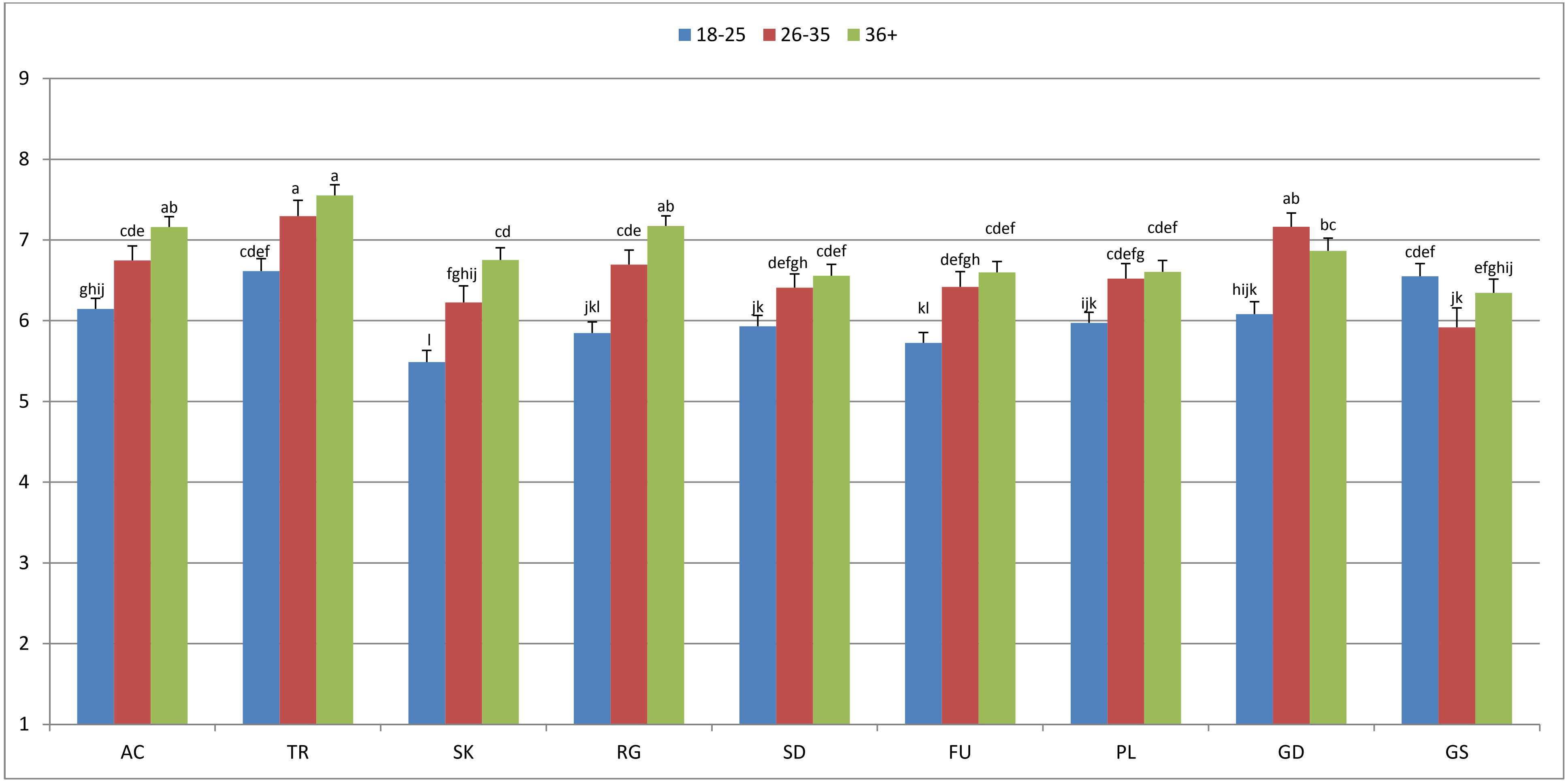

Figure 17 Mean appearance preference scores for the nine apple cultivars, i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS) by the consumers from three different age groups, i.e. 18-25, 26-35 and 36+. Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

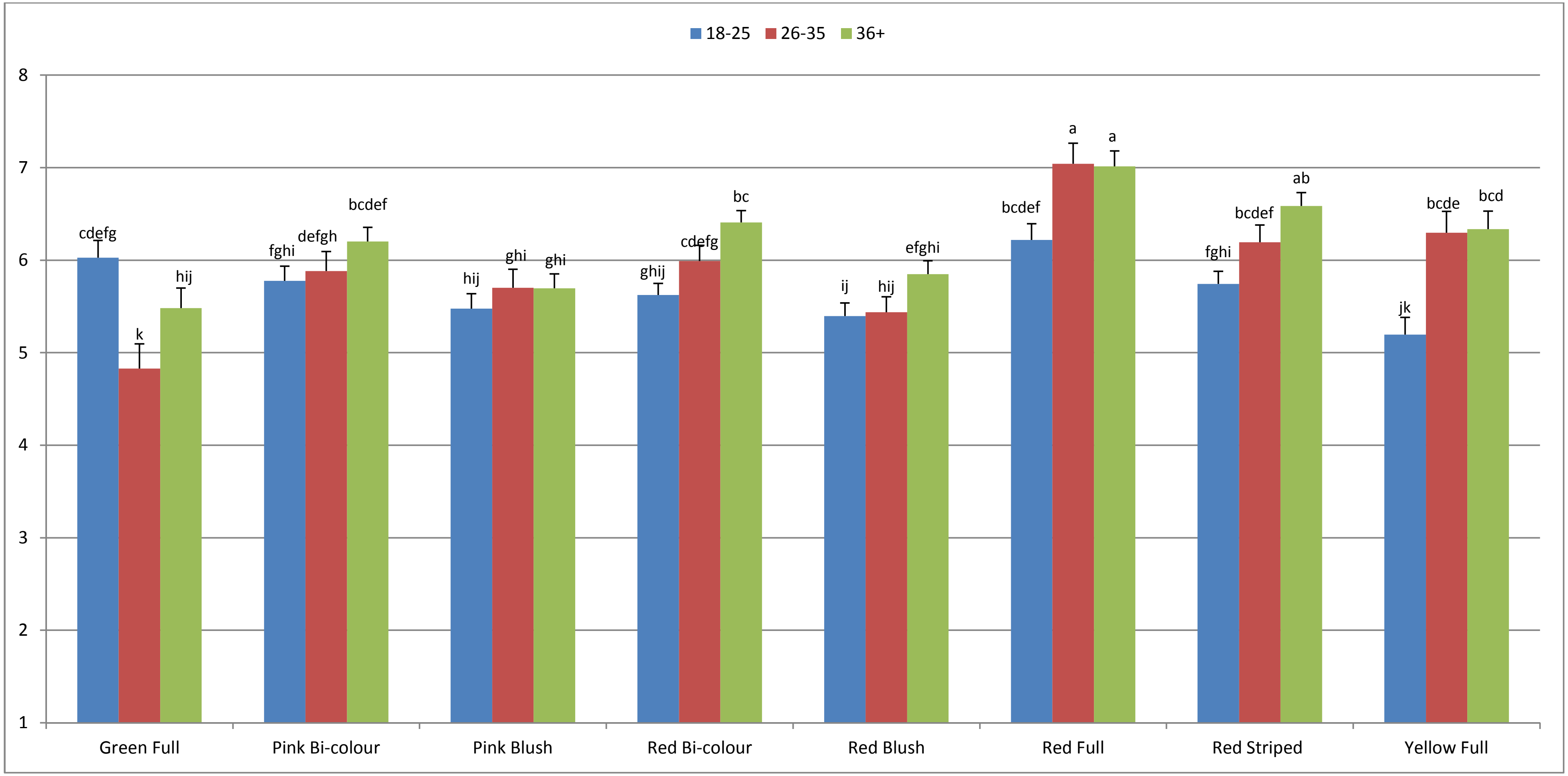

Figure 18 Mean preference scores for apple colours and colouring patterns as evaluated conceptually by consumers aged between 18-25, 26-35 and 36+. Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

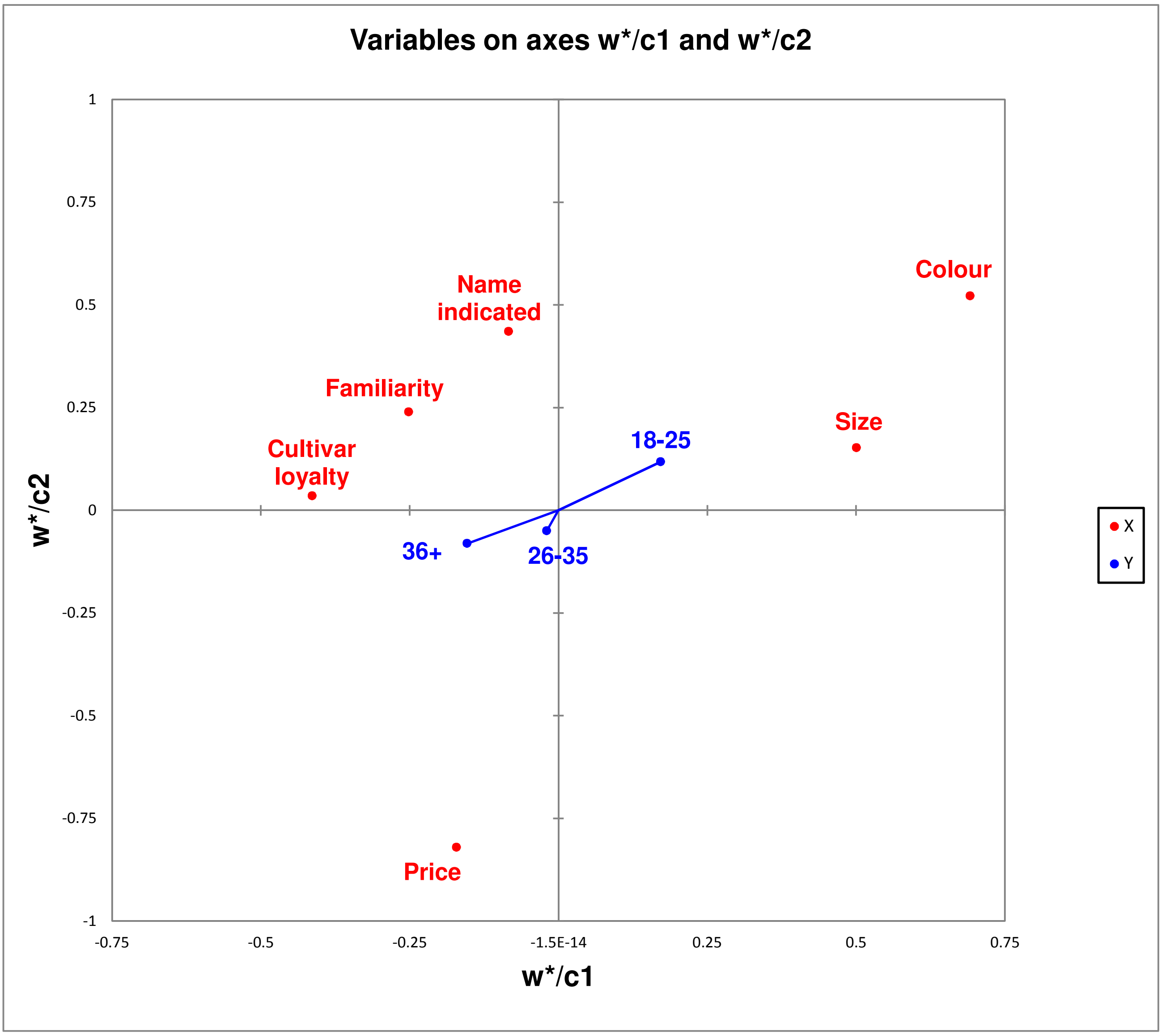

Figure 19 Partial least squares plot indicating the importance to consumers from the three age groups of several purchase factors, i.e., colour of the apple (colour), loyalty to specific cultivars (cultivar loyalty), familiarity with cultivar (familiarity), cultivar name indication on the packaging (name indicated), price and size of the apples.

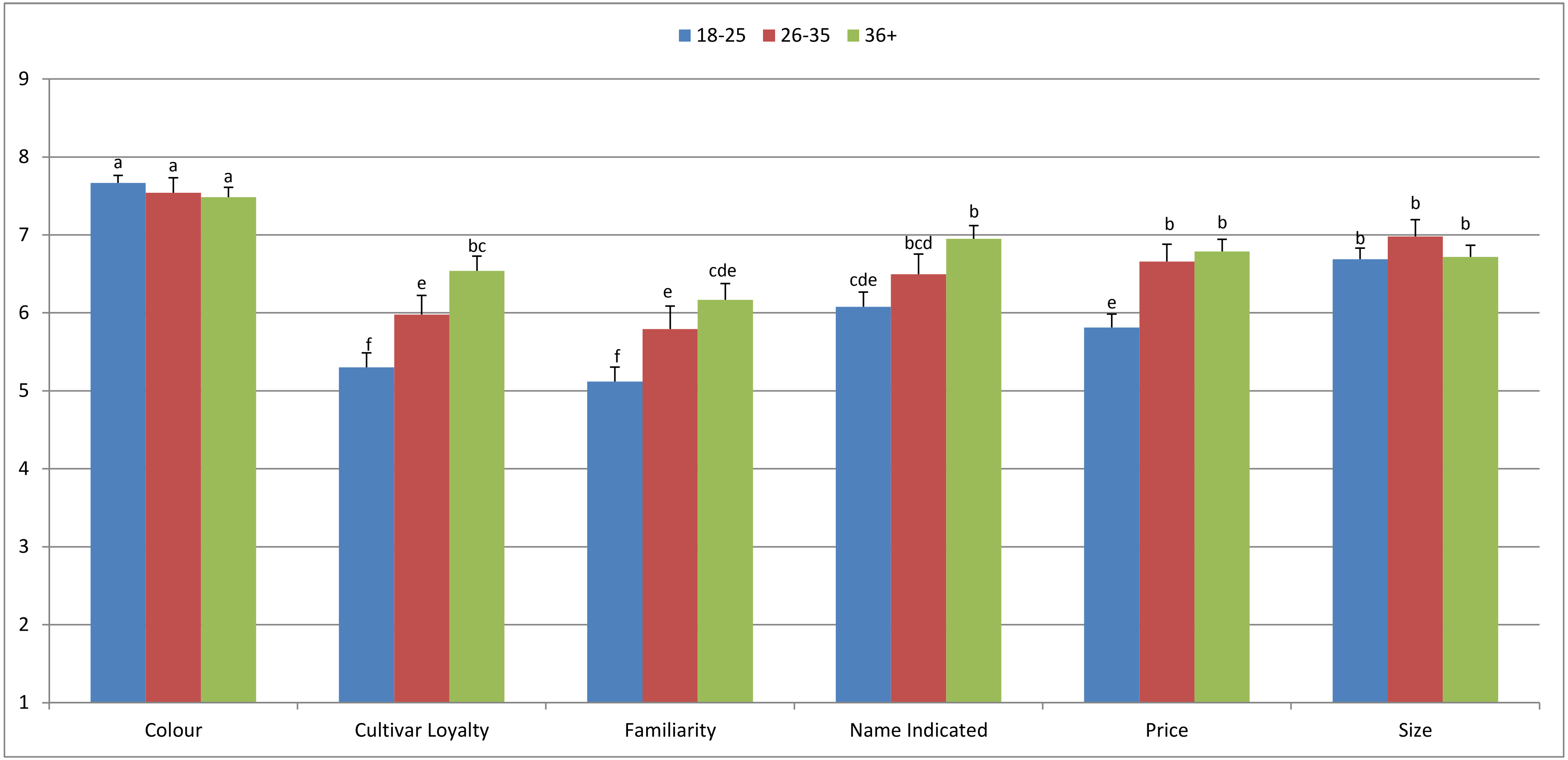

Figure 20 Importance ratings given to factors that influence purchase decisions for consumers from three age groups, i.e., colour of the apple (colour), loyalty to specific cultivars (cultivar loyalty), familiarity with cultivar (familiarity), cultivar name indication on the packaging (name indicated), price and size of the apples. Means +standard errors with different alphabetical letters differ significantly. The least significant difference for each group is indicated at the 5% level of significance.

CHAPTER 4

Consumer clustering based on preference for apple eating quality and appearance

1. ABSTRACT

Consumers' apple preferences are not homogenous, especially in a heterogeneous socio-economic society like South Africa where it was shown that consumers' ethnic and age group relate to their preferences for apple eating quality and appearance (Chapter 3). Ward's statistical clustering was applied to consumer preference data of nine commercially available apple cultivars that were generated in Chapter 3. Consumers with similar preferences could be segmented into three clusters based on their preferences for apple eating quality (eating quality clusters) and appearance (appearance clusters). Consumers' socio-demographic characteristics were related to their cluster membership in a posterior tabulation manner. Descriptive sensory analysis (DSA) data that were generated in Chapter 3 were projected unto the eating quality clusters' preference dimensions using principal component analysis (PCA) to identify drivers of liking. The following preference patterns were shown: Eating quality cluster 1 (E1) liked sensory attributes relating to firmness and tolerated sour taste, but liked sweet taste and mealiness less compared to the other clusters; eating quality cluster 2 (E2) liked sour taste and apple flavour; and eating quality cluster 3 (E3) disliked sour taste. Although E3 accounted for higher proportions of black and coloured consumers compared to E1 and E2, the coloured and black consumers in E1 and E2 who liked or tolerated sour taste constitute approximately 41% of the total consumer population in the Western Cape Province of South Africa. The three cluster solution based on consumers' preferences for apple appearance showed that appearance cluster 1 (A1) had a higher preference for green peel colour ('Granny Smith') and pink bi-colour ('Pink Lady®') compared to the other clusters, appearance cluster 2 (A2) liked green/yellow ('Golden Delicious') and red striped peel colour ('Starking' and 'Royal Gala') and appearance cluster 3 (A3) liked red and yellow/green peel colour ('African Carmine', 'Royal Gala', 'Topred' and 'Golden Delicious'). Consumers generally liked the appearance of the cultivars that traditionally associate with the eating quality attributes that they preferred.

Keywords Cluster analysis, consumer preference, *Malus x domestica* (Borkh.), principal component analysis, residual preference data, socio-demographic factors.

2. INTRODUCTION

South African apple producers and marketers are familiar with the apple eating quality that is generally required by consumers in the export market, but limited information is available on the preferences of the local market (Du Preez, 2011) where approximately 30% of the total production volume is sold (DFPT, 2011). Due to the limited shelf life of apples (Cliff *et al.*, 1999), supermarkets and other selling points of fresh produce yearly suffer enormous financial losses when fruit quality deteriorate to levels unacceptable for consumer purchasing (Nel, 2010). Targeting apple cultivars at the consumer groups who are more likely to purchase it could potentially reduce losses at selling points when apples are purchased before major reductions in eating quality. Local economic growth in recent years has led to an increased consumer market segment that can afford premium prices for high quality apples (STATSSA, 2006; Fick, 2011). A clear understanding of the preferences of local consumers should enable apple breeders to focus on the development of apple cultivars that would specifically meet the demands of consumers in the local market.

Consumers' preferences for apple eating quality and appearance are not homogenous (Harker *et al.*, 2003). The preference patterns of consumers in the Western Cape Province of South Africa relate to their age and ethnic group (Chapter 3), but preferences among consumers within the same ethnic group are often so big that overlap between the preferences of consumers from different groups is inevitable (Jaeger *et al.*, 1998). Not all consumers within each of the three ethnic groups were therefore expected to show similar preferences. It was shown that black, coloured and older consumers generally had a higher preference for sweet taste and lower preference for sour taste compared to white and younger consumers (Chapter 3). Considering the size of the coloured consumer group in the Western Cape and the black consumer group nationally (STATSSA, 2011), even small proportions of these consumers that show a preference for sour taste would constitute a large potential market for sour apples. It has been shown internationally that consumers can be divided into groups that either prefer sweet or sour apples (Daillant-Spinnler *et al.*, 1996; Carbonell *et al.*, 2008), but there is limited information available on how the sizes of similar consumer segments in South Africa compare to each other and how socio-demographic factors relate to these segments. Marketers are increasingly interested in describing consumer groups with similar preference patterns in terms of quantifiable socio-demographic characteristics, such as age, gender and socio-economic status, which is critical for the identification and targeting of specific markets (Péneau *et al.*, 2006).

In this part of the research, data generated in Chapter 3 were analysed in order to obtain a better understanding of individual consumers' preferences. In view of the above, the aims of this research were: 1) To establish the sensory attributes that drive the apple preferences of consumer clusters; 2) to determine the relative size of these clusters; 3) to determine whether cluster differences could be related to socio-demographic differences and 4) to predict how socio-demographic characteristics could be used in order to streamline cultivar distribution to the market segment who is most likely to purchase it.

3. MATERIALS AND METHODS

3.1 Sensory and consumer analysis

The plant material that were used, the descriptive sensory analysis (DSA), consumer recruitment and consumer preference analysis that were conducted are reported in Chapter 3 and will not be reported here.

3.2 Statistical procedures

Please refer to Chapter 3 for a description of the analysis of variance (ANOVA) that was applied to data generated by DSA.

Consumer preference data generated in Chapter 3 were subjected to cluster analysis by Ward's clustering method, using XLSTAT software (Addinsoft, Version 2007, Paris, France). Due to consumer differences in scale usage, it was decided to double centre (i.e. row and column centring) the preference data and conduct the clustering on the residual preference data (Martens *et al.*, 2005). A hierarchical clustering method was performed in which the software automatically detected the number of clusters that resulted in the best statistical fit. Mean values for each cluster were computed from the residual and actual (unprocessed) preference data for all clusters. Student's t-LSD's (Least Significant Difference) were calculated at a 5% significance level and used to determine preference patterns for eating quality. Consumer socio-demographic data were related to the different clusters (Næs *et al.*, 2010). Partial least squares (PLS) regression was used to relate consumers' cluster membership with their demographical information. Similar analyses were performed on consumers' appearance data. Consumers' cluster membership for the clusters based on eating quality preferences were related to importance ratings given to purchase factors and the preference for conceptual apple eating quality and appearance attributes in a PLS plot (Johansen *et al.*, 2010). In order to compare consumers' preference for eating quality with their preference for appearance, their cluster membership (based on their preference for eating quality) was projected onto their preference scores for appearance with PCA.

4. RESULTS

For the purpose of this part of the study and in order to refrain from vague terms for reporting, "preference for overall eating quality" indicates consumers' degree of liking for the flavour, taste and texture of the fruit, whereas "preference for appearance" indicates how consumers liked the overall colour and shape of the fruit. For the sake of brevity, the terms "Eating cluster 1" (E1), "Eating cluster 2" (E2) and "Eating cluster 3" (E3) will be used for the clusters that were obtained by consumers' responses to eating quality. Clusters that were obtained by consumers' responses to appearance will be referred to as "Appearance cluster 1" (A1), "Appearance cluster 2" (A2) and "Appearance cluster 3" (A3). The socio-demographic compositions of the different clusters were compared and tabulated as a percentage of the total group for each characteristic (i.e. age, income, education) per ethnic group. The distribution of the socio-demographic characteristics in relation to the different clusters was illustrated in a PLS plot. For the sake of brevity and readability, only the most important differences in socio-demographic characteristics and in actual and residual preference scores for the eating quality and appearance clusters will be reported. Conceptual preference data and importance ratings of purchase factors will be reported for eating quality clusters only.

4.1 Sample attributes

DSA of all samples are reported and discussed in Chapter 3 and will not be reported in this chapter.

4.2 Clustering based on preference for eating quality

Clustering on consumers' preference for overall eating quality resulted in a three cluster solution with the highest statistical fit.

4.2.1 Consumer socio-demographic data

E1, E2 and E3 constituted 34%, 22% and 44% of the total consumer group, respectively (Table 1). E1 constituted the largest proportion of the white and youngest consumer groups (Table 1; Figure 1). The white and coloured consumers in E1 were mostly younger than 25 (Table 1). Black consumers, especially of the youngest age group, were underrepresented in E1. In addition to E1, E2 showed a closer association with white consumers compared to E3, which associated with black and coloured consumers (Fig. 1). Black consumers were overrepresented in E3 (Table 1). The underrepresentation of white consumers in E3 was due to low representation of the youngest white consumers. All three age groups were well represented in E3. E3 constituted the largest proportion of consumers from the oldest age group and associated with this age group in Figure 1. Coloured consumers were well represented in all clusters. White consumers from the second age group were mostly in E2 (Table 1).

Fifty-three per cent of the total consumer group has obtained a qualification from a tertiary institute. The 17% of consumers who did not obtain a final school year qualification were overrepresented in E3 (Table 1) and associated negatively with E1 and E2 (Fig. 1). E1 and E2 associated positively with a final school year qualification and a tertiary qualification, respectively (Fig. 1). Black and coloured consumers with higher income levels (>R5 000 per month) and who obtained a tertiary qualification were overrepresented in E2 (Table 1). Black consumers from the higher income group were generally underrepresented. White consumers from the lower income group (<R5 000 per month) were overrepresented in E1 and slightly underrepresented in E3.

4.2.2 Consumer preference data

The first (PC1) and second (PC2) principal components accounted for 54.7% and 22.7%, respectively, of the variability in responses of the eating quality clusters (Fig. 2). The variability in preference for E1 and E3 was best explained by PC1, while PC2 mostly explained the preference of E2. Mealiness, juiciness, crunchiness and sour taste explained more of the variance in the data on PC1. The positioning of apple flavour opposite crispness and crunchiness illustrates the contribution made by these attributes on PC2. African Carmine and Granny Smith were important cultivars in explaining preference differences for the eating quality clusters on PC1, while Fuji, Pink Lady®, Sundowner® and Granny Smith explained differences on PC2.

The preference of E1 correlated positively with sensory attributes relating to firmer fruit, i.e. crunchiness (r=0.83; P=0.0061), crispness (r=0.83; P=0.0053) and juiciness (r=0.75; P=0.0203), and with sour taste (r=0.69; P=0.0391), as evident from their preference association with these attributes (Fig. 2). E1 disliked sweet taste (r=–0.75; P=0.0206) and mealiness (r=–0.71; P=0.0320). Apple flavour (r=0.94; P=0.0002) and sour taste (r=0.76; P=0.0167) were the strongest drivers of liking for E2, whose preference did not correlate significantly with sweetness or mealiness (Fig. 2). E3 disliked sour taste (r=–0.93; P=0.0003) and astringency (r=–0.70; P=0.0353) and showed a positive correlation with mealiness (r=0.68; P=0.0449) and non-significant correlation with sweet taste (r=0.54; P=0.1303).

The residual (computed from double mean centring) and actual (unprocessed) liking scores for the eating quality clusters showed that E1 and E2 liked Pink Lady® and Granny Smith (>6) and indicated higher preferences for these cultivars compared to E3 (Fig. 3 & 4). The residual preference scores of E2 for 'Granny Smith' and 'Pink Lady®' were higher than for 'Topred' (Fig. 3). However, the actual preference of E2 for 'Granny Smith' and 'Pink Lady®' was lower and similar , respectively, compared to 'Topred' (>7) (Fig. 4). Residual and actual preference scores of E2 were higher for 'Royal Gala' and 'Sundowner®' and lower for 'Fuji' compared to E1 and E3 (Fig. 3 & 4). E1 indicated greater preference for 'Sundowner®' and 'Fuji' compared to E3 and highly liked 'Fuji' (>6) (Fig. 3 & 4). Although residual preference scores of E1 for Starking, Royal Gala, Golden Delicious and especially Topred (Fig. 3) were low, E1 consumers generally liked these cultivars (≈6) (Fig. 3 & 4). Granny Smith was disliked by E3 (<4), who indicated significantly lower preference ratings compared to other cultivars. E3 highly liked African Carmine, Topred, Starking (>7) and Golden Delicious (>6) and indicated higher actual preference scores compared to other cultivars (Fig. 4). Residual preference scores for E3 computed for the latter cultivars were higher compared to E1 and E2 (Fig. 3 & 4).

4.3 Clustering based on preference for appearance

Clustering on consumers' preference for appearance resulted in a three cluster solution with the highest statistical fit.

4.3.1 Consumer socio-demographic data

A1 constituted the largest proportion of the total consumer group (45%), while 38% and 17% of the consumers belonged to A2 and A3, respectively (Table 2). White consumers were over- and underrepresented in A1 and A3, respectively, while the opposite was seen for the coloured and black consumers (Table 2 & Figure 5). The youngest consumers were mostly in A1 (Table 2). A2 associated positively with the older two consumer age groups (Figure 5). The black and white consumers in A1 were mostly from the youngest age group. The youngest black and oldest coloured consumers were underrepresented and the oldest white consumers overrepresented in A3. The oldest coloured consumers were mostly in A2, but were underrepresented in A1 (Table 2).

A1 accounted for the highest proportion of consumers who obtained a final school year qualification, while this group was underrepresented in A3 (Table 2). Black consumers who did not obtain a final school year qualification were over- and underrepresented in A1 and A3, respectively (Table 2 & Fig. 5). Larger proportions of black consumers in A2 and coloured consumers in A1 indicated that they obtained a final school year qualification, but this group was underrepresented for the coloured consumers in A3. White consumers with and without final school year qualifications were overrepresented in A1 and A3, respectively. Consumers from the higher income group (>R5000 per month), especially black consumers, were underrepresented in A1. Coloured consumers from the higher income group were mostly in A2. White consumers from the lower income group (<R5000 per month) were over- and underrepresented in A2 and A3, respectively (Table 2).

4.3.2 Consumer preference data

The first two principal components explained approximately all of the variability in consumer preference for apple appearance (≈100%) (Fig. 6). The preferences of A2 and A3 could be distinguished from A1 on PC1, which accounted for 62.2% of the variability in the data (Fig. 6). The preferences of all three clusters differed on PC2, which explained 37.8% of the variability in the data. ‘Golden Delicious’ and ‘Granny Smith’ were positioned on the extreme sides of PC1 and explain a large part of the variance on this component, while 'Topred’ and 'Granny Smith' mostly explained the variance on PC2.

The preference of A1 associated with 'Granny Smith' on the far right side of the plot, and also with ‘Fuji’, ‘Sundowner®’ and ‘Pink Lady®’, which were situated towards the centre of the plot (Fig. 6). A2 showed a positive preference association with Golden Delicious, Starking and Royal Gala, while preference of A3 associated with full red (Topred and African Carmine) and striped red (Royal Gala and Starking) cultivars (Fig. 6).

Large preference differences between the three clusters were observed for 'Granny Smith'. A3 disliked (<4) the appearance of Granny Smith and had significantly lower actual and residual preference scores compared to other cultivars and other clusters (Fig. 7 & 8). A2’s residual and actual preference scores were lower for Granny Smith compared to A1, who highly liked (>7) this cultivar. Although A1’s residual preference score for Topred was significantly lower than for Granny Smith (Fig. 7), the actual preference scores for these cultivars were similar and higher than for other cultivars (Fig. 8). A1 indicated a lower liking for ‘Starking’, ‘Royal Gala’ and ‘Golden Delicious’ compared to A2 and A3 (Fig. 7 & 8). The appearance of Golden Delicious was highly liked by A2 (>7), who liked it significantly more than other cultivars and clusters (Fig. 7 & 8). Although A2 liked the appearance of Topred (>6), they indicated lower actual and residual preference scores compared to other clusters (Fig. 7 & 8). A3 highly liked the appearance of African Carmine (>8), Topred and Royal Gala (>6) and indicated higher preference for these cultivars compared to A1 and A2 (Fig. 7 & 8). No significant residual preference differences were observed for ‘Pink Lady®’ (Fig. 7).

4.4 The relation between preference for eating quality and appearance

Consumers’ cluster membership (based on their preference for eating quality) was projected onto their appearance liking scores (Fig. 9). The PCA bi-plot could explain 100% of the variability in consumers’ responses. Granny Smith was the most important cultivar in explaining the variability on PC1 and together with Pink Lady® associated positively with the preference of consumers in E1 and E2 (Fig. 9). The preferences of consumers from these clusters associated closely on PC1, but showed larger differences on PC2 and differed from E3 on both PC1 and PC2. Preference differences for 'Starking', and to a lesser extent ‘Sundowner®’ and ‘Golden Delicious’, made the largest contributions to the variability in consumer response on PC2. The preference of E1 associated with ‘Golden Delicious’, while E2 showed a closer association with ‘Starking’ on PC2 compared to E1. The appearance preferences of E3 associated with the red cultivars Topred, African Carmine and Royal Gala, but these consumers also liked the yellow Golden Delicious (Fig. 9).

4.5 Factors relating to apple purchase decisions

PLS regression was applied to the eating quality clusters and cluster membership (Y variables) were projected onto the residuals of the importance ratings given to external attributes and the hedonic liking of conceptual sensory and appearance attributes (X variables) (Fig. 10). External attributes were less important than sensory and appearance attributes in the formation of this plot, indicated by their positions close the second component. Sour taste, green colour and sweet taste contributed greatly to the formation of the plot, indicated by their positions on the far sides of the first component (Fig. 10). The responses of E1 and E2 were similar, and differed from those of E3. E1 and especially E2 associated with sour taste and green colour, but E1 had a close association with apple flavour, cultivar loyalty and cultivar indication on the packaging, while E2 associated with price. E3 associated with the conceptually evaluated sensory attributes sweet taste and mealiness, and the appearance of red striped fruit (Fig. 10).

5. DISCUSSION

General preference tendencies for apple eating quality and appearance among consumers from different ethnic (black, coloured and white) and age (18-25, 26-35, 36+) groups in the Western Cape were identified in Chapter 3, i.e., coloured, black and older consumers had a higher preference for sweet taste and lower preference for sour taste compared to white and younger consumers. However, the average preference values that were used are limited to the identification of general tendencies, but did not specifically account for individual preferences within these groups (Carbonell *et al.*, 2008). Preferences that are based on nationalities and ethnicities are often complex (Harker *et al.*, 2003) and members of the same ethnic group have shown different consumption habits and food preferences (Rozin & Vollmecke, 1986; Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998; Carbonell *et al.*, 2008; Symoneaux *et al.*, 2012). Cluster analysis conducted on residual preference scores in this chapter showed that consumers could clearly be divided into three segments according to their preference for apple eating quality or appearance. However, the socio-demographic composition of these clusters was not homogenous.

5.1 Preference for eating quality

Preference differences between the two biggest consumer clusters, viz. E1 (34%) and E3 (44%), were best explained by diverse responses to the cultivars Granny Smith and African Carmine and to attributes relating to texture (mealiness, crispness, crunchiness and juiciness) and sour taste

(Fig. 2). E2 constituted only 22% of the total consumer group, whose preference for sour taste and apple flavour distinguished them from E3 on PC1 and from E1 and E3 on PC2. The concomitant sensory attributes of the specific combination of apple cultivars that were used in the present study complicated the identification of individual sensory drivers of liking for the different clusters, i.e. different flavour and texture levels did not vary independently between the cultivars. Limitations imposed by the genotypic variation of the cultivars that were used in this study are illustrated in the PCA bi-plot: Apple cultivars with a sweet taste associated with mealiness on PC1, which were situated opposite firm, juicy cultivars that were also sourer. E1 had a lower preference for sweet taste compared to E2 and E3, but liked firm, juicy and sour fruit. Conversely, E3 strongly disliked sour taste and showed a closer association with mealiness and sweetness. Consumers' apple preferences could have adapted to the limitations of genotypic variation (Harker *et al.*, 2003). Sour taste and firmness that are co-localised on the same quantitative trait loci (QTL) (King *et al.*, 2000) could have caused consumers to develop preference for the sour taste of firm apples or tolerance to sour taste due to high preference for firmness (typically found in 'Granny Smith'). Sugar levels in apple increase during ripening and storage (Visser *et al.*, 1968), while mealiness that also develops in certain cultivars during storage (Carbonell *et al.*, 2008) could have caused consumers to develop a preference for high sweetness levels despite higher levels of mealiness.

Similarities as well as discrepancies between results reported in the literature and the current study were found. Similar to studies conducted among British (Daillant-Spinnler *et al.*, 1996), Spanish (Carbonell *et al.*, 2008) and French (Symoneaux *et al.*, 2012) consumers, the current study showed a clear consumer segment that liked sour taste (E2) and a segment that disliked it (E3). Daillant-Spinnler *et al.* (1996) and Symoneaux *et al.* (2012) only distinguished between these two consumer segments, which constituted approximately equal proportions of the total consumer group. However, Carbonell *et al.* (2008) segregated four different consumer segments, of which the segments that liked and disliked sour taste constituted 29% and 22%, respectively, of the total consumer group. The preferences of the remaining two clusters were situated between the first two clusters and can be compared to E1 in the current study. Identification of four clusters by Carbonell *et al.* (2008) and two groups by Daillant-Spinnler *et al.* (1996) and Symoneaux *et al.* (2012) could be related to different statistical methodologies that were applied in these studies. Carbonell *et al.* (2008) used the Ward's statistical clustering method, while Daillant-Spinnler *et al.* (1996) and Symoneaux *et al.* (2012) relied on visual clustering of consumers that showed proximity on preference maps to identify two groups. Only about half of the total consumer group fitted the statistical grouping that was conducted by Daillant-Spinnler *et al.* (1996). The sour taste of 'Braeburn' and 'Granny Smith' drove the preference of the consumer segments that associated with sour taste in the studies of Daillant-Spinnler *et al.* (1996) and Carbonell *et al.* (2008). The preferences of the corresponding cluster in the current study (E2) were driven by sour 'Granny Smith', 'Pink Lady®' and 'Sundowner®'. In the literature (Daillant-Spinnler *et al.*, 1996; Carbonell *et* *al.*, 2008) and in the present study, sweet fruit of cultivars such as Topred and Golden Delicious drove the preference of the consumer group who disliked sour taste.

Discrepancies between results reported in the current study and in literature could relate to differences in the type of preference data used for consumer clustering. While double mean centred data were used in the current study, Daillant-Spinnler *et al.* (1996) and Carbonell *et al.* (2008) used actual preference data. The sour aversive clusters reported by these authors had a high preference for sweet taste, while the preference of the sour aversive consumers in E3 did not correlate significantly with sweet taste despite their high preference for highly sweet fruit of 'Topred' and 'African Carmine'. Although consumers from all three clusters indicated high preference for sweet fruit such as 'Topred', the relative importance of sweetness as a driver of liking compared to other sensory attributes is portrayed for the different clusters. Thus E3 consumers probably had a high preference for sweet taste, but other sensory attributes were of greater overriding importance in distinguishing their preferences from that of other consumer segments. Similarly, although consumers in E2 liked sour taste more compared to E1 and especially E3, they still preferred sweet 'Topred' to sour 'Granny Smith'. Another possible reason for the non-significant correlation with sweet taste could pertain to low preference scores for 'Pink Lady®' that showed high levels of sweetness and sourness (Chapter 3).

The sour aversive consumer group reported by Daillant-Spinnler *et al.* (1996) also liked hardness. The comparable consumer segment shown by Carbonell *et al.* (2008) associated with mealiness and the segment shown by Symoneaux *et al.* (2012) preferred textural attributes ranging from crunchy to mealy. Differences between results from these and the present study could further be ascribed to the different sensory profiles of the specific fruit that were used. While highly sweet 'Fuji' apples were used by Daillant-Spinnler *et al.* (1996), the specific 'Fuji' apples that were used in the current study showed low levels of sweetness (<45 on a 100-point intensity scale). Sweet fruit with high levels of crispness and crunchiness were not included in the present study, but were used by Daillant-Spinnler *et al.* (1996). Higher levels of mealiness in the sweet cultivars that were favoured by E3 (African Carmine, Topred and Starking) resulted in E3's association with mealiness. Preference was probably not given to fruit that were specifically mealier, but a higher tolerance to slightly mealy samples of sweet fruit were shown by E3 compared to E1 and E2. It should be noted that the PCA bi-plot illustrate differences between clusters relative to each other. Although E3 liked the mealiest samples more than other clusters, 'African Carmine', the mealiest fruit used in the study, cannot be considered as being mealy (rated 5 on a 100-point scale). Therefore, it is not clear whether the preference of E3 would have associated with mealiness if very mealy fruit were used in this study. Although the preference of the sweet liking and sour aversive cluster in the study of Carbonell *et al.* (2008) also associated with mealiness, these consumers did not like mealiness *per se*, but rather liked sweetness despite higher mealiness, considering that they preferred 'Topred' samples with lower levels (4.4 measured on a ten-point intensity scale) of mealiness compared to mealier (8.2) 'Topred' samples. The conceptual preference of E3 associated with sweet taste and mealiness, indicating that these consumers were familiar with their preference for sweet taste and tolerance to mealiness.

E1 probably did not have a strong preference for sour taste *per se*, but rather tolerated sour taste due to their preference for firmness, as evidenced by comparably high residual preference scores and higher actual preferences for firm and sour Granny Smith compared to firm Fuji with low levels of sour taste. Low sweet taste in these cultivars probably resulted in E1's negative association with sweet taste. Considering that E1 gave high (≈6) preference scores to sweet 'Topred', 'Starking' and 'Royal Gala', their negative association with sweet taste should rather be seen as a lower preference for sweet taste relative to E2 and E3. Contrary to E1's significant negative and positive correlation with sweetness and firmness, respectively, E2 showed non-significant correlations with these attributes, probably due to higher preference scores for the softer, sweeter 'African Carmine', 'Topred' and 'Royal Gala' fruit used in the study. E2's high preference for apple flavour and sour taste (Fig. 2) probably caused lower liking scores for the 'Fuji' fruit with low levels of apple flavour and sour taste that were used in this study (Chapter 3, Fig. 1). The drivers of liking for conceptual preference of E1 and E2 were generally in accordance with the taste attributes that drove their preference and these consumers gave a higher conceptual liking score for sour taste.

5.2 Socio-demographic factors for eating quality clusters

Marketers of fresh produce are increasingly interested in individual preference differences and how they relate to personality characteristics such as attitudes, values and socio-demographic factors (Næs *et al.*, 2010). Personality characteristics could be difficult to conceptualise and marketers are therefore especially interested in easily quantifiable differences between groups of consumers with similar preference patterns and responses to marketing stimuli in order to direct consumer driven marketing programmes at the consumers who are most likely to respond. In the current study, tabulation was used to relate and describe the consumer data of clusters with similar preferences for eating quality and appearance. Although each of these clusters could partly be characterised by its socio-demographic composition, consumers from all ethnic and age groups were found in all three clusters. Larger proportions of consumers from any age or ethnic group within a cluster should rather be seen as tendencies and not a clear-cut answer to the socio-demographic factors that relate to the apple preferences of a cluster. The largest proportion of the total white consumer group (41%) belonged to E1, which liked firmness and tolerated sour taste. In accordance with results obtained in Chapter 3 and the perception in the apple industry that coloured and black consumers generally prefer sweet above sour taste (Fick, 2011), black (54%) and coloured (45%) consumers were mostly assigned to sour aversive E3. Coloured consumers constitute 50%, the black consumers 30% and the white consumers 18% of the total consumer group in the Western Cape Province of South Africa (STATSSA, 2011). This ethnic composition should be considered in relation to the cultivar distribution volumes for this region. Although E1 constituted the largest proportion of white consumers, the consumers in E1 taken as a percentage of the total consumer group in the Western Cape comprised of more black (14%) and coloured (11%) compared to white (7%) consumers. Further contributions to the sour liking black and coloured consumer groups were made by the these consumers in E2, who constituted 10% and 6% of the total consumer group in the Western Cape, respectively. Therefore, a large proportion of the total production volume for cultivars that tend to be more sour such as Granny Smith, Pink Lady® and Sundowner® could be successfully sold and marketed in the coloured and black communities, considering that approximately a third of these consumers were assigned to A1 that also liked the appearance of these cultivars. Black and coloured consumers in sour aversive E3 constituted 39% of the total consumer group in the Western Cape and remain an important market for sweet apples. Although white consumers in E3 constituted only 6% of the total consumer group, they still constitute an important market segment, considering that the fruit expenditure for white consumers is higher compared to coloured and black consumers in the Western Cape (STATSSA, 2006).

Considering that 45% of the consumers in the Western Cape are currently younger than 24 (STATSSA, 2011), comprehensive knowledge of their apple preferences is required in the future. The preferences of younger consumers could indicate whether differences between ethnic groups as remnant from the past could be narrowing due to the gradual normalisation of the South African society since democracy. Greater similarity in the preference patterns of younger consumers should indicate to local breeding programmes that the development of new cultivars should maybe not be aimed at current disparate preferences of the different ethnic groups. This study did not represent the large proportion of the young population without secondary or tertiary education, but mostly students at the University of Stellenbosch. Consumers who were younger than 25 years were overrepresented in E1 (40%) and production volumes should thus reflect their preference for firm, crisp cultivars such as Granny Smith, Fuji, Pink Lady® and Sundowner® in the future. E3 accounted for larger proportions of consumers from the older age groups, who showed a high preference for sweet taste and a higher tolerance to mealiness in Chapter 3. Consumers from the second age group were mostly attributed to E2, who liked apple flavour and sour taste. It is unclear why the importance given to purchase factors by E2 associated with price and that of E1 with cultivar loyalty and indication on packages.

In order to streamline distribution and marketing of apple cultivars to the socio-demographic groups who are mostly likely to purchase the specific cultivars, it is necessary to know how to target minority groups whose preferences differ from those of the largest proportion of the consumer group, i.e., black and coloured consumers who like sour taste or white consumers who dislike it.

Income might serve as a guide to the spending power of a consumer segment and is especially important since selling points of fresh produce often serve consumers from the same socio-economic group. However, the students who participated in the current study might not have a high income at present, but could contribute greatly to the consumer segment with a higher disposable income in the near future. It is therefore also necessary to consider the education of the consumers who partook in the study, since a correlation between income and education level is often observed. Furthermore, the current income of these students might differ from the income level in the household when they grew up and when their eating patterns were developed (Cliff *et al.*, 2002). Sweet fruit that were slightly mealy or sweet cultivars such as Golden Delicious that are more susceptible to develop mealiness were preferred by E3. Mealiness and soft texture are prone to develop at room temperature (Harker *et al.*, 1997), as is the case with the storage conditions on the informal market where the large proportion of black and coloured consumers from the lower income group are more likely to purchase their fruit (Viljoen & Gericke, 2001; Fick, 2011). Frequent purchases from the informal market could have led to the familiarity and subsequent tolerance to slightly mealy apples of E3.

E1 constituted a larger proportion of the white and youngest consumers whose preferences for firmness and tolerance to sour taste have been confirmed in Chapter 3. Sour and crisp cultivars might gain importance in the future in the coloured consumer markets that constitute approximately half of the total consumer group in the Western Cape (STATSSA, 2011). A large proportion of the youngest coloured consumers belonged to E1 and E2 accounted for a larger proportion of coloured consumers form the higher income group. E2 also accounted for more coloured and black consumers with tertiary and final school year qualifications. If these qualifications manifest in a higher income, it could be suggested that an important proportion of coloured and black consumers who are able to pay premium prices would prefer higher levels of apple flavour and sour taste. Although E3 accounted for the lowest proportion of the white consumer group, sweet cultivars could be successfully marketed to older white consumers.

5.3 Preference for appearance

Granny Smith and Golden Delicious were the most important cultivars in explaining appearance preference differences between the clusters on PC1, while preference differences for Topred were pronounced on PC2 (Fig. 6). A2 and A3 showed similar preferences on PC1, and their negative association with A3 could be ascribed to preference differences for 'Granny Smith'. Consumers' association between the eating quality and appearance of Granny Smith and Golden Delicious probably drove their appearance preference, considering that they were mostly familiar with the sensory profiles of these cultivars (Chapter 3). Differences in appearance preferences could thus be ascribed to consumers' preference for sour, firm cultivars (in which case they liked the appearance of Granny Smith), or their aversion to sour taste and preference for sweet taste (in which case they liked the appearance of Golden Delicious, Royal Gala and Starking) or red peel colour (in which case they preferred the appearance of red cultivars such as Topred and African Carmine to Golden Delicious and Granny Smith).

A1 constituted the largest proportion of the total consumer group (45%). These consumers' appearance preferences associated with the green peel colour of Granny Smith and they also liked newer cultivars such as Fuji, Sundowner® and Pink Lady® more compared to traditional sweet cultivars such as Royal Gala, Golden Delicious and Starking. However, they did like red 'Topred' (Fig. 8). Their preferences mostly differed from A2 and A3 by higher and lower liking scores for 'Granny Smith' and 'Golden Delicious', respectively. A2 liked a variety of apple appearances, such as yellow/green Golden Delicious and striped red Starking and Royal Gala, which these consumers preferred to full red cultivars such as Topred and African Carmine. Full red and striped red cultivars such as African Carmine, Topred, Fuji, Starking and Royal Gala associated with A3, although they also liked the appearance of Golden Delicious (Fig. 8). The appearance preferences of A3 were possibly driven by an association between sweetness and red peel colour (Steyn, 2012 and references therein) and the familiar yellow/green peel colour of sweet 'Golden Delicious'. Likewise, A3 possibly negatively associated the green peel colour of 'Granny Smith' with sourness.

Appearance preferences of the eating quality clusters were investigated in order to obtain a better understanding of how consumers' preferences for eating quality drive their appearance preferences. It was shown that consumer clusters responded to the sensory profiles that associated with specific appearances. The appearance of the 'Granny Smith' photograph was liked by E1 and E2, who also had a higher preference for sour taste. The appearance preference of E2, whose preference for eating quality was primarily driven by apple flavour and sour taste, associated with the appearance of 'Pink Lady®', which was characterised by high levels of these attributes. E3 disliked the eating quality and appearance of Granny Smith, but preferred the eating quality and appearance of sweet tasting red (Topred and Royal Gala) and yellow/green (Golden Delicious) cultivars. E3 also liked the appearance of Fuji, probably because it is traditionally seen as a sweet cultivar (Daillant-Spinnler *et al.*, 1996) and because they associated red peel colour that develop during maturity with higher sugar levels in mature fruit (Steyn, 2012).

The association between eating quality and appearance preference was also shown during the conceptual evaluation. The preferences of E1 and E2 associated positively with sour taste in the eating quality evaluation and with sour taste and full green coloured apples (this combination being typical of 'Granny Smith') in the conceptual evaluation. E3 had a higher preference for sweetness than E1 and E2 in the actual evaluation. Consequently, their conceptual preference showed a closer association sweet taste and striped red apples that is traditionally sweet.

These preference associations between appearance and eating quality suggest that appearance does not only serve as a quality cue, but that consumers also rely on appearance as a source of flavour information (Steyn, 2012 and references therein). Variables such as shape, colour and eating quality are nested within any particular cultivar and cannot be studied in isolation from each other (Cliff *et al*., 1999). It is thus difficult to separate preference for colour from the preference for the attributes associated with that colour (Shankar *et al*., 2010). Consumers have learned colour-flavour associations that resulted from repeated co-pairings of specific colours and flavours (Shankar *et al*., 2010). Consumers who prefer sour apples would therefore also prefer the appearance of the green 'Granny Smith'. Similarly, Cliff *et al.* (2002) illustrated that consumers' responses towards appearance were related to their flavour and texture expectations when Canadian and New Zealand consumers gave a lower preference score to the appearance of a cultivar that had a similar shape than a cultivar that is known to acquire a mealy texture and poor flavour during storage.

5.4 Socio-demographic factors for appearance clusters

Comparison of socio-demographic characteristics of appearance and eating quality clusters showed that corresponding consumers preferred the set of sensory attributes that traditionally associate with specific peel colours. Similarly to the tolerance to sour taste and preference for firmness of E1 in the eating quality analysis, the cluster that showed a higher preference for green peel ('Granny Smith') and pink bi-colour ('Pink Lady®') (A2) constituted larger proportions of white and young consumers. Black consumers who were mostly in E3 for the eating quality clusters were also mostly in the appearance clusters that liked the appearance of sweet cultivars (A2 and A3). Coloured consumers have a high preference for the appearance of cultivars that associate with higher levels of sweetness (Chapter 3). Although they were underrepresented in the cluster that liked the appearance of cultivars that associate with higher levels of sour taste (A1), approximately half of the coloured consumers either tolerated or preferred sour taste. Possibly not all coloured consumers are conscious of their preference for a variety of eating quality attributes.

6. CONCLUSIONS

Consumers could be clustered based on their eating quality and appearance preference differences for green, sour and firm cultivars (i.e. Granny Smith) and sweet or red cultivars (i.e. African Carmine). Firmness was liked by the largest proportion of the total consumer group in the current study. Although the apple industry suppose that coloured and black consumers in general have an aversion to sour taste, this study showed that approximately equal numbers of black and coloured consumers liked or tolerated sour taste compared to these consumers who disliked it. Coloured consumers, who constitute half of the total consumer group in the Western Cape

(STATSSA, 2011), liked a variety of eating quality attributes and their preferences should be reflected in diverse apple cultivars that are destined for this market.

The black and coloured consumers with a tertiary qualification mostly had a high preference for sour taste and apple flavour and could be an important market segment for cultivars that represent these attributes. White consumers in general had a higher preference for sour taste and the white consumers who liked sweet cultivars were mostly older than thirty-six. Considering white consumers' high fruit expenditure of household heads that are probably from the older consumer group, sweet cultivars might still play a prominent role in white consumers' apple purchases. Consumers' appearance preferences associated with the cultivars that traditionally represent the set of sensory attributes that they liked. Segments based on appearance preference showed that consumers either preferred the appearance of sour, firm cultivars (Granny Smith), sweet cultivars (Golden Delicious, Royal Gala and Starking) or red peel colour (Topred and African Carmine).

This study imposed certain limitations to the identification of isolated sensory drivers of liking. It should be noted that the specific fruit that were used in this study did not span a wide range of sensory attribute combinations and that sensory attributes varied concomitantly between cultivars. Fruit with higher sweetness levels were mostly also slightly mealier, while the firmer fruits also showed higher levels of sourness. It should thus be considered that consumers' preference for sour taste could be driven by their preference for firmness, while the higher tolerance to slight mealiness could have resulted from a preference for sweeter fruit. In order to circumvent these limitations, it is advised that fruit with high sweetness and firmness as well as sour fruit subjected to longer storage periods, are included in subsequent studies. The fruit that were used in this study showed only slight levels of mealiness and therefore we cannot conclude on the tolerance to mealiness among Western Cape consumers. The young consumers who partook in this study were mostly students at the University of Stellenbosch and were not representative of the total consumer group in the Western Cape that is younger than 25 and do not have access to higher education. However, these consumers possibly represented those consumers with higher income levels in the future.

The statistical procedures applied in this part of the research should be interpreted with caution. Although residual preference scores could be used to distinguish between the clusters' main preference differences, these preference scores portray the relative importance of sensory attributes to consumers in each of the clusters. Actual preference scores of these clusters should be considered as a guideline to the preference and possible purchase patterns of consumer clusters. Although consumers from all three clusters liked sweet fruit, consumers from E3 liked sweetness more compared to E1 and E2. E2 consumers had a higher preference for sour taste than E1 and E3 consumers, while E1 consumers tolerated the sour taste of very firm fruit and liked sweetness less.

It is important to understand that not all South African consumers have similar preferences for apple eating quality and appearance. It was shown that there is a higher incidence of certain ethnic and age groups within different preference clusters (in accordance with the preferences reported in Chapter 3). Although half of the coloured and black consumers preferred sweet apple fruit, sole marketing of sweet cultivars to black and coloured consumers could be fruitless because the other half of these consumers either tolerate or actually prefer sour cultivars. However, it should be noted that younger consumers (<36) were overrepresented in the current study. A larger proportion of consumers could have preferred sweet cultivars if more older consumers partook in the study.

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Table 1 Socio-demographic information of each eating quality preference cluster, presented per ethnic group. Values indicate the percentage of consumers from each of the three ethnic groups for each factor (i.e. age group, income group and education) per cluster. The overall percentage of the subdivision of each socio-demographic group is presented in the last column

Socio-demographic factors		Cluster 1 (34% of total group)	Cluster 2 (22% of total group)	Cluster 3 (44% of total group)	Average
Ethnic groups					
Black		27	19	54	**37**
Coloured		35	20	45	**29**
White		41	28	31	**34**
Age groups					
Total	Age 1 (18-25)	40	22	38	**41**
	Age 2 (26-35)	28	43	29	**23**
	Age 3 (36+)	30	22	48	**36**
Black	Age 1 (18-25)	26	19	55	**40**
	Age 2 (26-35)	38	16	46	**40**
	Age 3 (36+)	32	21	47	**20**
Coloured	Age 1 (18-25)	40	17	43	**31**
	Age 2 (26-35)	35	23	42	**24**
	Age 3 (36+)	30	21	49	**45**
White	Age 1 (18-25)	53	28	19	**52**
	Age 2 (26-35)	25	43	32	**8**
	Age 3 (36+)	29	24	47	**41**
Education					
Total	Tertiary	32	25	43	**53**
	Matric (final school year)	39	23	38	**30**
	Not final school year	33	14	53	**17**
Black	Tertiary	26	23	51	**57**
	Matric (final school year)	26	16	58	**20**
	Not final school year	30	11	59	**23**
Coloured	Tertiary	33	27	40	**37**
	Matric (final school year)	36	19	45	**34**
	Not final school year	37	14	49	**29**
White	Tertiary	36	26	38	**61**
	Matric (final school year)	49	29	22	**39**
	Not final school year	0	100	0	**1**
Income groups (monthly income)					
Total	Income < R5000	36	19	45	**61**
	Income >R5000	33	27	40	**39**
Black	Income < R5000	27	16	57	**68**
	Income >R5000	20	18	62	**32**
Coloured	Income < R5000	33	17	50	**55**
	Income >R5000	36	23	41	**45**
White	Income < R5000	50	25	25	**53**
	Income >R5000	31	31	38	**47**

Table 2 Socio-demographic information of each appearance preference cluster, presented per ethnic group. Values indicate the percentage of consumers from each of the three ethnic groups for each factor (i.e. age group, income group and education) per cluster. The overall percentage of the subdivision of each socio-demographic group is presented in the last column

Socio-demographic factors		Cluster 1 (45% of total group)	Cluster 2 (38% of total group)	Cluster 3 (17% of total group)	Average
Ethnic groups					
Black		39	41	20	36
Coloured		32	44	24	28
White		62	30	8	36
Age groups					
Total	Age 1 (18-25)	53	35	12	43
	Age 2 (26-35)	41	37	22	23
	Age 3 (36+)	39	41	20	35
Black	Age 1 (18-25)	45	41	14	42
	Age 2 (26-35)	36	38	26	36
	Age 3 (36+)	36	40	24	22
Coloured	Age 1 (18-25)	34	40	26	31
	Age 2 (26-35)	36	31	33	30
	Age 3 (36+)	28	57	15	39
White	Age 1 (18-25)	70	28	2	52
	Age 2 (26-35)	58	33	9	8
	Age 3 (36+)	53	32	15	40
Education					
Total	Tertiary	38	39	23	53
	Matric (final school year)	53	38	9	31
	Not final school year	44	37	19	16
Black	Tertiary	39	41	20	57
	Matric (final school year)	30	47	23	19
	Not final school year	49	35	16	24
Coloured	Tertiary	30	40	30	37
	Matric (final school year)	42	46	12	36
	Not final school year	26	45	29	27
White	Tertiary	56	32	12	61
	Matric (final school year)	73	27	0	38
	Not final school year	0	0	100	8
Income groups (monthly income)					
Total	Income < R5000	49	36	15	61
	Income >R5000	41	39	20	39
Black	Income < R5000	42	39	19	75
	Income >R5000	32	44	24	25
Coloured	Income < R5000	36	39	25	53
	Income >R5000	31	46	23	47
White	Income < R5000	69	30	1	42
	Income >R5000	69	20	11	58

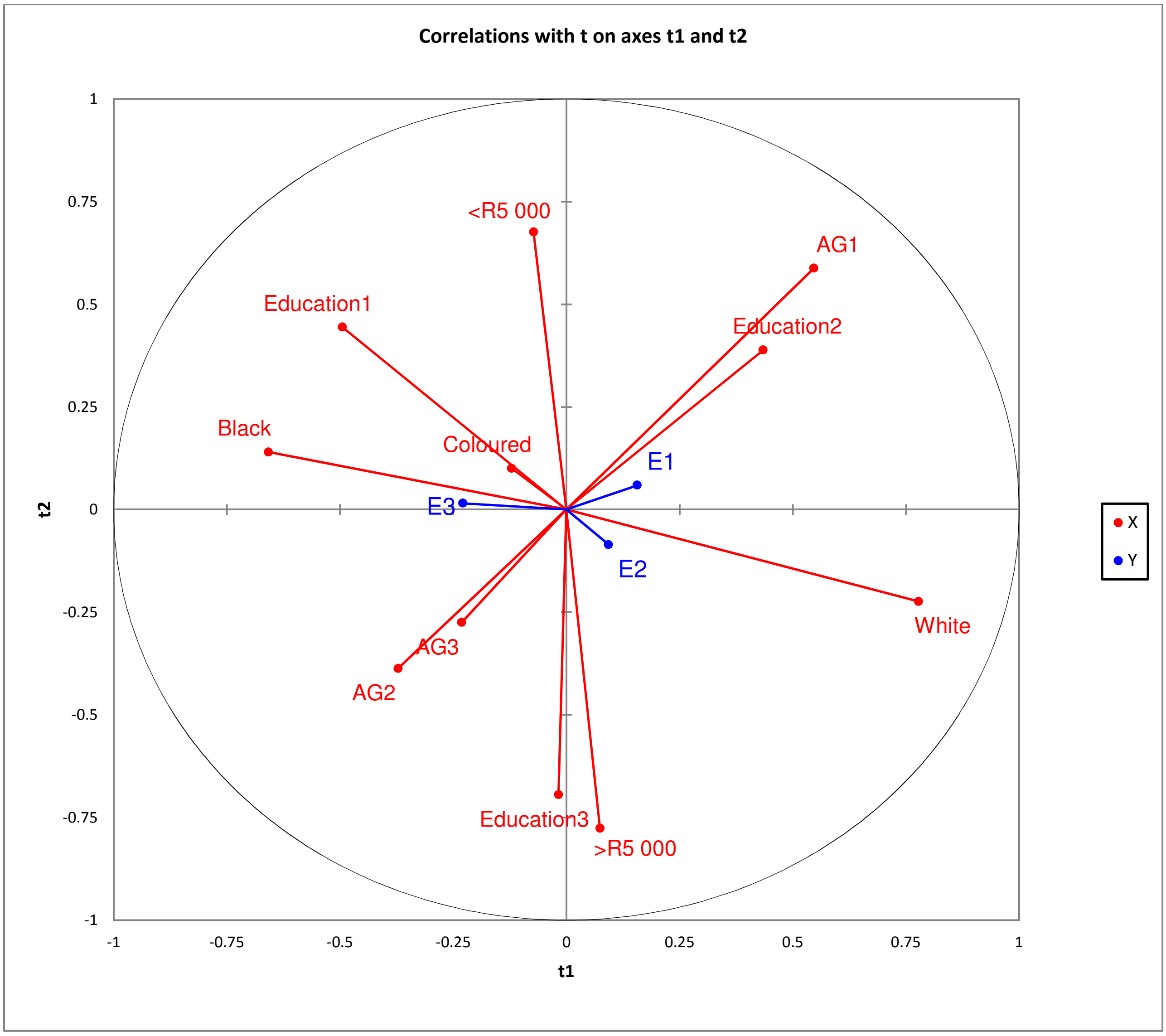

Figure 1 Partial least squares plot indicating the distribution of consumers' socio-demographic characteristics between the different eating quality clusters (E1-E3). Socio-demographic factors included ethnic group (black, coloured and white), monthly income (<R5 000 and >R5 000), level of education [not final school year (education 1), final school year (education 2) and tertiary (education 3)] and age group [18-25 (AG1), 26-35 (AG2) and 36+ (AG3)].

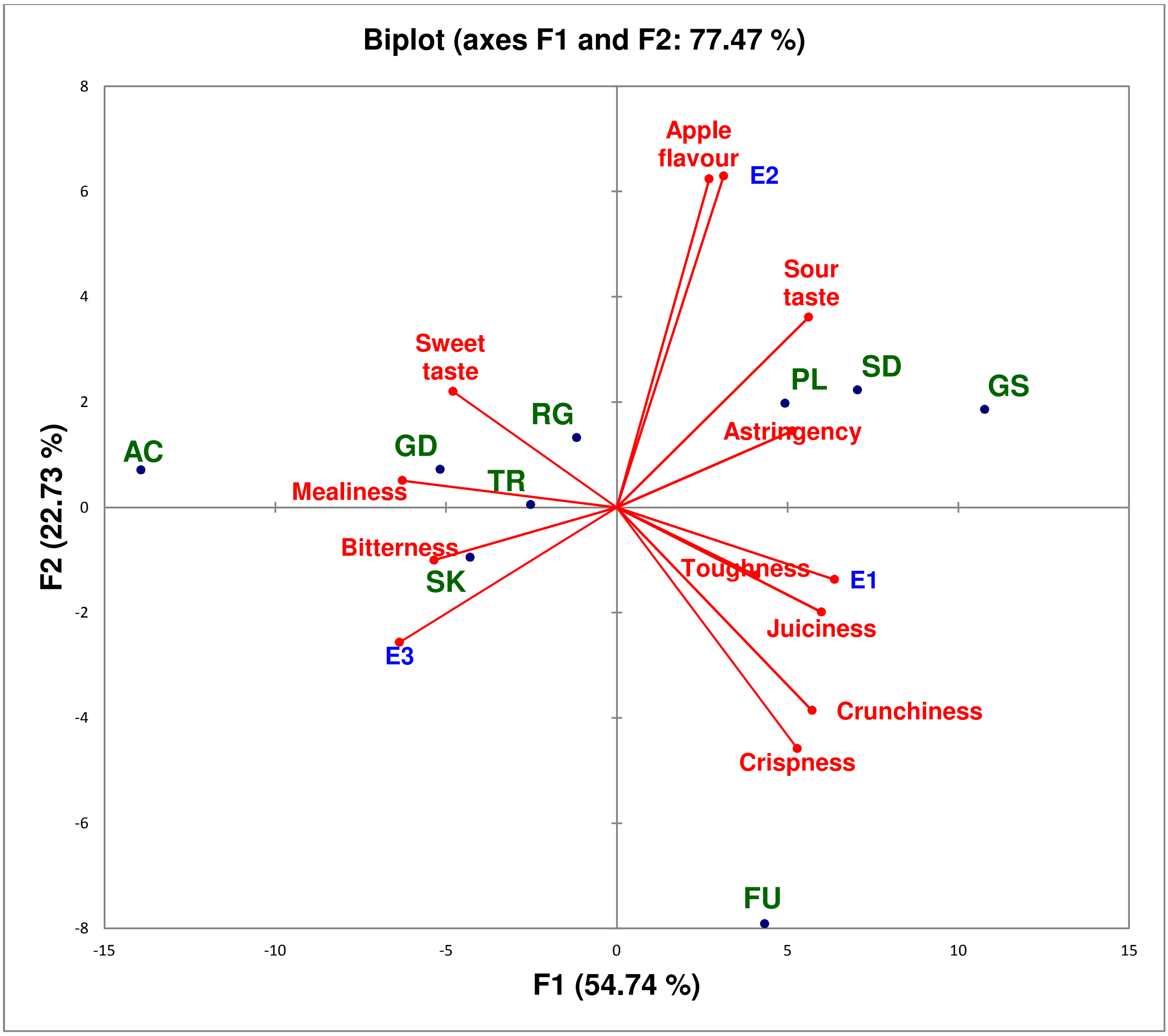

Figure 2 Principal component analysis bi-plot indicating the position of preference for the eating quality clusters (E1-E3) in relation to sensory attributes of apple fruit from nine cultivars, i.e., African Carmine (AC), Starking (SK), Pink Lady® (PL), Golden Delicious (GD), Granny Smith (GS), Royal Gala (RG), Fuji (FU), Topred (TR) and Sundowner® (SD).

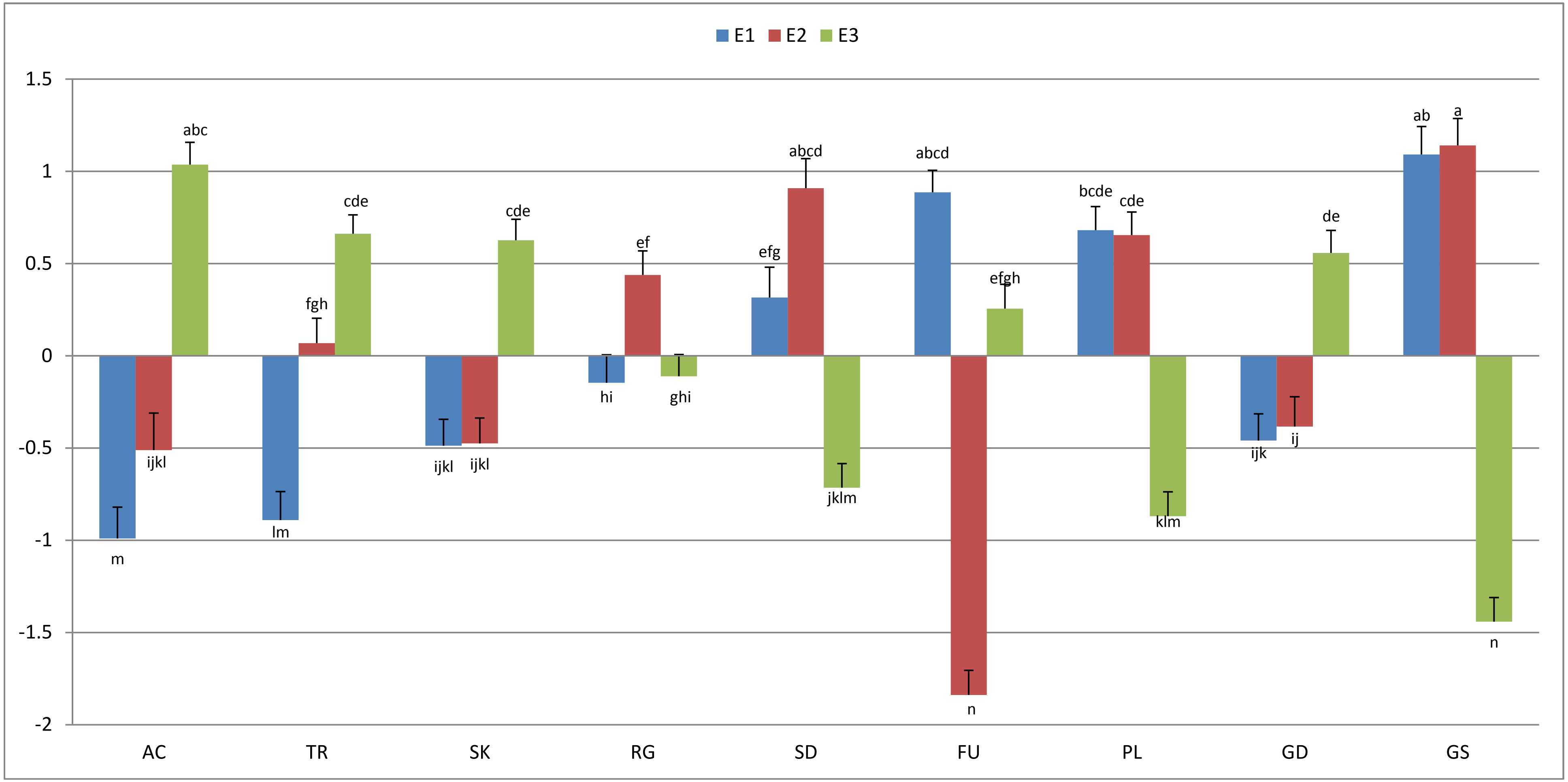

Figure 3 Residual mean preference scores for the eating quality of nine apple cultivars analysed by consumers from three eating quality clusters (E1-E3), i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS). Means +standard errors with different alphabetical letters differ significantly. The least significant difference within each group is indicated at the 5% level of significance.

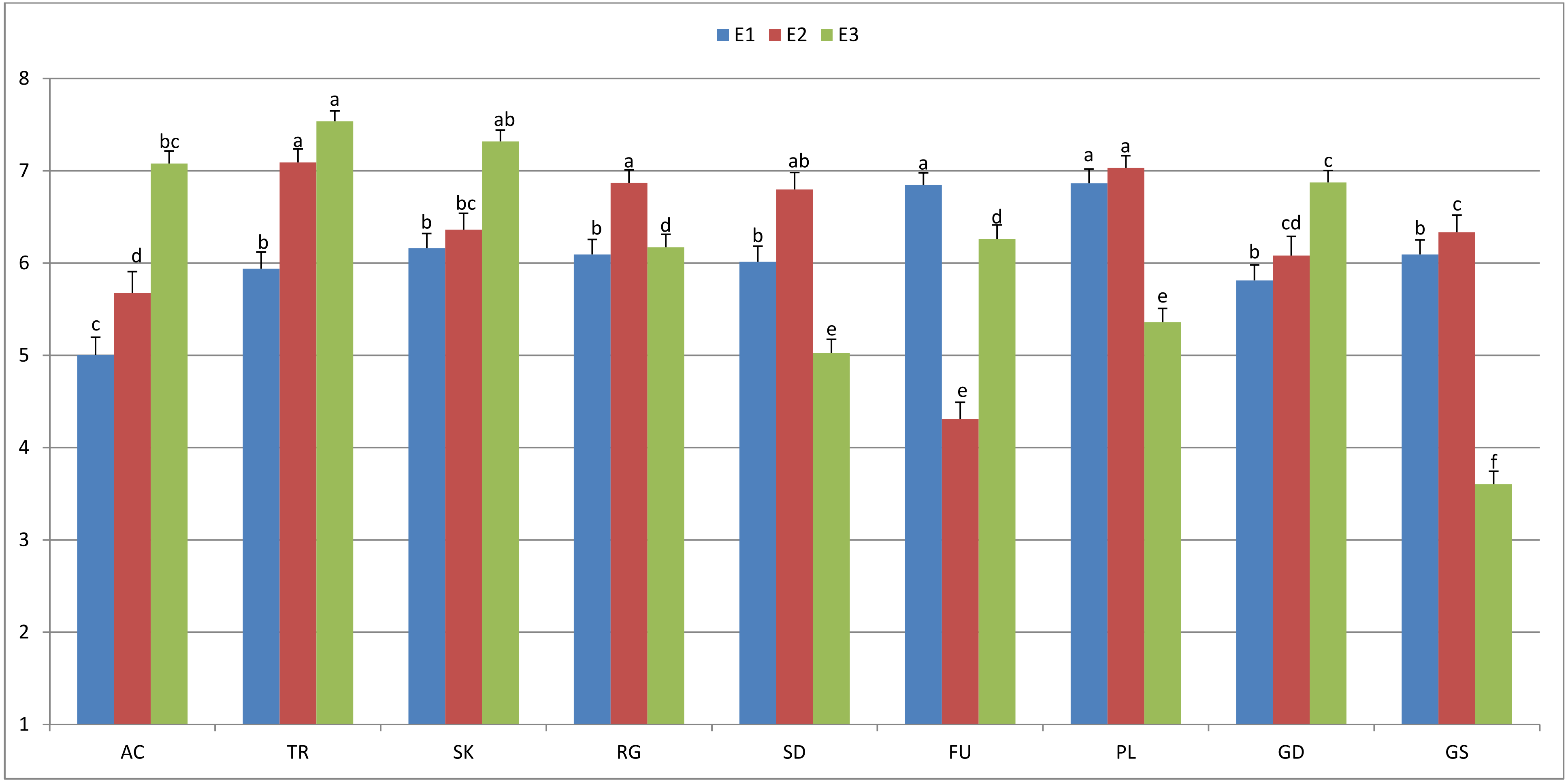

Figure 4 Actual mean preference scores for the eating quality of nine apple cultivars analysed by consumers from three eating quality clusters (E1-E3), i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS). Means +standard errors with different alphabetical letters differ significantly. The least significant difference within each group is indicated at the 5% level of significance.

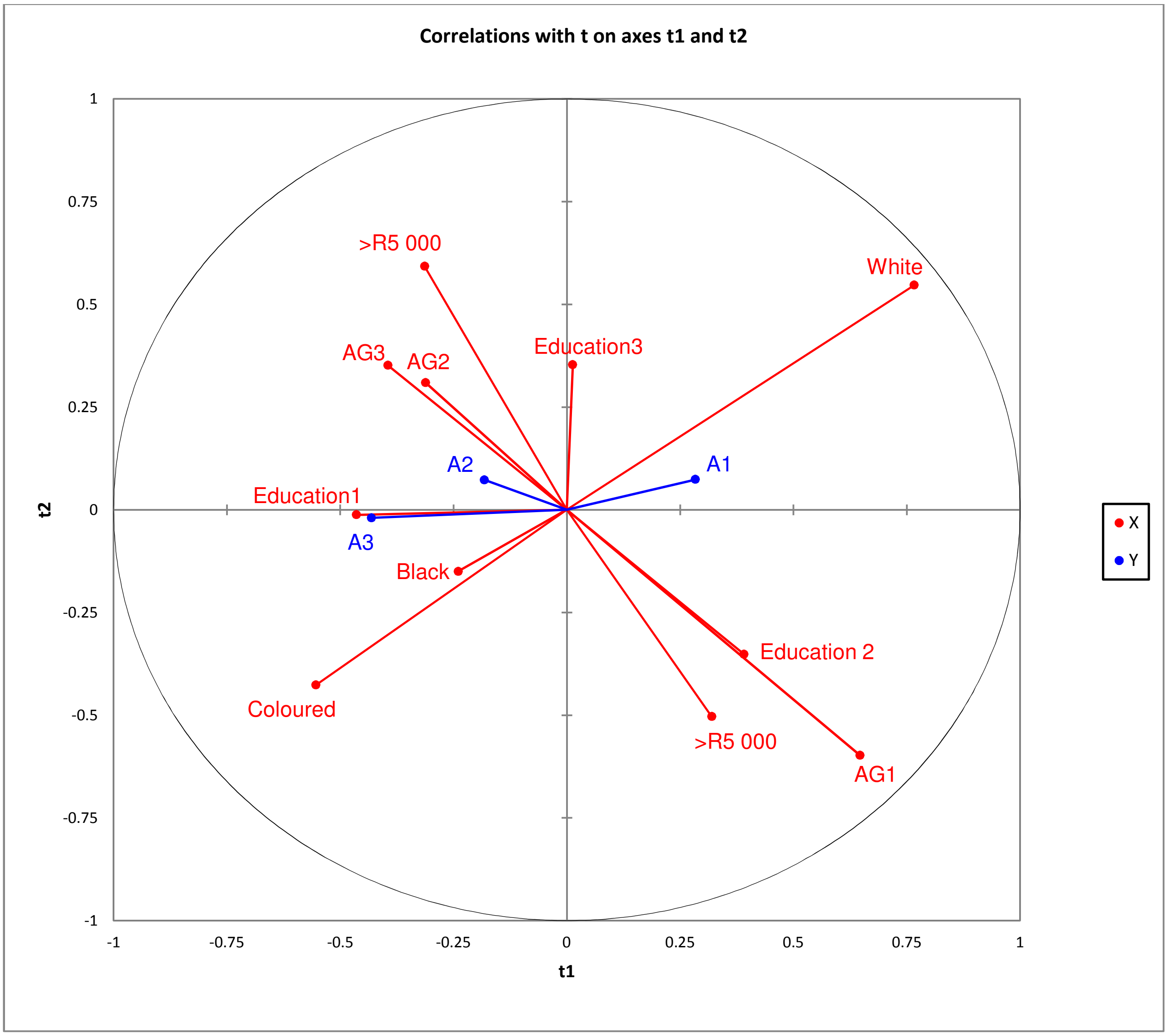

Figure 5 Partial least squares plot indicating the distribution of consumers' socio-demographic characteristics between the different appearance clusters (A1-A3). Socio-demographic factors included ethnic group (black, coloured and white), monthly income (<R5 000 and >R5 000), level of education [not final school year (education 1), final school year (education 2) and tertiary (education 3)] and age group [18-25 (AG1), 26-35 (AG2) and 36+ (AG3)].

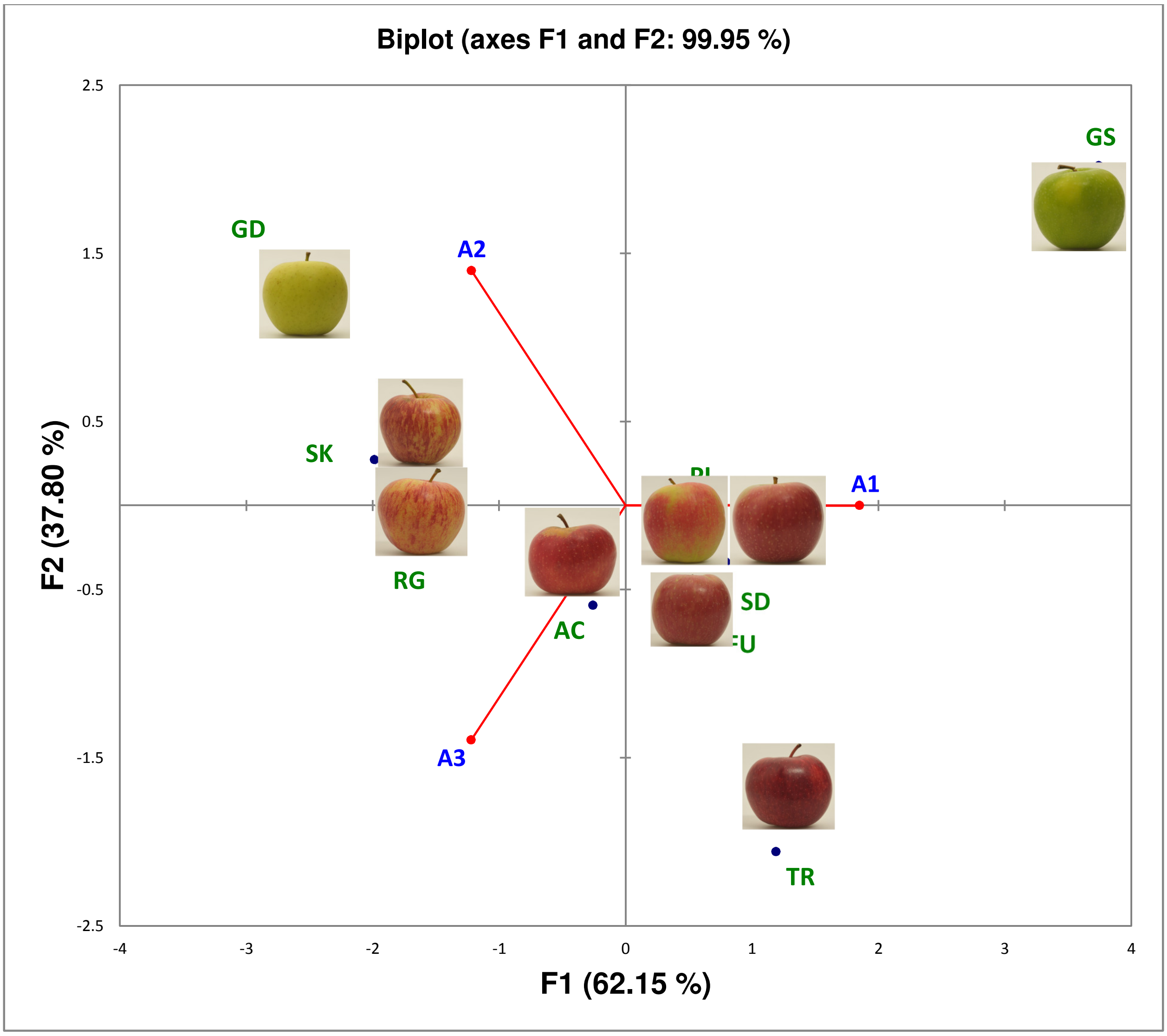

Figure 6 Principal component analysis bi-plot indicating the position of preference for the three appearance clusters (A1-A3) in relation to nine cultivars, i.e., African Carmine (AC), Starking (SK), Pink Lady® (PL), Golden Delicious (GD), Granny Smith (GS), Royal Gala (RG), Fuji (FU), Topred (TR) and Sundowner® (SD).

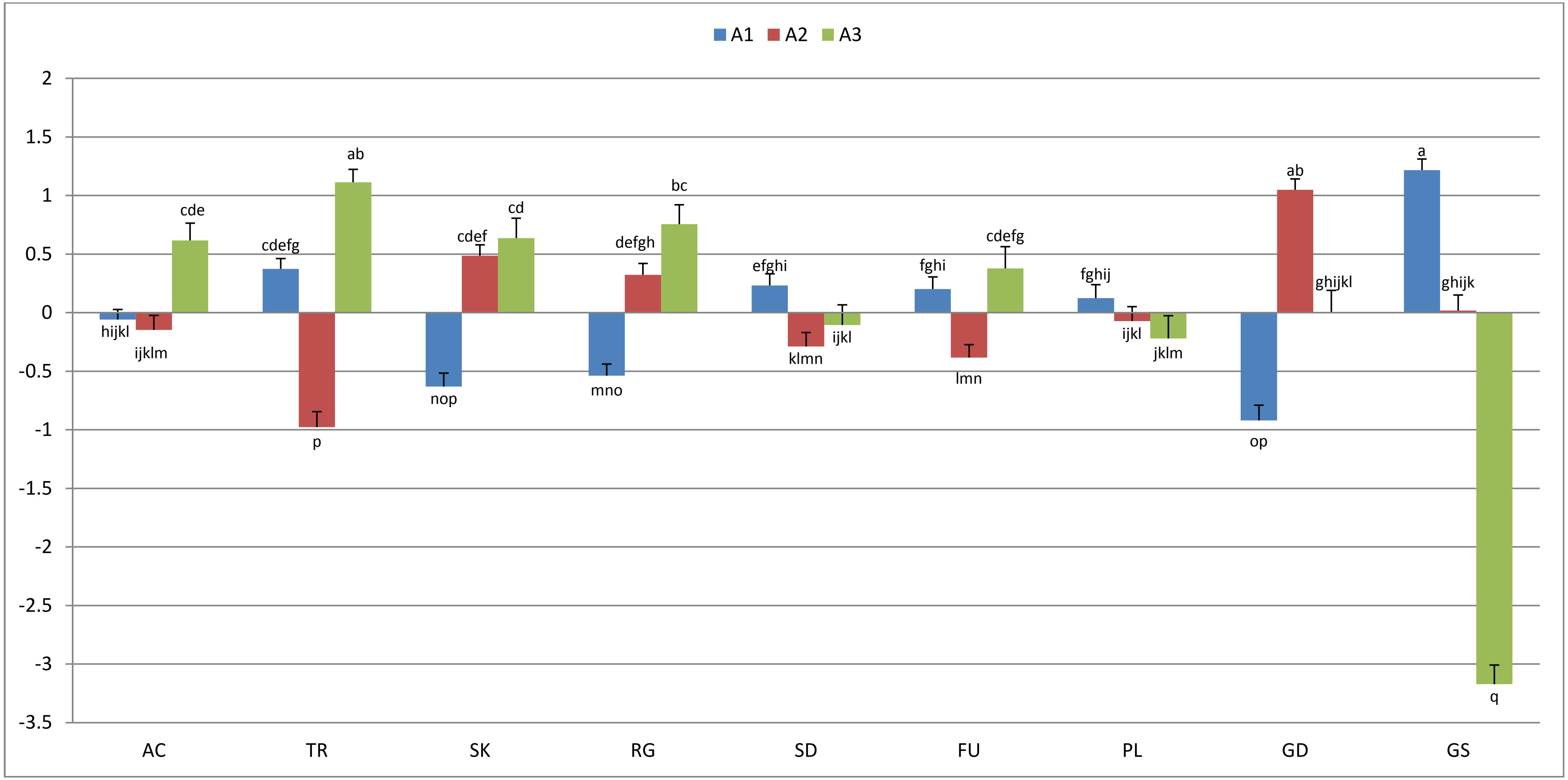

Figure 7 Residual mean preference scores for the appearance of nine apple cultivars analysed by the consumers from three appearance clusters (A1-A3), i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS). Means +standard errors with different alphabetical letters differ significantly. The least significant difference within each group is indicated at the 5% level of significance.

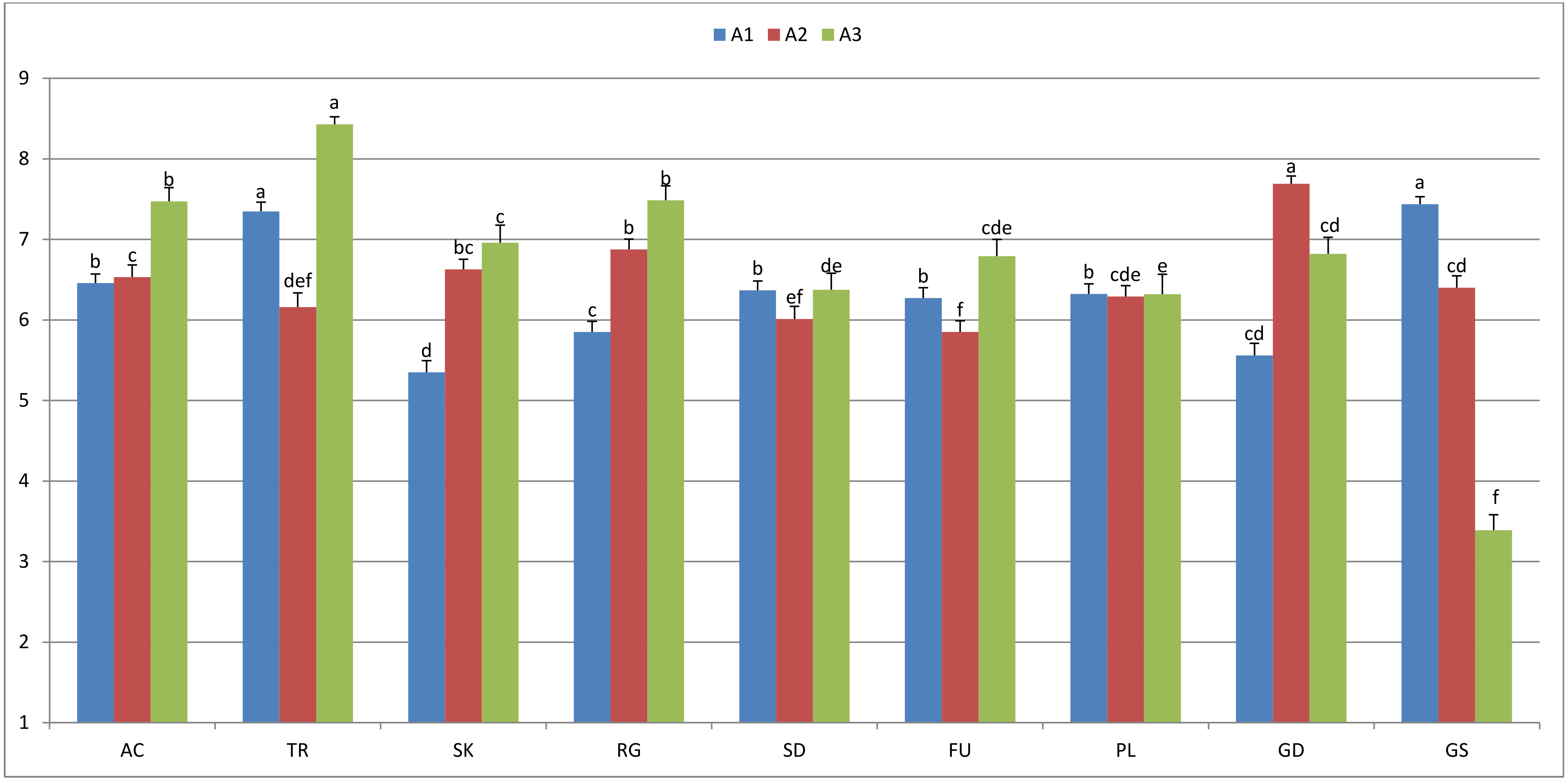

Figure 8 Actual mean preference scores for the appearance of nine apple cultivars analysed by consumers from three appearance clusters (A1-A3), i.e., African Carmine (AC), Topred (TR), Starking (SK), Royal Gala (RG), Sundowner® (SD), Fuji (FU), Pink Lady® (PL), Golden Delicious (GD) and Granny Smith (GS). Means +standard errors with different alphabetical letters differ significantly. The least significant difference within each group is indicated at the 5% level of significance.

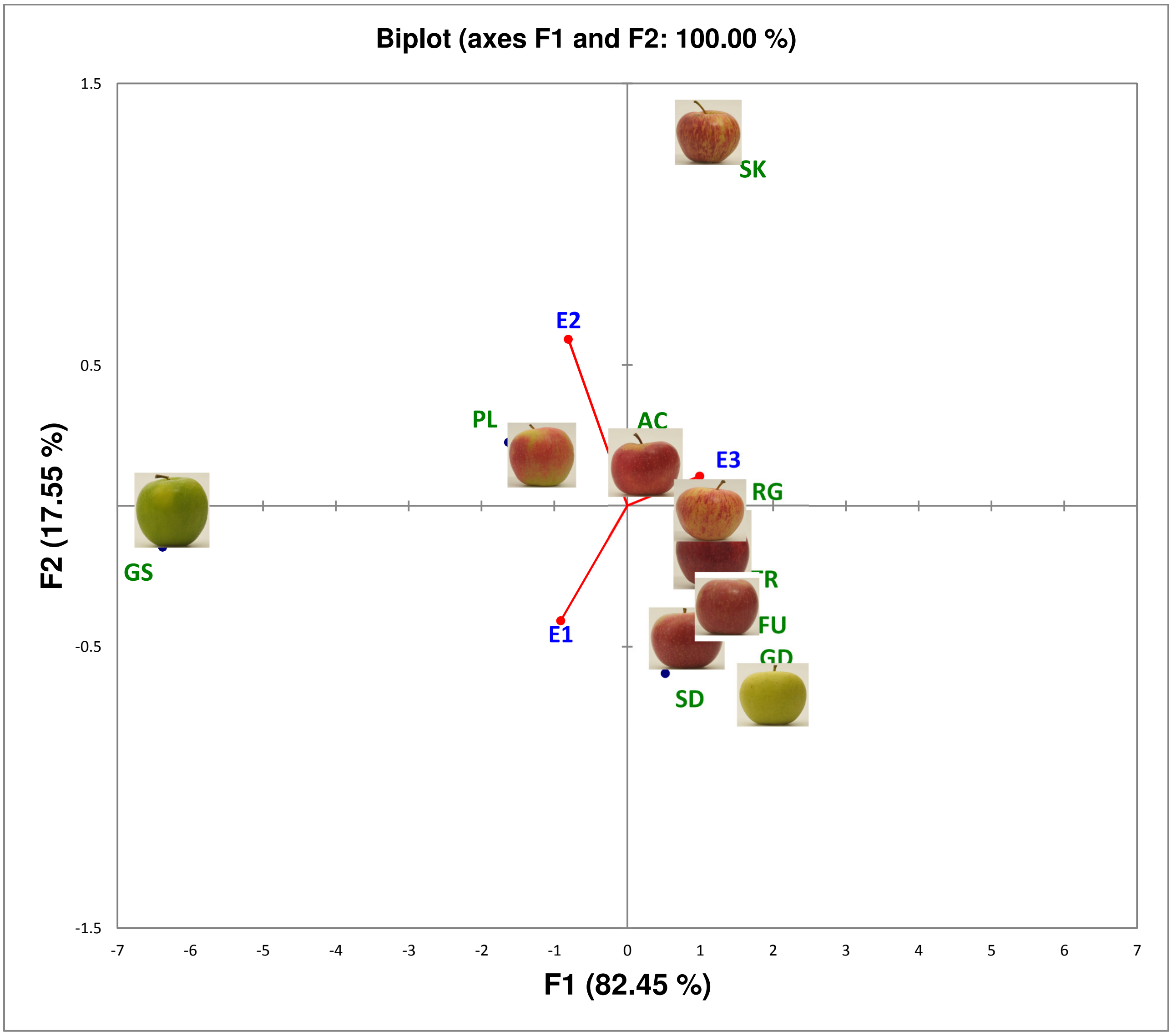

Figure 9 Principal component analysis bi-plot indicating the position of appearance preference for the three clusters obtained by their responses to preference of eating quality (E1-E3) for the nine cultivars, i.e., African Carmine (AC), Starking (SK), Pink Lady® (PL), Golden Delicious (GD), Granny Smith (GS), Royal Gala (RG), Fuji (FU), Topred (TR) and Sundowner® (SD).

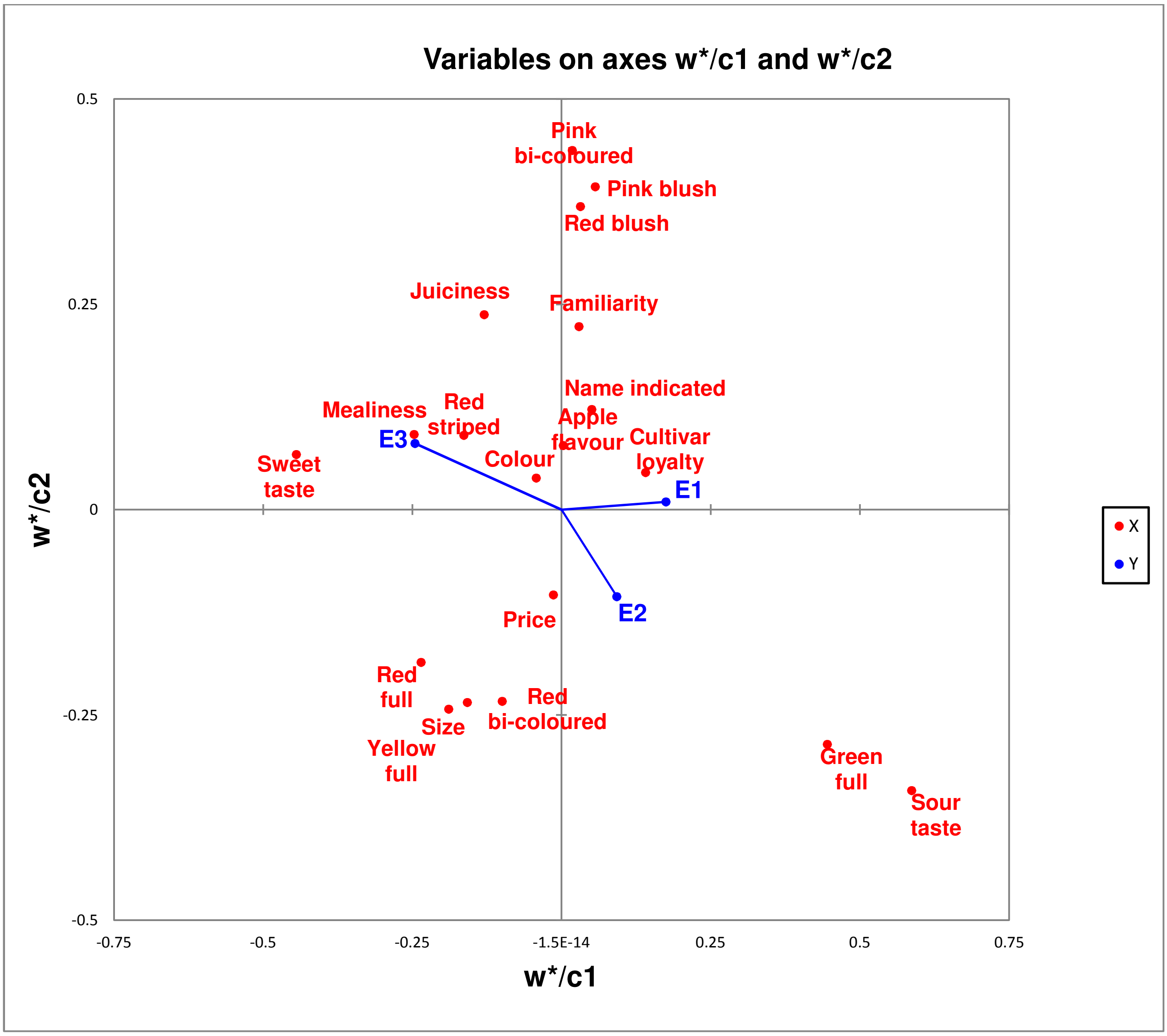

Figure 10 Partial least squares plot indicating the importance of purchase factors and the liking of conceptual sensory and appearance attributes of consumers from the three eating quality clusters (E1-E3). Purchase factors included colour of the apple (colour), loyalty to specific cultivars (cultivar loyalty), familiarity with cultivar (familiarity), cultivar name indication on the packaging (name indicated), price and size of the apples.

CHAPTER 5

Impact of eating quality expectations on degree of liking of selected apple cultivars

1. ABSTRACT

Descriptive sensory analysis (DSA) with a trained panel, instrumental measurements and consumer preference testing were performed to investigate the extent to which associations between appearance and eating quality affect preference for the eating quality of apple cultivars among consumers in the Western Cape Province of South Africa. Instrumental measurements included puncture tests, titratable acidity (TA) and total soluble solids (TSS) concentration measurements on the cultivars Starking, Pink Lady®, Granny Smith, Fuji and Golden Delicious. Consumer preference for apple eating quality was assessed by a nine-point hedonic scale in three questionnaires that contained different levels of direct product information based on visual perception, viz. 1) no visual information, 2) a photograph depicting the typical appearance associated with that specific cultivar and 3) an incorrect photograph, misleadingly depicting the appearance of another cultivar than what was tasted. 'Golden Delicious' was kept as a control sample in order to test consistency of consumer preference upon presentation with the three questionnaires. Analysis of variance (ANOVA) was conducted to compare the effect of level of visual information on consumers' preference for the eating quality of apples, with cultivar and visual information level as main factors. Principal component analysis (PCA) was performed to project instrumental measurements onto the sensory dimensions to investigate the eating quality parameters that associated with each of the cultivars. Mean hedonic preference values were compared between cultivars that were presented with different levels of visual information. The impact of established associations between appearance and eating quality on consumers' apple preferences was confirmed when a mismatch between the sour taste associated with the green peel colour of 'Granny Smith' and the sweet taste associated with red 'Fuji' lead to lower preference scores when 'Fuji' was presented with a 'Granny Smith' photograph. The 'Pink Lady®' photograph evoked a positive brand image among consumers who liked the fruit more when it was presented together with the corresponding photograph compared to the presentation with an incorrect 'Starking' image. Results indicate that it is important to educate consumers on the eating quality of new cultivars especially if deviation occurs from the familiar colour-quality association.

Keywords Consumer preference, colour-flavour interactions, descriptive sensory analysis, *Malus* x *domestica* (Borkh.), quality expectations.

2. INTRODUCTION

Consumers' decisions to purchase food products depend on the ability of the products to meet their quality expectations. Quality expectations can result from memories of actual experiences, information from the media and other consumers and perceptions of current stimuli (Deliza *et al.*, 2003). Although consumers are faced with an immense amount of information stimuli daily, only a small portion can be processed. Therefore consumers strongly rely on vision, their primary perceptual sense, for the subjective and selective information processing systems that are used to derive food quality perceptions (Von Alvensleben & Meier, 1990; Shankar *et al.*, 2010).

Cultivar, appearance, price, packaging and brand name are the most important direct product information for fresh fruit (Von Alvensleben & Meier, 1990). When consumers are familiar with a fruit cultivar, two types of simplified information processing systems are used to extract additional information from the direct information: Total product quality can be deduced from single product properties (in which case these product properties are regarded as key information); or, if the fruit product has a stable brand image that is stored in the memory of consumers, they often set up expectations of what the fruit will taste like (Von Alvensleben & Meier, 1990; Jaeger & MacFie, 2001). This interdependency between the image and perceived properties of the product is known as the "halo-effect" (Von Alvensleben & Meier, 1990) that occurs when positive experiences are transferred across a number of attributes (Oraguzie *et al.*, 2009). Consumers might expect to have a higher preference for the eating quality of a cultivar if they also like its appearance. Simple information processing systems are involved when consumers purchase low-involvement products, i.e. products that require limited thought processing in the decision making process, as is the case with apples (Von Alvensleben & Meier, 1990). Consumers often use brand names or appearance for low-involvement products as key information cues to deduce the non-perceptible properties relating to the eating quality of fresh produce (Racskó *et al.*, 2009; Cerjak *et al.*, 2010). In contrast, new apple cultivars have no key information function and their perceptions would therefore be based mainly on appearance (Von Alvensleben & Meier, 1990).

Appearance is of vital importance to consumers, who perceive fruit colour as key information for maturity, eating quality and safety (Steyn, 2012). Fruit appearance is often the only quality parameter offered to consumers to make purchase decisions when they do not have access to flavour or textural information, as in the case of pears (Gamble *et al.*, 2006). Consumers' learned associations between colour and flavour are created by expectations based on previous experiences (Clydesdale, 1993; Cliff *et al.*, 1999) and they can easily recognise the appearance of the fruit they prefer (Harker *et al.*, 2003). Cultivar-specific eating quality and appearance associations are therefore firmly established in the mind of regular apple consumers (Harker *et al.*, 2003). An example of such a sensory integration that resulted from learned associations include consumers' association of sour taste with green colour and sweet taste with red colour (Steyn, 2012). This association further depends on the fruit that consumers grew up with, as this have a long lasting effect on their association between colour and taste (Shankar *et al.*, 2010). Cliff *et al.* (2002) showed that regional preferences for apples seemed to be greatly influenced by the consumers' familiarity with the appearance of the cultivars. Canadian consumers who partook in the latter study preferred the appearance of those cultivars that were grown in their own region or that were sold in their local marketplace. It was, furthermore, found that regional differences for visual preferences were more pronounced than for textural preferences (Cliff *et al.*, 2002), demonstrating the effect of familiarity on appearance preference.

In view of the above, the aims of this study were to determine 1) the extent to which apple appearance affects consumers' liking scores and 2) the impact of established appearance and flavour/texture associations on the apple cultivar preference of consumers in the Western Cape Province of South Africa.

3. MATERIALS AND METHODS

3.1 Plant material and instrumental analyses

Five apple cultivars (*Malus x domestica* Borkh.) were selected for this study to include cultivars from all four quadrants in the sensory and preference principal component analysis (PCA) bi-plot (see Chapter 3, Figure 3). It was previously found that 'Cripps' Pink', 'Starking', 'Granny Smith', 'Golden Delicious' and 'Fuji' vary with regard to consumer preference, flavour and textural attributes and appearance (see Chapter 3). First grade quality 'Granny Smith', 'Golden Delicious', 'Fuji' and 'Starking' fruit were harvested from farms of the Dutoit Group in the Ceres area (latitude 33°22'S; longitude 19°19' E) in the Western Cape at optimum maturity during 2010. First grade quality 'Pink Lady®' fruit were purchased one week prior to analysis from Woolworths, Stellenbosch, South Africa. 'Pink Lady®' is the trademark name reserved for 'Cripps' Pink' fruit with more than 40% blush coverage (Anonymous, 2000). All fruit were kept in cold storage at −0.5 °C at the Department of Horticultural Science, Stellenbosch University, until commencement of instrumental analyses at the fruit analysis laboratory. Instrumental analyses included measurement of total soluble solids (TSS) concentration, titratable acidity (TA) and flesh firmness, as described in Chapter 3.

3.2 Descriptive sensory analysis

Sensory profiling was carried out from 15 to 20 September 2010 in the sensory research laboratory at the Department of Food Science, Stellenbosch University. The sensory panel consisted of eight female judges, all experienced in descriptive analysis of apples. Training was conducted using the consensus method and analyses were performed according to 'Generic Descriptive Analysis', as described by Lawless and Heymann (2010). The panellists agreed on a list of attributes for describing the taste, flavour and texture of the peeled samples of the selected cultivars: Sour taste, sweet taste, overall apple flavour, crispness, crunchiness, juiciness, mealiness and sponginess.

The fruit were analysed during two sessions, in which each panellist assessed three replications of five fruit per session. Apples were cut into eight equal slices from stem end to calyx end so that every apple was analysed by the entire panel during each replication. Slices of unpeeled fruit were presented on Petri dishes (Kimix, South Africa) and coded with three digit randomised codes in a complete block design, balanced for order and carry-over effects. Panellists were instructed to peel the samples prior to analysis. The fruit were assessed on 100 mm line scales anchored with “absent” at 0 mm and “very strong” at 100 mm. Data were collected electronically using the Compusense® five data collection software (Version 4.2; Compusense Inc., Guelph, Ontario, Canada). Distilled water and water biscuits (Woolworths, South Africa) were provided as palate cleansers between samples. Profiling was conducted in tasting booths with standardised artificial daylight lighting and temperature control (21 °C).

3.3 Consumer preference analysis

One hundred and fifty-two consumers were recruited for the consumer preference analysis on 22 September 2010, on the basis that they regularly consume apples. Consumers were asked to complete a set of three questionnaires (A-C). In each of these questionnaires, consumers were presented with a sample set of slices of 5 peeled apple cultivars and were requested to indicate their degree of liking for the eating quality of the samples, using the nine-point hedonic scale. In this test, consumers were asked to indicate which term best describe their attitude towards the products being tasted (Lawless & Heymann, 2010). For Questionnaire A, consumers received a sample set of the cultivars, but no photographs depicting fruit appearance were provided. Five samples were again presented with Questionnaire B, but photographs were now provided with the corresponding cultivars. Consumers were specifically instructed to analyse their preference for the overall eating quality of the fruit in the context of the photograph, and not simply their preference for the appearance of the fruit. They were told that the photographs were only included to serve as an indicator of the cultivar they were analysing. For Questionnaire C, consumers were misleadingly told that the cultivar on the photograph corresponded to the cultivar they had to taste: A photograph of ‘Fuji’ was presented with a taste sample of ‘Granny Smith’ and *vice versa*. Similarly, the taste samples and photographs of 'Starking' and ‘Pink Lady®’ were exchanged. The sensory analyses of these cultivars (refer to Chapter 3) revealed that Starking and Pink Lady® and also Fuji and Granny Smith had distinctly different flavour and texture profiles. ‘Golden Delicious’ was kept as a control reference sample in order to compare the consistency of the questionnaires, and the correct photograph was thus provided with the taste sample for Questionnaires B and C.

During the tasting sessions, consumers were requested to drink water between samples. A sample consisted of an 8th of a peeled apple, presented as described in Chapter 3. Every group of eight consumers analysed the exact same samples of the respective cultivars. In order to address the potential compounding effect of the presentation order of the questionnaires, approximately half of the consumers received Questionnaire C before Questionnaire B. In total 19 fruit of each cultivar were used for the consumer preference test.

3.4 Experimental design

Instrumental measurements were conducted on six replications of each cultivar, where a single fruit was regarded as a replicate. Upon removal of fruit from storage, each apple was uniquely coded. Approximately a quarter of each fruit was used for instrumental analyses. The remaining parts were kept in the cold room overnight and used for DSA on the next day. Six replications of each of the five cultivars were thus analysed by the panel of eight trained judges. As the apples were coded, a tracking system could be used to match the instrumental scores of individual fruits with samples presented to the trained panel.

Three tests were performed in the consumer preference analysis: A) Analysis of preference with no additional visual information provided (no photograph); B) analysis of preference of a slice of apple whilst looking at a photograph depicting the typical appearance associated with that specific cultivar (correct photograph) and C) analysis of preference of a slice of apple whilst looking at a photograph illustrating another cultivar (incorrect photograph).

3.5 Statistical procedures

Sensory analysis and instrumental measurements were subjected to the same procedures of analysis of variance (ANOVA) as described in Chapter 3. In order to compare the effect of information level on consumers' preference for apple eating quality, their hedonic preference scores were subjected to a 5 x 3 factorial ANOVA, with factors cultivars (Starking, Pink Lady®, Fuji, Granny Smith and Golden Delicious) and information levels (no photograph, correct photograph and wrong photograph), using SAS statistical software (SAS, version 9, 1999, Cary, North Carolina, USA). The changes in liking scores for samples presented without pictorial information and samples with the correct and incorrect photographs were also computed separately for the group that received Questionnaire B first, and the group that received Questionnaire C first. Means for cultivar*information_level were compared between all cultivars for the total group, as well as for the two groups that received the questionnaires in different presentation orders, with Student's t-LSD (Least Significant Difference) at a 5% significance level. XLSTAT software (Addinsoft, Version 2007, Paris, France) was used to perform PCA to study the associations between sensory and instrumental attributes within and between cultivars.

4. RESULTS AND DISCUSSION

4.1 Sensory and instrumental attributes

Figure 1 illustrates the replicates of the five cultivars in association with the various sensory and instrumental attributes, thereby explaining about 73% of the flavour and textural variation among the cultivars. Sensory attribute scores were averaged across panellists and replicates for each of the five cultivars presented in Figure 2. Instrumental measurements were conducted to serve as an external data set for the multivariate analyses, and to confirm the differences in apple attributes reported by the sensory panel (Table 1). The textural attributes crispness and crunchiness had the largest factor loadings on the first principal component (PC1), suggesting that PC1 distinguished between cultivars based on these attributes (Fig. 1). The second principal component (PC2) accounted for differences in sour taste, sweet taste and juiciness. 'Starking', 'Pink Lady®', 'Fuji' and 'Granny Smith' were mainly situated in four different quadrants in the PCA bi-plot, therefore showing a variation in their flavour and texture profiles (Fig. 1). Consumer preference differences were thus expected as a result of these differences in eating quality profiles.

The positioning of Fuji and Granny Smith on opposite sides of PC2 indicated clear differentiation in flavour profiles between these cultivars. 'Fuji' showed a closer association with juiciness, crispness, crunchiness and firmness on the right side of PC1 compared to 'Granny Smith' (Fig. 1). 'Fuji' and 'Granny Smith' were comparably and highly firm (Table 1), crispy and crunchy, but 'Fuji' (72.5) was significantly juicier than 'Granny Smith' (65.4) (Fig. 2). 'Granny Smith' associated with sour taste and TA and had a significantly higher sour taste (68.0) and TA (0.45) than 'Fuji', which had the lowest sour taste (21.8) and had a low TA (0.22) (Fig. 2 and Table 1). Although differences in sweet taste were not as prominent as for sour taste, Fuji (63.2) and Granny Smith (44.4) were the most and least sweet cultivars, respectively (Fig. 2). Instrumentally measured TSS did not differ significantly between 'Fuji' and 'Granny Smith' (Table 1). 'Granny Smith' had a significantly higher apple flavour (58.6) than 'Fuji' (51.6) (Fig. 2). The TSS/TA ratio for 'Fuji' (62.8) was significantly higher than that for 'Granny Smith' (27.4) (Table 1). These cultivars were not spongy or mealy (results not shown). Considering the importance of sour taste in driving consumer preference (refer to Chapter 3), it could be expected that consumer preference differences between 'Fuji' and 'Granny Smith' would predominantly relate to different levels of sour taste.

'Starking' associated positively with sweet taste, TSS and TSS/TA ratio and negatively with sour taste, whereas 'Pink Lady®' showed a closer association with sour taste in Figure 1 compared to 'Starking'. Pink Lady® (35.7) was significantly more sour than Starking (27.1) (Fig. 2), but TA for these cultivars were comparably low (Table 1). Although 'Starking' had a significantly higher TSS (15.4) than 'Pink Lady®' (11.6) (Table 1), it was not rated significantly sweeter than 'Pink Lady®' (Fig. 2). 'Starking' (74.8) had a significantly higher TSS/TA ratio than 'Pink Lady®' (52.9) (Table 1). Apple flavour for 'Starking' and 'Pink Lady®' was comparably high (Fig. 2). The texture profiles for these cultivars did not differ significantly, with similar crispness, crunchiness and firmness values shown for Starking and Pink Lady® (Fig. 2 & Table 1). Starking (1.9; 2.0) and Pink Lady® (1.5; 2.0) were respectively slightly more spongy and mealy than the other cultivars. However, these values were regarded as extremely low and probably did not affect consumer liking and are therefore not presented here. The textural similarities between Starking and Pink Lady® suggest that differences in consumer preference for these two cultivars could possibly be ascribed to differences in TSS and sour taste.

Sensory and instrumental attributes for 'Golden Delicious' were situated between 'Pink Lady®', 'Granny Smith' and 'Starking' (Fig. 1). 'Golden Delicious' had an average apple flavour (53.3), sour taste (37.8), sweet taste (55.2), TSS (12.6) and low TA (0.26). Crispness and crunchiness for 'Golden Delicious' were average and significantly higher than for 'Pink Lady®' and 'Starking', but lower than for 'Granny Smith' and 'Fuji'. Juiciness and firmness for 'Golden Delicious' were also average and significantly lower compared to 'Fuji' and 'Granny Smith' (Fig. 2 & Table 1).

4.2 Consumer preference

Consumers tasted all apple cultivars with different levels of visual information to ascertain the extent to which appearance affects overall degree of liking for the eating quality of the respective samples. For the purpose of this part of the study, preference for the "overall eating quality" of the apples refers to consumers' liking of the overall flavour and texture of the fruit.

Consumers liked the eating quality of 'Pink Lady®' significantly more (6.7) when it was presented with its corresponding photograph compared to presentation without pictorial information (6.3) (Fig. 3). All other cultivars received higher hedonic scores for presentation without pictorial information than for presentation with photographs (Fig. 3). The increase in the hedonic liking that resulted from presentation with the correct photograph for Pink Lady® could be ascribed to the positive brand image of this cultivar. Although the Pink Lady® fruit used in this study were not highly crispy, crunchy and juicy, Pink Lady® is characterised as a crispy, crunchy, hard cultivar with a sweet taste (Cripps *et al.*, 1993; Corrigan *et al.*, 1997), which have been proven as important drivers of liking for a large proportion of the consumers who partook in the study (Chapter 3).

Furthermore, the pink blush of Pink Lady® fruit offers a distinctive appearance that has been preferred over full green, full red and red striped cultivars by New Zealand consumers who were willing to pay more for Pink Lady® apples, compared to cultivars such as Fuji and Granny Smith (Corrigan *et al.*, 1997). New Zealand and Canadian consumers preferred the appearance of blushed apples on a green background (similar to Pink Lady®) as opposed to a yellow background, probably due to their familiarity and eating quality preference for blushed cultivars on a green background (Cliff *et al.*, 2002). Eighty-eight per cent of the consumers in the current study were familiar with 'Pink Lady®' (Chapter 3) and it is therefore suggested that they associated the distinguishable appearance of 'Pink Lady®' with its acceptable eating quality attributes (Fig. 1) created by the positive brand image. Consumers consequently expected to have a higher preference for the eating quality of Pink Lady® when they realised that they were presented with this cultivar. The interdependency between product image and perceived attributes, i.e. the halo effect (Von Alvensleben & Meier, 1990), could have lead consumers to have higher expectations of the eating quality of 'Pink Lady®'.

Consumers liked the eating quality of 'Starking' (6.5) significantly more when it was presented without pictorial information compared to presentation with its corresponding photograph (5.9) and the 'Pink Lady®' (6.0) photograph (Fig. 3). Low preference scores for the 'Starking' photograph could be the result of a negative product image of 'Starking' apples, which are prone to develop mealiness during storage (Nara *et al.*, 2001). Mealiness is a strong, negative driver of liking for a large proportion of consumers (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998; Chapters 3 & 4). Furthermore, consumers could have a lower preference for the appearance of striped red apples.

In a study conducted by Jaeger and MacFie (2001) where consumers were presented with written and pictorial information, it was similarly found that the presentation of photographs of predominantly red apples created lower expectations for the eating quality of these fruit among consumers. Regular consumers of red apples indicated that they expect red apples to be less acidic, juicy and crisp, compared to consumers who usually eat green or bi-coloured apples (Jaeger & MacFie, 2001). Sixty-two per cent of the consumers in the current study indicated that they were familiar with Starking (Chapter 3), but it could be suggested that even more consumers were familiar with Red Delicious-type apples, although they were not necessarily familiar with the name of the particular cultivar. Consumers who were familiar with the eating quality profile of Red Delicious-type apples possibly associated red, striped cultivars with a softer texture (Jaeger & MacFie, 2001). Highly coloured red cultivars taste sweeter than fruit from the same cultivar with poor colour development (Dever *et al.*, 1995). Although sweet taste is a positive driver of liking for apple eating quality among a large proportion of consumers (Daillant-Spinnler *et al.*, 1996; Hampson *et al.*, 2000; Chapter 3), the expectation of mealiness created by the appearance of 'Starking' probably overruled consumers' expectations of sweet taste created by the red colour (Clydesdale, 1993). The negative image evoked by pictorial information of 'Starking' was further illustrated by the significantly lower preference scores for the eating quality of 'Pink Lady®' when it was presented as 'Starking', compared to presentation with its corresponding photograph (Fig. 3). This illustrates the expectations created by cultivar appearance and it is suggested that consumers' familiarity with 'Pink Lady®' resulted in the realisation that they did not receive the corresponding 'Pink Lady®' taste sample or that their expected preference for 'Pink Lady®' was not met. However, the possibility should be considered that the export quality 'Starking' fruit used in the current study were of a higher quality than the first grade 'Pink Lady®' fruit bought from a local supermarket.

Consumers liked Golden Delicious significantly more (6.5) when it was presented without pictorial information compared to when they received corresponding photographs of this cultivar (Fig. 3). Identical photographs of 'Golden Delicious' were presented in Questionnaires B and C, and understandably consumer liking for 'Golden Delicious' did not differ significantly in these questionnaires (Fig. 3). 'Golden Delicious' may develop mealiness and poor flavour during prolonged storage (Nara *et al.*, 2001). It is therefore suggested that consumers associated the distinctive yellow-green appearance of Golden Delicious with a poor texture, resulting in lower expectations of liking and consequently lower preference scores for the actual eating quality of this cultivar. Consumers' lower preference for the appearance of an apple that resembled a cultivar that is known to acquire mealiness suggests that they judged the appearance of the fruit according to their expectations of its eating qualities (Cliff *et al.*, 2002). Consumers increasingly prefer newer bi-coloured cultivars to traditional cultivars such as Golden Delicious (Jaeger & MacFie, 2001), which could imply that consumers' association with eating quality, but also their lower preference for yellow-green full coloured fruit resulted in lower preference scores.

Contrary to 'Golden Delicious', 'Starking' and 'Pink Lady®', presentation of 'Fuji' with its corresponding photograph did not significantly ($P>0.05$) affect consumers' preference for its eating quality compared to presentation without pictorial information (Fig. 3). Fuji was liked significantly more than any other cultivar when presented without pictorial information (Fig. 3). The eating quality of 'Fuji' associated with measures of firmness (juiciness, crispness, crunchiness and instrumental firmness) and sweet taste (Fig. 1), which were important drivers of liking for a large proportion of consumers (Daillant-Spinnler *et al.*, 1996; Hampson *et al.*, 2000; Chapter 3). Most consumers (61%) were unfamiliar with 'Fuji' (Chapter 3) and probably have not yet established such strong appearance and eating quality associations as they would have for more familiar cultivars. Consequently, they did not have clear expectations of their preference for its sensory attributes. A study conducted on the effect of brand familiarity on consumers' beer preferences similarly showed that consumers evaluated the taste *per se* of unfamiliar brands, and not the outcome of their expectations (Cerjak *et al.*, 2010).

Granny Smith was the least liked cultivar (5.9) in Questionnaire A (presentation without photographs) (Fig. 3). Aversion to strongly acidic apples among a large proportion of consumers (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998; Chapters 3 & 4) and the high acidity of 'Granny Smith' (Fig. 2) probably resulted in low preference scores for the eating quality of 'Granny Smith'. Interestingly, the addition of the photographs did not cause a significant preference decrease for the eating quality of 'Granny Smith', which might be ascribed to consumers' awareness that they were analysing 'Granny Smith' even when it was presented without pictorial information. Granny Smith is a well-known cultivar among the consumers who partook in the study (95% of the consumers were familiar with Granny Smith, Chapter 3) and, together with Golden Delicious, have the highest production volumes in South Africa (DFPT, 2011). Consumers were probably acquainted with the distinctive sour taste of 'Granny Smith', or associated a green appearance with lower sweetness, probably resulting from their association with the colour of immature fruit (Clydesdale, 1993). Liking scores for 'Granny Smith' were not significantly lower when it was presented with the 'Fuji' photograph (Fig. 3). Again it could be argued that most consumers realised that they were analysing 'Granny Smith', while the association between red apples and sweetness (Jaeger & MacFie, 2001) possibly led other consumers to expect a sweeter sample. Similarly, consumers' expectation of a sour apple probably resulted in significantly lower preference scores for 'Fuji' when it was presented with the 'Granny Smith' photograph (Fig. 3). The cognitive creation of expectations for both sensory (belief that the product will possess certain sensory attributes) and hedonic experiences (belief that the product will be liked/disliked to a certain degree) (Cardello & Sawyer, 1992) was seen when consumers associated a green colour with a sour taste and their expected preference thereof.

The extent to which appearance affects consumer preference for eating quality was further investigated in the current study by comparing the preference scores obtained for cultivars in Questionnaires B and C. Fifty per cent of the consumers received Questionnaire B first (correct photograph), whereas the other fifty per cent received Questionnaire C first (incorrect photograph). According to Figure 4 the serving order of questionnaires impacted on consumers' preference for the eating quality. When consumers analysed the eating quality of 'Pink Lady®' with the correct photograph first, their preference scores were on average 0.65 higher than when tasting the product without the photograph (Fig. 4a). The group that received Questionnaire B first indicated a significantly greater liking for 'Pink Lady®' presented with the correct photograph compared to the incorrect photograph (Fig. 4a). The product image evoked by the photograph of this cultivar probably had a bigger influence on their liking scores for eating quality. However, the group that received the incorrect photographs first (Questionnaire C) did not rely on the pictorial information as a quality cue to the same extent and did not like 'Pink Lady®' with the correct photograph significantly more than with the incorrect photograph (Fig. 4b). Differences in the preference scores were most evident in the analysis of the eating quality of 'Starking'. The consumers who received the correct photograph of Starking first, scored this cultivar significantly higher when it was presented with its corresponding photograph, compared to when it was incorrectly presented with the 'Pink Lady®' photograph (Fig. 4a). The lower preference scores for presentation with the incorrect photograph could result from consumers' expectations that were not met, or their realisation by then that they have been misled. The group that received the incorrect photograph of

'Starking' first liked its eating quality less when it was presented with its corresponding photograph than when it was analysed together with the 'Pink Lady®' (Fig. 4b).

Both groups liked 'Fuji' and 'Granny Smith' moderately, but not significantly more when it was presented with its corresponding photographs, independent of the order in which it was presented. Consumers' lower preference scores for these cultivars when presented with the incorrect photographs could be a result of the discrepancy between their taste expectations and the actual taste of Fuji and Granny Smith. Consumers who received 'Fuji' with its corresponding photograph first (Fig. 4a), gave lower preference scores to its eating quality than consumers who received 'Fuji' and its corresponding photograph in the final analysis (Fig. 4b). Similarly, consumers who received Questionnaire B first rated their preference for 'Granny Smith' eating quality lower when presented with its corresponding photograph (Fig. 4a), than consumers who received Questionnaire C first (Fig. 4b). This tendency possibly indicates that the first group of consumers (depicted in Figure 4a) had a greater aversion towards the appearance of both 'Fuji' and 'Granny Smith'.

For 'Golden Delicious', the same photographs were provided in the 'correct' and 'incorrect' presentation orders. All consumers gave lower preference scores when analysing the apple samples together with visual information. What is also interesting is that the lowest preference score was given for the 'Golden Delicious' sample that was analysed in the last instance, i.e. Questionnaire C with "wrong" photograph in Figure 4a and Questionnaire B with "correct" photograph in Figure 4b. This could be as a result of a slight carry-over effect of sensory fatigue, or consumers' realisation that there was a discrepancy between the taste samples and the pictorial information.

5. CONCLUSIONS

From this study it can be concluded that consumers' expectations created by apple appearance impact on their eating experience. Consumers expected to have a lower preference for the sour 'Granny Smith' and discrepancies in sensory attributes resulted in a reduced liking when 'Granny Smith' was presented as 'Fuji', and sweet 'Fuji' as 'Granny Smith'. Discrepancies between the expected and actual sensory attributes of a product result in so-called "disconfirmation" that leads to a reduced preference for the eating quality of the product (Cardello & Sawyer, 1992).

Higher preference scores for a familiar cultivar such as Pink Lady® when it was presented with its corresponding photograph, illustrate the impact of fruit cultivar branding on consumers' expectation of the quality attributes of the product. 'Pink Lady®' had a positive brand image among consumers that created expectations of higher preference. Consumers' expectations of lower preference for the eating quality of Starking probably resulted from their association between striped, red cultivars and mealiness. It is suggested that consumers did not have accurate expectations regarding the eating quality of Fuji, partly due to their unfamiliarity with the cultivar. Some consumers could have associated the red colour with sweetness and the possibility of mealiness. It is therefore essential to introduce new cultivars via taste tests through market or in-store demonstrations, especially where a fruit product deviates from the familiar colour-quality association (Steyn, 2012) as was seen for the crisp texture and red colour of Fuji. This would allow consumers the opportunity to become familiar with the internal eating quality of the cultivar before rejecting the cultivar on visual appeal.

The presentation order had a clear effect on consumers' preference for apple eating quality and should be taken into consideration in future studies that analyse consumers' preferences for apple eating quality. In order to reduce the carry-over effect of presentation order in the case of a big sample size (15 in the current study), it is suggested that the presentation of questionnaires should be randomised among consumers. Due to the important effect of apple appearance on consumers' expectation for the sensory attributes and their consequent preference for apples, preference studies where consumers are presented with a small segment of an apple sample might possibly not give an accurate estimate of consumers' preference for the cultivar as a whole. If consumers are more likely to purchase apples according to their preference for the overall product, it is important that apple taste samples in future studies should be depicted with a realistic representation of its total appearance.

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Table 1 Overall means ± standard deviations of instrumental measurements of titratable acidity (TA), total soluble solids (TSS), TSS/TA ratio and firmness for each cultivar. Means with different letters within columns indicated significant differences at the 95% level of significance

Cultivar	**TA (% malic acid)**	**TSS (ºBrix)**	**TSS/TA**	**Firmness (N)**
Pink Lady®	0.23 ± 0.02[b]	11.6 ± 0.37[c]	52.9 ± 5.82[b]	59.8 ± 0.40[b]
Starking	0.21 ± 0.01[b]	15.4 ± 0.72[a]	74.8 ± 3.68[a]	57.8 ± 0.27[b]
Golden Delicious	0.26 ± 0.03[b]	12.6 ± 0.45[bc]	51.0 ± 6.75[b]	63.7 ± 0.21[b]
Granny Smith	0.45 ± 0.04[a]	11.9 ± 0.58[bc]	27.4 ± 2.44[c]	74.5 ± 0.09[a]
Fuji	0.22 ± 0.01[b]	13.3 ± 0.20[b]	62.8 ± 3.76[ab]	72.5 ± 0.29[a]
P-value	<0.0001	0.0001	<0.0001	0.0003

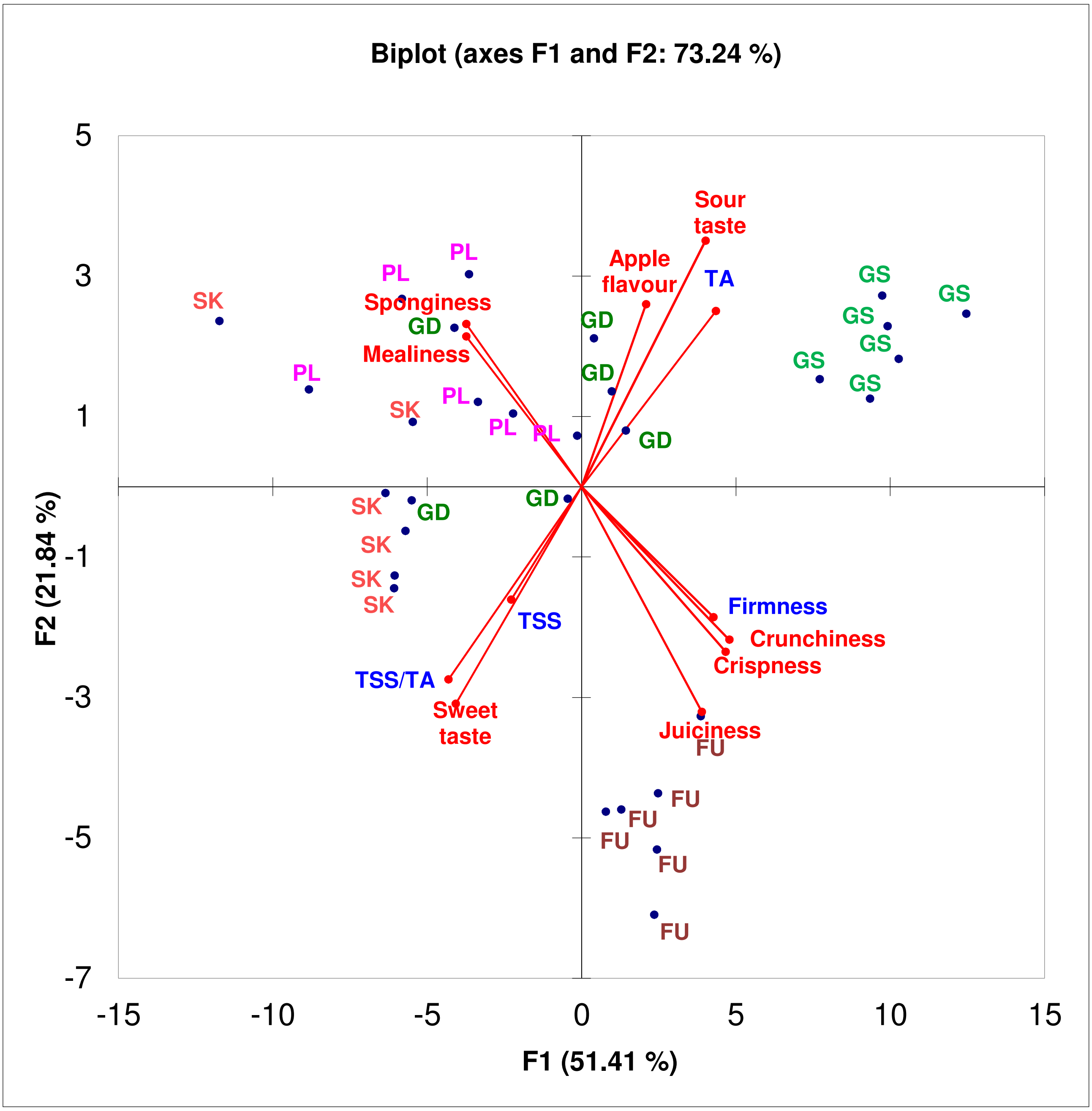


Figure 1 Principal component analysis (PCA) bi-plot illustrating the association between the sensory (depicted in red) and instrumental (depicted in blue) attributes (loadings) for each of the six replications of the respective cultivars (scores), i.e., Pink Lady® (PL), Fuji (FU), Granny Smith (GS), Golden Delicious (GD) and Starking (SK). Instrumental measurements included firmness, total soluble solids (TSS), titratable acidity (TA), and the relation of TSS to TA (TSS/TA).

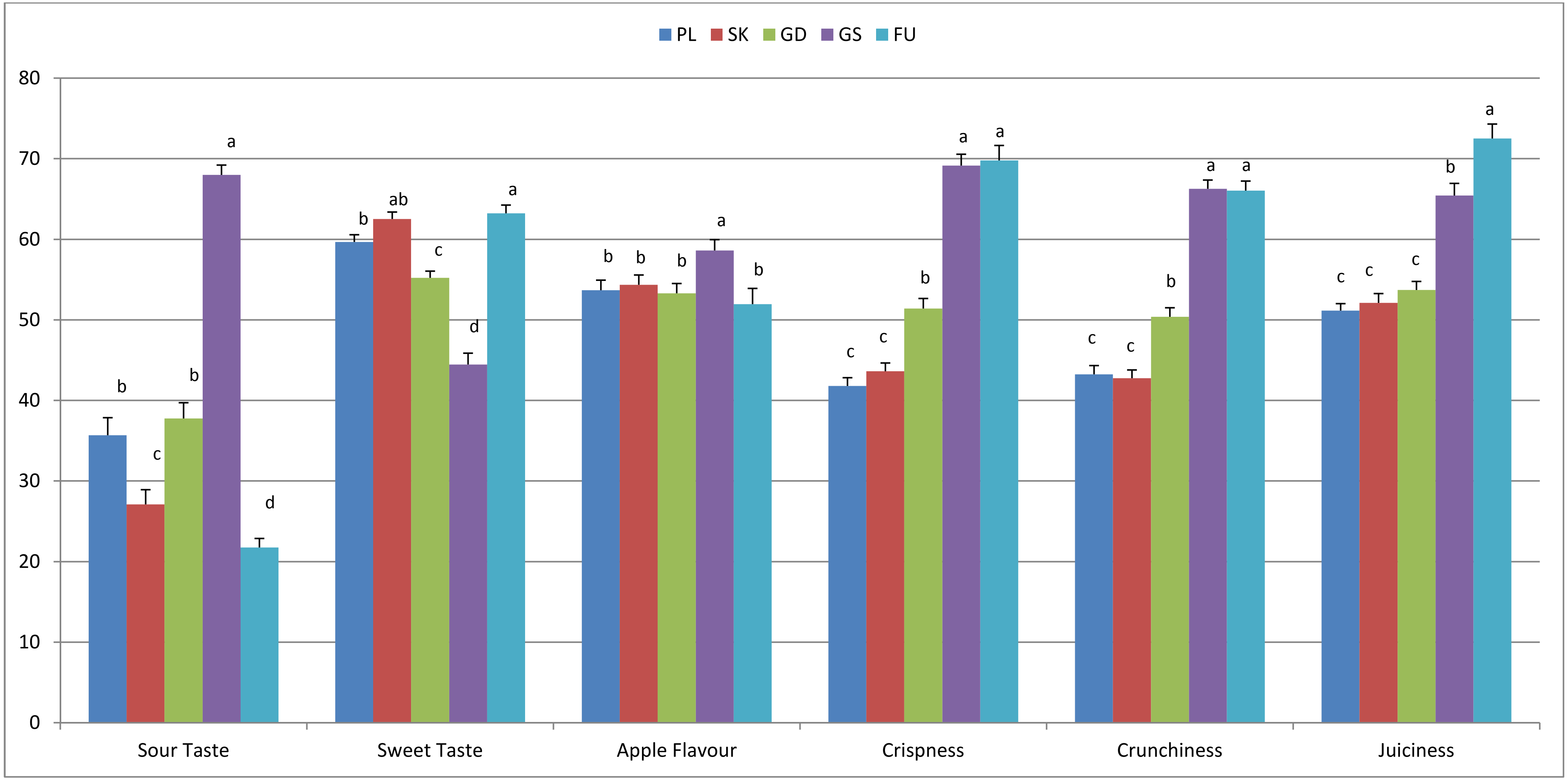


Figure 2 Mean values for sensory attributes analysed without peel for all five cultivars, i.e., Pink Lady® (PL), Starking (SK), Golden Delicious (GD), Granny Smith (GS) and Fuji (FU). Means +standard errors with different alphabetical letters differ significantly between cultivars for each sensory attribute. The least significant difference for each attribute is indicated at the 95% level of significance.

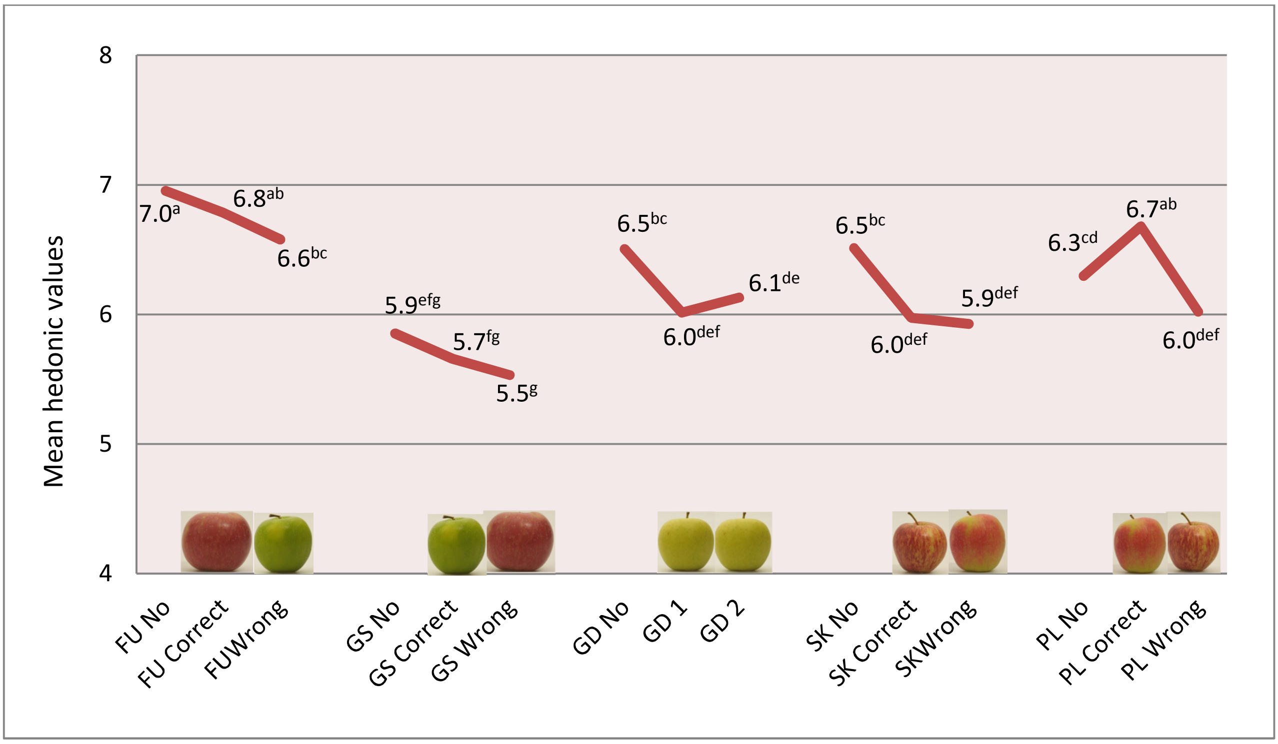
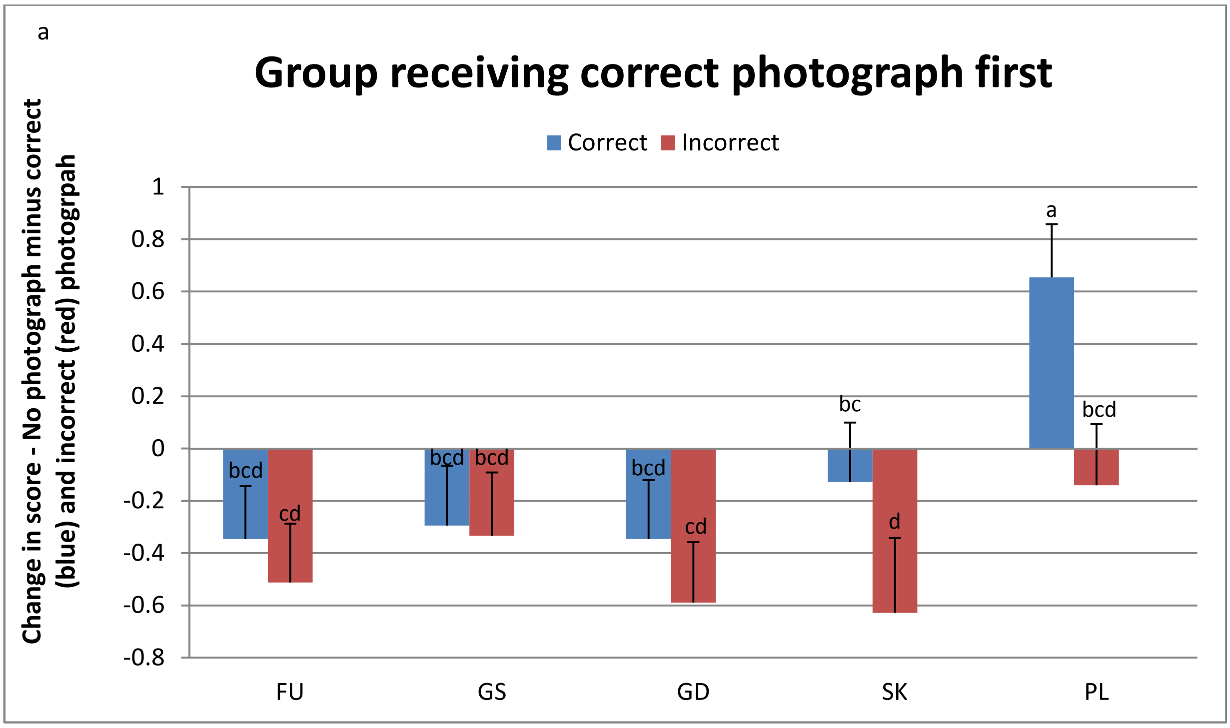


Figure 3 Change in mean hedonic values for apple cultivars when tasted with 1) no photograph (no), 2) the correct photograph (correct) and 3) the incorrect photograph (incorrect). The correct and wrong photographs for the respective cultivars are illustrated for Fuji (FU), Granny Smith (GS), Starking (SK) and Pink Lady® (PL). The same photograph was used for Golden Delicious (GD) 1 and 2. Means with different alphabetical letters differ significantly between cultivars for presentation with the different levels of visual information. The least significant difference for each cultivar is indicated at the 95% level of significance.



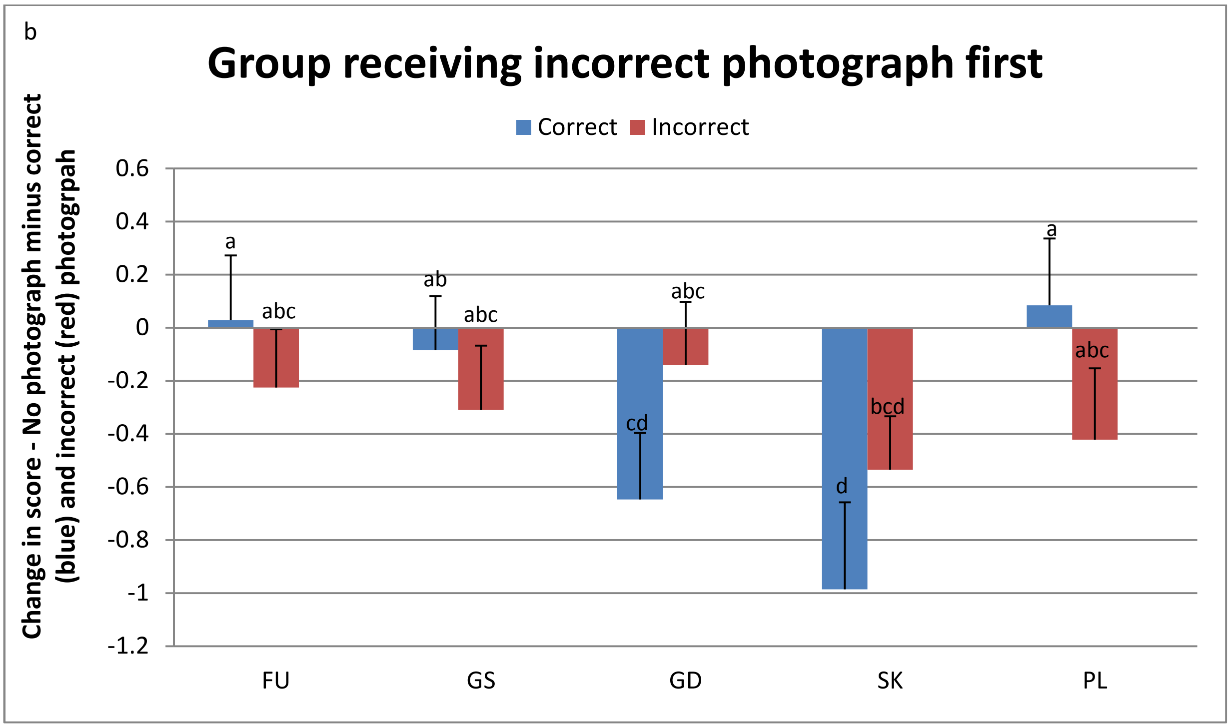


Figure 4 Change in liking scores when re-tasting samples with correct or incorrect representations of the general appearance using photographs of the cultivars Fuji (FU), Granny Smith (GS), Golden Delicious (GD), Starking (SK) and Pink Lady® (PL). The consumer group in (a) was presented with the correct photographs first and in (b) the consumers received the incorrect photographs first. Means +standard errors with different alphabetical letters differ significantly between cultivars for presentation with the correct or incorrect photograph compared to presentation without visual information. The least significant difference for each cultivar is indicated at the 95% level of significance.

CHAPTER 6

Fruit quality parameters to measure and how to best assess these parameters to screen breeding selections for consumer preference

1. ABSTRACT

Fruit breeding is a time-consuming and expensive process that requires a clear understanding of how fruit quality parameters relate with consumer preference. During this investigation, visual and sensory attributes of apple breeding families were evaluated by means of instrumental measurements, individual assessment, a panel trained in descriptive sensory analysis (DSA) and consumer preference analysis. Instrumental measurements included puncture tests, TA (titratable acidity), TSS (total soluble solids) concentration and chromameter measurements. An individual assessor evaluated eating quality and appearance attributes of apple parental genotypes and seedlings from breeding families, as well as a control sample, using a 100 mm unstructured line scale. DSA was performed using similar line scales. Consumer preference was analysed by using the nine-point hedonic scale. Principal component analysis (PCA) was performed to project sensory attributes and instrumental measurements onto consumers' preference dimensions. The aims of this research were to determine the extent to which sensory analysis of fruit quality parameters by a trained panel and an individual assessor could be predicted by instrumental measurements, and also if these measurements were good predictors of consumers' preference for apple eating quality and appearance. We could not accurately conclude on the validity of individual and instrumental assessments as predictors of sensory quality parameters analysed by a trained panel or consumer preference, due to practical limitations relating to the use of breeding selections. Instrumental measurements in the current study could not predict the sensory attributes that they characterised, as analysed by the individual assessor. TSS/TA, but not TSS that is often used, might be a valuable measurement in predicting the sensory perception of sweetness. Sweet taste, sensory texture attributes and apple flavour as quantified by DSA and instrumental measurement of TA and TSS/TA should be used to analyse breeding families due to the ability of these parameters to predict consumers' responses. The individual assessor could not accurately predict the preference of the total consumer group. Visual assessment of colour attributes provided a better prediction of consumers' preference for peel colour compared to instrumental colour measurements and can be assessed by an expert breeder.

Keywords Consumer preference testing, descriptive sensory analysis, *Malus* x *domestica* (Borkh.), fruit breeding, principal component analysis.

2. INTRODUCTION

Most major apple production regions in the world fund breeding programmes aimed at developing new, novel cultivars that will increase the market share and economic well-being of the region. The increasing number of countries that support free trade and the consequent globalisation of the apple market (Harker *et al.*, 2003, O'Rourke, 2011) have challenged apple breeders to develop apples from their breeding programmes that will retain their quality from harvest to handling and transportation to meet consumer demands at international destinations. Fruit breeding is a time-consuming and expensive process due to the long generation interval and the high heterogeneity within progenies (Liebhard *et al.*, 2003). Clear identification of the breeding goals is therefore essential in a breeding programme (Hjeltnes, 1994). One of the most important breeding goals for the South African Agricultural Research Council's (ARC) apple (*Malus* x *domestica* (Borkh.)) breeding programme is to produce fruit of high internal and external quality that appeal to local and international consumers (Labuschagné *et al*., 2000).

There are limited universally agreed methodologies for the evaluation and identification of genotypes with a high probability of commercial success and for the selection of superior parents for new generations. It is necessary to find reliable and rapid methods to quantify and report fruit quality attributes and to understand their relation to consumer preference in all phases of apple breeding (Hjeltnes, 1994). Breeding and evaluation of apple cultivars in the ARC breeding programme can be divided into 4 phases: 1) During the first phase, visual and sensory evaluation of approximately 5000-10000 seedlings are conducted in the field each year by an individual breeder in order to select the 30-50 most promising genotypes; 2) During the second phase, these selections are again subjected to instrumental, visual and sensory evaluation by the individual breeder, including pre- and post-storage assessments; 3) During the third phase, these selections are given a semi-commercial status and are properly evaluated by postharvest specialists before and after cold storage where fruit are collected from regions with varying climatic conditions; 4) After evaluations in the third phase, exceptional cultivars reach the commercial phase. Breeders should be confident that consumers would have a high preference for a new cultivar before it can be introduced on the market.

Protocols for instrumental and physiological assessment of apple fruit quality are well established in literature and have become one of the cornerstones of fruit quality assessment (Oraguzie *et al.*, 2009; Brookfield *et al.*, 2011). Quality standards set by the industry are often based on texture measurements using a penetrometer (Harker *et al.*, 2002a), while total soluble solids (TSS) and titratable acidity (TA) are used as measurements of sweetness and acidity, respectively (Harker *et al.*, 2002b). The relevance of these instrumental measurements will, however, not only depend on the extent to which they are able to predict sensory attributes (Oraguzie *et al.*, 2009), but also how they relate to consumers' preference for apple eating quality.

The development of sensory analysis techniques has greatly influenced the approach of fruit analysis in recent years (Lawless & Heymann, 2010). The concept of descriptive sensory analysis (DSA), in which a panel is trained to evaluate selected food against a set of defined attributes using quantitative scales, has particularly changed protocols for fruit evaluation (Oraguzie *et al.*, 2009). DSA has been used to help quantify the attributes relating to the overall eating quality of apples (Daillant-Spinnler *et al*., 1996; Andani *et al*., 2001; Kühn & Thybo, 2001; Carbonell *et al*., 2008; Oraguzie *et al*., 2009; Brookfield *et al*., 2011). DSA studies on apples are usually relatively small and conducted on a maximum of 12 established cultivars over a period of a few days. The number of seedlings that need to be analysed in a breeding population usually far exceeds 12 treatments (Oraguzie *et al*., 2009). Therefore, only a limited number of apple breeding programmes have used DSA by trained panels on breeding families (Hampson *et al*., 2000; King *et al*., 2000; Oraguzie *et al*., 2009). Hampson *et al.* (2000) used 12 in-house panellists and King *et al.* (2000) an 11-member trained panel (where each genotype was tasted once by each assessor) to conduct DSA as part of the evaluation of apples from a Canadian and Dutch breeding programme, respectively. Due to practical limitations, most apple breeding programmes rely on single or a small number (2-4) of experienced assessors, or experts, for the sensory assessment of seedling quality attributes for selection purposes (Oraguzie *et al*., 2009). These "expert tasters", usually breeders, are well-experienced and familiar with the sensory attributes of apple fruit, usually as a result of exposure over a long period of time (Gawel, 1997).

Consumer preference analysis is usually conducted by consumer panels that consist of approximately 100 – 150 consumers, which restricts the use of these panels early in the breeding process (Hampson *et al*., 2000). Postharvest biologists are often reliant on a single "expert taster" or breeder (Brookfield *et al*., 2011) to predict consumers' preference and thereby identify the most promising seedlings amongst the many generated by controlled crossings (Harker *et al*., 2003). Furthermore, limited information is available from the literature on the accuracy with which these "expert tasters" can predict the preferences of large consumer groups.

Knowledge of the relationship between instrumental measures, DSA, expert assessment and consumer acceptance would help the industry to identify the most efficient parameters to measure fruit quality. These relationships have been studied by using multivariate statistical analysis and were proven useful in directing fresh fruit cultivar development (Jaeger *et al*., 2003). However, analysis methods usually lack the use of instrumental measures of fruit quality as an additional source of data in preference mapping. Due to the importance of these measurements in horticultural product development, the inclusion of such measures in multivariate statistical analysis is one way of incorporating information that is immediately meaningful and highly relevant to horticultural scientists.

The ultimate goal of this research is to develop ways to increase the efficiency of breeding in the ARC apple breeding programme. In view of this, the questions that we aimed to address in this study were:

1) To what extent can instrumental measurements be used to predict sensory attributes assessed by an individual assessor or by a panel trained in DSA?
2) To what extent can instrumental measurement, DSA or individual assessment of fruit quality attributes predict consumer preference?
Since instrumental assessment can be automated, is objective and is cheaper, this would be the preferred means to assess a large number of selections. Currently, fruit quality attributes are assessed by an individual, expert breeder and we want to establish to what extent the expert breeder can predict the preference of a large consumer group.

3. MATERIALS AND METHODS

3.1 Plant material

Seedlings were planted in a seedling evaluation orchard at the ARC Drostersnes experimental farm in the Vyeboom area, Western Cape Province of South Africa (latitude 34°4'S; longitude 19°4' E). Breeding families used in this study were identified from controlled crosses performed for the purpose of selecting individual seedlings with good fruit characteristics with no attention to any specific mating design. The progenies (in this study the term "family" is used) were derived from four sets of crosses, viz.: 'Anna' (F1P1) and 'Scarlet Gala' (F1P2) to deliver family 1 (F1); 'Prima' (F2P1) and 2B-19-22 (F2P2) to deliver family 2 (F2); 'Treco Red' (F3P1) and 'Golden Delicious' (F3P2) to deliver family 3 (F3); 8F-8-6 (F4P1) and 'Cripps' Pink' (F4P2) to deliver family 4 (F4). F1 and F2 were harvested early in the season, while F3 and F4 were harvested later in the season.

Approximately 150 sibling seedlings within each family were planted adjacently in progeny rows in four randomised blocks. The parents used in the crosses were planted within their family rows. In the case where these trees did not bear sufficient fruit, parental fruit were harvested from adjacent blocks on the same farm or from another experimental farm in the area. 'Royal Gala' (RG) fruit were harvested from multiple trees on these sites and used as a control sample. Orchard management was typical of commercial practice.

3.2 Harvest

The fruit were harvested when maturity (based on appearance, texture and flavour) was judged to be optimal and at a stage where the fruit were eat-ripe (70% to 90% starch breakdown). This was done by weekly testing and harvesting during the January to May 2008, 2009 and 2010 harvest seasons (Fig. 1). Only trees that were fruiting and had nine or more fruit were selected for this part of the study. Consumer and sensory analyses were conducted on two assessment dates for each of the three harvesting seasons, i.e. firstly after all the fruit from the early families were harvested (March), and secondly when all the fruit from the late families were harvested (May).

3.3 Experimental design

Sensory attributes of all 150 seedling trees as quantified by the individual assessor were projected onto a principal component analysis (PCA) plot in 2008. A sub-selection of thirty-two seedlings was selected for trained panel analysis from each of the four families to represent the largest genotypic variation within each family on the PCA plot. Although it was attempted to use the same sub-selection of thirty-two seedling trees within each family for the three consecutive harvest seasons, all the seedlings trees selected in 2008 did not bear a sufficient number of fruit in the 2009 and 2010 harvest seasons. In this case, a replacement was made from the remaining seedling trees to represent the trees that bore insufficient fruit.

Nine fruit were harvested from each of these thirty-two seedling trees of each of the four breeding families. Fruit were also harvested from approximately sixteen trees of each parent and the RG control. The nine fruit were used as depicted in Fig. 1: Three fruit were used for individual assessment and instrumental analyses; one fruit was used for sensory analysis by a trained panel; four fruit were used for testing consumers' preference for eating quality and one representative fruit was photographed for testing consumers' preference for appearance. The late families of 2010 were kept in cold storage (–0.5 ºC) at the fruit analysis laboratory of the Department of Horticultural Science, Stellenbosch University, South Africa where it was analysed one day after all parental genotypes and seedlings were harvested and removed from storage. Individual assessment, maturity indexing and TSS of all other fruit (2008 harvest, 2009 harvest and F1 and F2 in 2010) were performed at room temperature (21 ºC) one day after harvest at the fruit analysis laboratory of the ARC experimental farm, Bien Donne, South Africa. TA measurements were conducted at a later stage. All other fruit were kept in cold storage (–0.5 ºC) at ARC Bien Donne for up to eight weeks until DSA and consumer testing commenced.

3.4 Quantification of the phenotypic variation in fruit quality parameters

3.4.1 Instrumental measurements

Instrumental analyses were conducted on a composite representative sample of three fruit from each of the thirty-two seedling trees, sixteen parent trees and RG control trees. Measurements were averaged across each sample of three fruit and used for further statistical analyses.

Fruit firmness (N) was determined as the maximum force required to push an 11 mm diameter probe with a convex tip into the flesh using a motorised penetrometer after peeling two equatorial sites (Guss Instruments, Stellenbosch, South Africa). The remaining flesh and peel of the three fruit were juiced together and analysed for TSS with a digital refractometer (Atago, Tokyo, Japan). The remaining juice was kept frozen until titration with 0.1 M NaOH (719S Titrino autotitrator, Metrohm 50, Herisau, Switzerland) up to pH 8.1. Results were expressed in gram-equivalents of malic acid per litre of juice, i.e. TA. The TA/TSS ratio was calculated for all samples.

External fruit colour was measured with a chromameter (NR-3000; Nippon Denshoku, Tokyo, Japan), where lightness (L), chroma (C) and hue angle (H) were recorded. These measurements were taken on the background colour, as well as on the overcolour of the fruit. In the case of blushed, full red, full yellow and green apples, overcolour refers to the blushed, reddest, most yellow and greenest side of the fruit, respectively. Normal standardisation protocols were followed on a white tile (L^* =92.30, a^* =0.32 and b^* = 0.33). Sixteen replications were performed on each parent and the RG control.

3.4.2 Individual assessment

A set of sensory assessments was carried out by an individual, which will henceforth be referred to as "individual assessment" by the "individual assessor". The assessor was trained in sensory analysis practices at the sensory research laboratory, Department of Food Science, Stellenbosch University and was also given a training course by an expert breeder specifically on the sensory assessment of apples and the evaluation methods typically used for the assessment of a breeding programme. A 100 mm unstructured line scale was used for attribute intensity analysis, of which the left hand side corresponded to the lowest intensity and the right hand side to the highest intensity. Several visual, taste, flavour and textural attributes were analysed by the individual assessor (*ind*), including brightness, overall lightness, coloured area, stripeness, sweet taste, sour taste, overall apple flavour, juiciness and hardness (Table 1). A composite sample of three fruit from each seedling tree, as well as 16 replicates of parent trees and RG control, were analysed together where after average scores were calculated. In 2010, preference for eating quality and appearance was also analysed by the individual assessor by using the standard nine-point hedonic scale that is typically used for consumer preference analysis (Lawless & Heymann, 2010).

3.4.3 Descriptive sensory analysis

Taste, flavour and textural sensory profiling were carried out during March and May 2008, 2009 and 2010 in the sensory research laboratory of the Department of Food Science, Stellenbosch University. Training was conducted using the consensus method and analyses were performed according to “Generic Descriptive Analysis”, as described by Lawless and Heymann (2010). The panel consisted of eight female judges and was tested for consistency. Samples were chosen to represent the sensory variation in the seedlings to train and calibrate the panel for the analysis of sensory attributes. Unstructured line scales that were used for attribute intensity analysis were similar to the scales used for individual assessment. The trained panel (*tp*) came to a consensus on the list of attributes for describing apple flavour and texture, viz. sour taste, sweet taste, overall apple flavour, astringency, crispness, hardness, crunchiness, juiciness, astringency and mealiness. The definitions used for the sensory attributes were similar to those used in Chapter 3.

After completion of the training, thirty-two seedlings of each of the families and eight replications of all parents and RG were analysed during eight sessions. Apples were cut into eight slices from stem end to calyx end in order to ensure that the entire panel analysed the exact same fruit during each replication. Each sample set that was presented per replication included a slice of the RG control, four parental genotypes and eight seedlings. The position of the control sample was indicated for the panel to use it as a reference to score the other samples against, since the eating quality of RG was expected to be consistent throughout the analyses. Panellists received cut, unpeeled sample slices presented on Petri dishes (Kimix, South Africa) and were instructed to peel the samples prior to analysis. Samples were coded with three-digit random codes and served in a complete randomised order, balanced to minimise order and carry-over effects. Data were collected manually via paper questionnaires in 2008 and 2009 and electronically in 2010 using Compusense® Five data collection software (Version 4.2, Compusense Inc., Guelph, Ontario, Canada). Distilled water and water biscuits (Woolworths, South Africa) were provided as a palate cleanser between samples. Profiling was conducted in tasting booths with standardised artificial daylight lighting and temperature control (21 ºC).

3.5 Consumer analysis

One-hundred and twenty-eight consumers were recruited for each of the analyses conducted during March and May 2008, 2009 and 2010. Consumer preference analyses were conducted as central location tests in the sensory research laboratory of the Department of Food Science, Stellenbosch University. Consumers were selected on the basis that they regularly consume apples. Their gender, age and frequency of apple consumption were recorded as socio-demographical data. The experimental design of the samples used for consumer preference analysis was similar to the design used for DSA, i.e. consumers received sample sets of thirteen samples, consisting of eight seedlings, four parents and the RG control. The 128 consumers were divided into eight groups so that every sixteen consumers received the same eight genotype samples. The samples were served in a complete randomised order and coded with three-digit random codes, balanced for order and carry-over effects. A sample consisted of a quarter of an unpeeled apple, presented on a Petri dish on a white tray in a room with standardised artificial daylight lighting and temperature control (21 ºC).

Consumers were instructed to peel the samples prior to analysis only if they usually consume peeled apples. Therefore, the majority of the consumers analysed the peel and the flesh, while a few consumers analysed only the flesh. Using paper ballots, consumers were instructed to indicate their preference for the total eating quality of the samples, including texture, taste and flavour, using the nine-point hedonic scale. In this test, consumers were asked to indicate which term best describe their attitude towards the products being tasted by rating each sample for degree of liking from “dislike extremely” (1) to “like extremely” (9), as described by Lawless and Heymann (2010). Consumers were requested to drink water between samples. After analysis of eating quality preference, consumers were presented with thirteen photographs (eight seedlings, four parents and a RG control) and instructed to indicate their degree of liking on the nine-point hedonic scale for the overall appearance of the samples. Similar experimental designs were used for analysis of preference for eating quality and appearance. Parental genotypes presented in this part of the study are shown in Table 2.

3.6 Statistical procedures

All thirty-two genotypes from each of the four breeding families were subjected to individual and instrumental assessment, DSA and consumer preference analyses. For the DSA and consumer analysis, a randomised complete block design was used where each judge received twelve samples (eight seedlings and four parents) and the RG control. The instrumental, DSA and individual assessment data sets were all subjected to analysis of variance (ANOVA) using SAS statistical software (SAS, Version 9, 1999, Cary, North Carolina, USA). The Shapiro-Wilk test was used to test for non-normality of the residuals (Shapiro & Wilk, 1965). If non-normality was significant ($P \leq 0.05$) and caused by skewness, outliers were identified and removed until the residuals were symmetrically distributed (Glass *et al.*, 1972). DSA data for each attribute were subjected to a two factor ANOVA using families and panellists as main effects. Panellist*family interactions were not significant for the sensory attributes, indicating that the mean scores gave a reliable estimate of the samples’ sensory attributes and therefore family attributes were averaged across panellists and replicates. Instrumental data for firmness, TSS, TA and TSS/TA were subjected to one-way ANOVA, with family as main effect. These measurements discriminated significantly between the four breeding families ($P \leq 0.05$). The final ANOVA was performed after the above-mentioned procedures have taken place. Student’s *t*-least significant difference (LSD) was calculated at the 5% significance level to compare family means within years.

Multivariate statistical techniques were performed using the XLSTAT software package (Addinsoft, XLSTAT Software, Version 2007, Paris, France). PCA was performed in order to study the instrumental and DSA data structure and the association between these measurements and consumer preference (Kühn & Thybo, 2001). Mean consumer preference scores for each seedling, together with the sensory and instrumental means, and the corresponding number of observations, were taken as input to a PCA using the correlation matrix. Pearson's correlation coefficients were calculated with XLSTAT software (Addinsoft, Version 2007, Paris, France) to measure the linear relationship between sensory attributes (DSA and individual assessment) and instrumental measurements, and also between consumers' preference and instrumental measurements and sensory attributes (DSA and individual assessment) (Næs *et al.*, 2010). In order to account for different storage times of F3 and F4 in 2010, separate correlation coefficients were calculated for early and late families for every year. Scatterplots were calculated with XLSTAT software.

4. RESULTS

For the sake of readability and brevity, only the most important and relevant results will be reported here.

4.1 Quantification of the phenotypic variation in fruit quality parameters

4.1.1 Individual assessment versus instrumental measurements

Correlations between individually assessed and instrumentally measured fruit quality attributes were mostly poor ($r<0.50$) (Table 3). Instrumental-sensory correlations varied between early (F1 and F2) and late (F3 and F4) families in different years, mostly shown by the different textural correlations for F1 and F2 in 2008 (Table 3). Individually assessed texture and juiciness showed similarly poor correlations with puncture measurements, ranging from $r=-0.04$ ($P=0.7831$) to $r=0.65$ ($P<0.0001$). The group of genotypes with higher firmness measurements were not always perceived as crispier by the individual assessor (Fig. 2a). Sensory-instrumental correlations were strongest between TA and sour taste (ranging from $r=0.40$ to 0.70; $P\leq0.001$) (Table 3). Poor correlations were shown for TSS and sweet taste (ranging from $r=-0.06$; $P=0.6656$ to 0.34; $P=0.0092$). The individual assessor could not discriminate between the sweetness of a group of genotypes with high and low TSS (Fig. 2b). Poor correlations between sweet and sour taste showed that the individual assessor did not generally integrate the perception of these tastes. TSS/TA correlated poorly with sweet taste (Table 3).

4.1.2 Trained panel assessment versus instrumental measurements

Instrumental measurements generally correlated better with attributes analysed by the trained panel compared to the individual assessor, although instrumental-sensory correlations were seldom stronger than r=0.70 (Table 3). Correlations between puncture measurements and crispness, hardness and crunchiness were similar (ranging from r=0.07; P=0.6111 to r=0.67; P<0.0001) and stronger than with juiciness. The group of genotypes with higher firmness measurements were not always perceived as harder by the trained panel (Fig. 2c). Sensory-instrumental correlations were strongest between TA and sour taste (ranging from r=0.41 to 0.79; P<0.05). Poor correlations were shown for TSS and sweet taste (ranging from r=0.16; P=0.2641 to 0.41; P=0.0033). The trained panel (Fig. 2d) could not discriminate between the sweetness of a group of genotypes with high and low TSS. TSS/TA was a better predictor of sweet taste and correlations as high as r=0.71 (P<0.0001) were shown for TSS/TA and sweetness (Table 3). TSS/TA correlated poorly with apple flavour (P>0.05) (not shown). The inverse relationship between sweet and sour tastes was more pronounced in trained panel compared to individual analysis, with correlations as high as r=–0.88 (P<0.0001).

Mean scale values for crispness, hardness and crunchiness showed similar intensity patterns for all samples in all three years, i.e. samples that were rated high for crispness, also received high hardness and crunchiness scores (Table 4). F1P2 and F4P2 were crispy, hard and crunchy (>50) (Table 4), while F1, F3 and F4P2 showed high firmness (Table 5). F2P2 mostly had a significantly lower crispness, hardness, crunchiness and firmness than the other samples (Tables 4 & 5). The ranking order of the seedlings and parents for juiciness differed slightly from crispness, hardness and crunchiness. F1P2, F4P2 and RG were juicy (>50), while F2P2 was generally less juicy and mealier than all other genotypes (Table 4). F1P1, F2 and F4P1 were mostly slightly mealy (>10), while all other genotypes were not considerably mealy (Table 4).

F2 and F2P1 showed high levels of TA and sour taste (Tables 5 & 6). F1P2 and F2P2 generally had a low sour taste, and together with RG had low TA values. F4P2 was highly sour in 2009 and 2010, but showed low TA levels and sour taste in 2008 (Tables 5 & 6). High TSS concentration and sweet taste were reported for F3, while F4P2 showed low values. F4 had a high TSS, and F3P1, RG, F1P2 and F3P2 had a high sweet taste, while low TSS was reported for RG, F4P1 and F1P2. Low sweet taste was shown for F2, F2P1 and F1P1. RG, F1P2, F2P2, F3 and F4P1 generally showed high and F2 low TSS/TA ratios (Table 5). RG had a high apple flavour. F1 and F2 seedlings and F1P1 had a low apple flavour on average (Table 6). None of the parents or family means scored high for astringency in any of the years (<10), but F2P1 and F2 were slightly more astringent than the other samples (Table 6).

4.2 Consumer socio-demographic data

The breakdown of the socio-demographic composition of the total consumer group (n=128) for the three years is reported in Table 7, illustrating that approximately 85% of the respondents consume apples once a week, or more, and that consumers were mostly female and younger than 30.

4.3 Drivers of consumer liking

4.3.1 Instrumental measurements

4.3.1.1 Appearance

As evident from mean lightness and hue angles, parental genotypes and seedlings of F1 and F2 were generally redder and darker in colour than fruit of F3 and F4 (Table 8). F3P1 was striped red and F3P2 yellow-green. F4P1 and F4P2 had a blushed appearance, of which the blushed side of F4P1 was darker and redder compared to F4P2 that had a greener, more colourful background colour (Table 8). The most and least coloured sides of F2 apples generally had a low colourfulness. Larger differences between the most and least coloured sides of fruit seen in the late harvesting families indicate a higher incidence of blushed fruit, while F1 and F2 showed more uniformly coloured fruit.

PCA conducted on instrumentally measured and individually assessed colour attributes showed that the first (PC1) and second principal components (PC2) explained 50.6% and 15.0% of the total variability in the appearance data, respectively (Fig. 3a). Hue angles and lightness of the most coloured side of the fruit explained a large part of the variability on PC1. Chroma of the most coloured side distinguished between consumer preferences on PC2. The position of genotypes in all four quadrants showed the appearance diversity among the genotypes used in the analysis (Fig. 3b). Consumers generally preferred redder, brighter and darker fruit (Fig. 3a). The hue angles, chroma measurements and lightness of the most ($r=-0.33$; $P\leq0.0001$, $r=0.02$; $P>0.05$ and $r=-0.29$; $P\leq0.0001$, respectively) and least ($r=-0.23$; $P\leq0.0001$, $r=-0.21$; $P=0.0001$ and $r=-0.15$; $P=0.0067$, respectively) coloured sides of the fruit correlated poorly with consumer preference.

4.3.1.2 Eating quality

PCA conducted on instrumentally measured and DSA of eating quality attributes showed that PC1 and PC2 accounted for 36.6% and 21.2% of the total variability in the eating quality data, respectively (Fig. 4a). Sensory attributes explained the largest part of the variation on PC1, but TA and TSS/TA distinguished between the samples on PC2 (Fig. 4a). TSS and firmness contributed to variability on the third principal component (results not shown). The wide distribution of the samples on the scores plot (Fig. 4b) illustrates the textural and taste diversity of the genotypes used in the analyses, although there was a tendency among seedlings from the same family to group together.

None of the instrumental measurements correlated strongly with consumer preference (r<0.50 mostly) (Table 9). TSS could not predict consumers' preference (P>0.05). Two groups of genotypes with different TSS levels were shown to be equally preferred by consumers, viz. one around 5 ºBrix and one around 15 ºBrix (Fig. 5). Although all measures of acidity were poor predictors of consumer preference, correlations with TA were mostly stronger than with *tp* and *ind* sour taste.

4.3.2 Individual assessment

4.3.2.1 Appearance

Sensory assessment of appearance attributes were generally better predictors of consumers' preference compared to instrumentally measured attributes (Fig. 3a). The percentage of coloured area (r=0.38; P≤0.0001) and overall lightness (r=−0.32; P≤0.0001) explained a large part of the variability on PC1 (Fig. 3), although they were not accurate predictors of consumers' preference for appearance. Brightness of the most (r=0.33; P≤0.0001) and least (r=0.23; P≤0.0001) coloured part of the fruit distinguished between consumer preference on PC2 and were also poor predictors of preference. Consumers preferred fruit with a higher incidence of stripes (r=0.25; P≤0.0001). The preference of the individual assessor showed an intermediate correlation with the preference of the total consumer group (r=0.37; P<00001).

4.3.2.2 Eating quality

Sensory attributes assessed by the individual assessor were mostly poor (r<0.30) predictors of consumer preference (Table 9). Juiciness and texture showed low but significant (P>0.05) correlations with consumer preference for F1 and F2 in 2008 and 2009, and also for juiciness of F3 and F4 in 2008. Correlations between consumer preference, and sweetness and apple flavour were mostly not significant (P>0.05), while sour taste was a slightly better predictor of consumer preference. The individual assessor was therefore a relatively poor predictor of the eating quality preference of this consumer group (r=0.26; P=0.0032).

4.3.3 Trained panel assessment

Despite similar protocols applied for trained panel and consumer preference analysis in all three years, different correlations were reported for the different families between the three years. Attributes generally showed weaker correlations with consumer preference in 2010 compared to 2008 and 2009. The position of crispness, crunchiness, juiciness and hardness on the opposite side of mealiness on PC1 in Figure 4a illustrates the variability explained by sensory textural attributes on the first principal component. Sour taste, astringency and sweetness distinguished between the samples on PC2 (Fig. 4a). Consumers' preference for eating quality (CPEat) associated with juiciness, crispness, hardness, crunchiness, sweet taste and apple flavour (Fig. 4a), although none of these measurements correlated strongly with consumer preference ($r<0.50$ mostly) (Table 9). Crispness, hardness and crunchiness were intermediate predictors of consumer preference, but juiciness was a slightly better predictor and correlations as high as $r=0.66$ ($P<0.0001$) with consumer preference were reported (Table 9). Sensory textural attributes assessed by the trained panel were mostly better predictors of consumer preference than individually or instrumentally ($P<0.05$) assessed attributes (Table 9). Mealiness was the strongest negative driver of consumer liking, although it was not a significant driver in 2010. Sweetness mostly showed significant but low correlations ($P<0.05$). Sour taste was a poor predictor of consumer preference (mostly $r<0.30$). Apple flavour correlated significantly with consumer preference in 2008 and 2009 (except for F3 and F4 in 2009) (Table 9). Astringency was a low, but significant negative driver of consumer liking (not shown).

5. DISCUSSION

5.1 Sensory versus instrumental quantification of the phenotypic variation in fruit quality parameters

Instrumental-sensory correlations in the current study were mostly poorer compared to results reported in literature (Płocharski & Konopacka 1999; Harker *et al.*, 2002a, b; Oraguzie *et al.*, 2009; Brookfield *et al.*, 2011), probably due to several challenges in the current study and discrepancies with methods applied in previous studies that will be discussed later.

Penetrometer measurements are the best predictors of sensory textural attributes such as firmness, crunchiness and crispness (Harker *et al.*, 2002a), which showed intermediate (ranging from $r=0.07$; $P=0.6111$ to $r=0.61$; $P<0.0001$ for crispness) correlations with puncture measurements in the current study. Possible softening of fruit texture during storage (Harker *et al.*, 1997a) should be considered when comparing instrumental measurements and DSA that were subjected to temporal differences (Fig. 1). Correlations that differed notably between consecutive harvest seasons with penetrometer measurements were reported by Harker *et al.* (2002a) for crispness (ranging from 0.70-0.90) and by Płocharski and Konopacka (1999) for firmness (ranging from 0.55-0.83). Stronger correlations were reported for puncture measurements with crispness (0.70) (Brookfield *et al.*, 2011) and firmness (ranging from 0.65-0.81) conducted by a small expert panel (Oraguzie *et al.* 2009) and for crunchiness (0.81) conducted by a large trained panel (Mehinagic *et al.*, 2004). Instrumental measurements are less sensitive than sensory analysis when soft fruit are analysed (Harker *et al.*, 1997b), but are better able to discriminate between the textures of very firm fruit (Płocharski & Konopacka, 1999). In our study, very poor instrumental-sensory correlations for F1 and F2 in 2008 resulted from highly firm genotypes with average hardness (Tables 4 & 5, Fig. 2a, c) that were harvested too early and may be attributed to the threshold plateau where sensory responses are saturated and panellists are less able to discriminate between different firmness levels (Harker *et al.*, 1997b). Mealiness that developed in F2 during storage in 2008 (Table 4) further contributed to poor instrumental-sensory correlations. Trained panellists were also not as experienced in the sensory analysis of apple texture in 2008, considering that it was the first season of analysis.

Penetrometer measurement is a weaker predictor of juiciness (Harker *et al.*, 2002a). The correlations between juiciness and firmness in the current study (ranging from r=0.01; P=0.9383 for *tp* juiciness to r=0.55; P<0.0001 for *ind* juiciness) were lower than that obtained by Mehinagic *et al.* (2004) (0.81) and Brookfield *et al.* (2011) (0.59). Juiciness is a function of the diameter and the way cells break open during mastication and although it is influenced by the mechanical properties of cell tissue, it is not only a product of the firmness of the fruit flesh (Harker *et al.*, 1997b). Partially hydrolysed starch in unripe fruit binds free water, which results in the perception of a dry mouthfeel (Harker *et al.*, 2002a) that possibly resulted in firmer fruit that were not generally juicier.

TA is the best predictor of acid taste (Harker *et al.*, 2002b) and correlations in the current study (ranging from r=0.41-0.79; P<0.05 for *tp* and *ind* sour taste) (Table 7) were mostly slightly lower than values reported by Harker *et al.* (2002b) (0.86) and Oraguzie *et al.* (2009) (ranging from 0.71-0.83 for four expert tasters). Sweet taste is difficult to predict using instrumental measurements, and although °Brix is the best objective predictor (Harker *et al.*, 2002b), the relationship between these measures is imperfect (Oraguzie *et al.*, 2009). Harker *et al.* (2002b) reported a correlation of 0.41 between sweetness and TSS for the median panellist and Oraguzie *et al.* (2009) found correlations that ranged from 0.22 to 0.47 for four expert tasters, while correlation values in the current study ranged from r=–0.06 (P=0.6656) for *ind* sweetness to r=0.41 (P=0.0033) for *tp* sweetness. The poor correlation between TSS and sweet taste could be ascribed to the influence of acid level on sweet taste that is under- or overestimated in the presence of a high and low sour taste, respectively (Visser *et al.*, 1968). This binary taste-taste interaction was also reported by Poinot *et al.* (2011) and Seppä *et al.* (2012). This interaction could have resulted in our study from a group of seedlings with low TSS (<10 ºBrix) that tasted sweeter (>50) than seedlings with higher TSS due to their low TA values (Fig. 2b, d). These results suggest that panellists perceived sweetness as a lack of acidity, and *vice versa*. The individual assessor, who used more extreme sides of the intensity scale, was better able to discriminate between sweetness and acidity and showed weaker inverse correlations between these tastes. Fruit maturity may affect perception of sweetness (Harker *et al.*, 2002b). High starch content in immature fruit could decrease the perception of sweetness, but is not represented in TSS measurements and could contribute to poor correlations between TSS and sweetness. An additional reason for this poor correlation is the quantitative dominance of fructose with its high relative sweetness in the sugar profile of apples that results in higher perceived sweetness than instrumentally measured TSS.

TSS/TA was better able to predict the perception of sweetness by the trained panel in the current study, as well as in the study of Oraguzie *et al.* (2009), because it accounts for the effect of acidity on sweet taste perception. However, TSS/TA could not predict sensory perception of apple flavour, which is a complex attribute that does not only represent sugar and acid concentrations, but also a vast number of flavour volatiles (Rowan *et al.*, 2009).

5.1.1 Individual assessment as predictor of quality

The methodologies applied in the current study for individual and instrumental analysis that were conducted at the same time on the same fruit clearly showed that instrumental measurements were not good predictors of the sensory attributes analysed by the individual assessor. Instrumental-sensory relationships for individual assessment of three fruit (that conformed to the protocol for quality analysis of the ARC apple breeding programme) were generally lower than for attributes analysed by the trained panel. The risk of sensory fatigue, a concept that is well recognised in the literature on DSA, is higher when multiple samples are assessed (Oraguzie *et al.*, 2009), as was the case with the individual analysis of all the seedlings from the breeding families. Note that although approximately 150 seedlings from each of the four breeding families were assessed by the individual assessor, only those results of the subset of thirty-two seedlings are reported in this part of the study. If the individual assessor only analysed the sample of thirty-two seedlings that were used in this part of the study, stronger instrumental-sensory correlations could possibly have resulted due to lower sensory fatigue and consequent higher discrimination ability. It is important to limit the sample size in future studies where a single assessor evaluates breeding selections. Assessment of only a small part of either the shaded or light-exposed side of the fruit by the individual assessor could have partly contributed to poor instrumental-sensory correlations. Furthermore, instrumental measurements were conducted on whole fruits, while individual assessments were conducted on a small section of each fruit for a composite three-fruit sample (although this area-specific effect could party be reduced by tasting of three samples). It has been shown that quality parameters differ within apple, i.e., the non-blush (shaded) side of apples are crispier and less sweet than the blush (light-exposed) side and the bottom section has lower TA than the top section (Dever *et al.*, 1995).

5.1.2 Trained panel assessment as predictor of quality

In our study, practical limitations pertaining to weekly harvesting of large numbers of seedling trees resulted in temporal storage differences between harvest, instrumental analysis and DSA, limiting the accuracy with which we can conclude on whether instrumental measurements are good predictors of sensory attributes analysed by the trained panel. The high number of fruit that had to be analysed instrumentally and individually (as discussed above) complicated matters and prevented us from performing instrumental and sensory measurements on the same day, as was performed by Płocharski and Konopacka (1999), Harker *et al.* (2002a), Oraguzie *et al.* (2009) and Brookfield *et al.* (2011). Fruit from the early families were stored until all seedling trees of these families were harvested in order to allow once-off DSA tests for these families in March. Similarly, fruit from the later families had to be stored until DSA tests in May each year. This method of weekly harvesting caused some genotypes to be stored for up to eight weeks, while genotypes that were harvested a week prior to analyses were subjected to shorter storage periods. The approach of an eight week storage period for analyses of commercial breeding lines to identify superior individuals for more advance testing and release (Brookfield *et al.*, 2011) was not practically viable in the current study. Instrumental measurements and individual assessment in the current study were therefore conducted before storage and DSA thereafter in 2008 and 2009, as well as F1 and F2 fruit in 2010. Due to changes in quality parameters that could occur during storage (Harker *et al.*, 1997a), we aimed to reduce this effect of different storage time on quality parameters by storing all F3 and F4 fruit after harvest in 2010 before individual, instrumental, DSA and consumer preference analyses commenced. This method caused challenges relating to fatigue of the individual assessor, who then had to assess up to 900 seedlings in a period of four days. However, correlations between instrumental and sensory measurements were not necessarily higher/different for F3 and F4 compared to F1 and F2 in 2010, suggesting that temporal storage differences had a limited effect on instrumental-sensory relationships. Although these differences in sensory-instrumental relationships between the early and late families for 2010 were not more pronounced than for other years, temporal storage differences should be taken into consideration during the interpretation of the results. Instrumental-sensory correlations that varied between different genotypes and seasons in the current study were also reported previously (Płocharski & Konopacka 1999; Harker *et al.*, 2002b, 2006; Brookfield *et al.*, 2011) and could have contributed to lower correlations reported in the current study compared to those in literature. In order to reduce the effect of temporal storage differences, DSA could be conducted with instrumental measurements on a weekly basis if more funds are available, considering that trained panel analysis is an expensive evaluation technique.

Furthermore, practical limitations relating to the often small size of the seedling fruit made instrumental measurements and DSA on the same fruit unfeasible. Płocharski and Konopacka (1999) used different fruit for instrumental and sensory measurements. Brookfield *et al.* (2011) conducted all analyses on the same side of the same fruit, while Harker *et al.* (2002a) and

Oraguzie *et al.* (2009) analysed different sides of the same fruit. The low instrumental-sensory correlations obtained in our study could be attributed to the large variability between the samples in the breeding populations (Harker *et al*., 2006; Oraguzie *et al*., 2009). Another limitation pertaining to seedling trees is the small number of fruit that is often available from these trees. Consequently, the trained panel analysed only one fruit per seedling tree, which could have been unrepresentative of the potential variability among fruit from a seedling tree. When trained panel and instrumental analysis are conducted on fruit from cultivar trees that bear more fruit, trained panel analysis on more fruit per tree should be considered. Although DSA was conducted on only one fruit per seedling tree (limiting within-tree variation, as well as controlling for panel performance), 32 trees from each family were used every year, thereby including more between-tree variation. Other reasons for the higher instrumental-sensory relationships obtained by trained panel analysis could relate to the calibration of the trained panel and panel mean values that were used in the statistical analyses. These two factors, in combination, would have reduced the degree of statistical error of the sensory analyses.

5.2 Drivers of consumer liking

5.2.1 Appearance

The importance of overall appearance on consumers' preference for apples is firmly established in the literature (Jaeger & MacFie, 2001). Apple appearance, and in particular apple colour, often serve as a pre-selection criterion, setting up expectations of the eating quality of the fruit (Cliff *et al*., 1999; Jaeger & MacFie, 2001; Steyn, 2012). Consumers' preference generally associated with red peel colour (Fig. 3a), which could either be the result of their preference for red colour *per se*, or their association between red colour and sweetness (Clydesdale, 1993).

5.2.1.1 Instrumental measurements as predictor of appearance liking

Few studies have been conducted on the relationship between consumers' preference for appearance and instrumentally measured colour attributes. Bushway *et al.* (2002) reported a high correlation between consumer preference and colour measurements. Hue angles in apple range from green (values above 110 º) through yellow (lower values) to red (lowest values, but >0 º). The negative association between consumer preference and hue angles showed that consumers had a higher preference for red fruit. Lighter fruit were indicated by higher lightness values and negative correlations between lightness measurements and consumer preference showed higher preference for darker fruit. Since the additional anthocyanin pigmentation of red fruit results in less light reflected from the fruit peel, darker fruit were also likely to be redder. The small aperture in chromameters provides measurements of a localised area (Telias *et al*., 2011) that makes it difficult to measure colour contrast. Colour contrast could have affected colour perception in the current study for consumers who used a two-dimensional side view that depicted both the blushed and background colour. Average colour measurements were computed for a composite three-seedling sample, which might have differed from the appearance of the specific seedlings that were presented to consumers. Poor correlations between colour measurements and consumer preference could further be ascribed to consumers' instructions to rate their overall liking of appearance, without specifically referring to preference for colour. Variables such as shape, size, russet, colour pattern, background colour and overcolour all influence consumer preference, but cannot easily be measured in isolation from each other because it vary concomitantly between cultivars and selections (Hampson & Quamme, 2000; Cliff *et al*., 2002). Consumers thus might have indicated their degree of liking based on a combination of appearance attributes and not on colour *per se*.

5.2.1.2 Individual assessment as predictor of appearance liking

Individually assessed colour attributes were generally better predictors of consumer preference than instrumental colour measurements. The individual assessor, who used a three dimensional view of the actual fruit, was better able to perceive the colour contrasts that probably affected consumers' appearance preferences. Visual assessment of the percentage of the coloured part of the fruit was the best predictor of consumer preference and showed a slightly stronger correlation with preference than instrumentally measured hue angles. The amount of red colour on apple peel was thus a better predictor of consumer liking than the average redness of the peel. Visual assessment of overall lightness was better able to predict consumer preference than instrumental lightness measurement of the overcolour and especially the background colour (Fig. 3a). Hampson and Quamme (2000) reported that consumers prefer bright coloured fruit over fruit with a dull appearance. Brightness assessed by the individual assessor in our study was better able to predict consumers' appearance preferences than instrumental measurement of chroma. However, it should be noted that these measurements did not represent exact attributes: Visual assessment specifically referred to the brightness of the peel colour (measured on a scale ranging from dull/muddy to bright); while chroma measured the colourfulness that related to the amount of hue exhibited by an area (Hunt & Pointer, 2011).

5.2.2 Eating quality

The control, parents and seedlings showed similar distribution patterns relative to each other during all three years, demonstrating the repeatability and consequent efficacy of using PCA plots in analysing breeding programmes to facilitate the prediction of consumers' responses. The positioning of seedlings between their parental genotypes illustrated the contribution of genetic factors to sensory attributes and consumer preference. Progenies that were scattered in all four quadrants of the plot illustrated the genotypic variation among the genotypes used in this study.

5.2.2.1 Instrumental measurement as predictor of eating quality liking

Instrumental measurements of eating quality attributes were generally poor predictors of consumer preference. The temporal difference between instrumental measurements and consumer preference tests limits the accuracy with which conclusions can be drawn on instrumental measurements as predictors of consumer preference in the current study. Some seedlings were stored for eight weeks after instrumental measurements before consumer preference tests commenced, while the temporal difference between analyses was smaller for later maturing seedlings. The high number of seedlings that had to be measured instrumentally (as previously discussed) required a longer assessment time, whereas instrumental and consumer preference analysis within a short time would have been possible with a smaller sample size (i.e. if only thirty-two seedlings were analysed for each family). Instrumental measurements that were conducted simultaneously with consumer preference tests in 2010 on F3 and F4 seedlings were not better predictors of consumer preference than instrumental measurements in earlier seasons. However, correlations between instrumental measurements and consumer preference varied between the different seasons for the early and late families.

Poor correlations between consumer preference and instrumental measurements of flavour could partly be ascribed to the fact that measurements such as TSS and TA can objectively quantify the compounds of an extract, but cannot analyse the composition of the flavour within the fruit during chewing in the mouth when enzyme action occurs (Harker *et al.*, 2003). TSS failed to predict sweet taste and was therefore not a good predictor of consumer preference. Consumers' preferred level of sweetness depends on the acidity level that influences the perception of sweet taste (Visser *et al.*, 1968), which is reflected in TSS/TA measurements that were better predictors of consumer preference than TSS. TA was a better negative predictor of consumer preference than sour taste. Apple flavour, which was mostly a good predictor of consumer preference, could not be accurately predicted by instrumental attributes measured in the current study. More advanced forms of flavour analysis (such as gas chromatography-mass spectrometry) could be included in the final evaluation phases of a breeding programme.

The positioning of firmness towards the centre of the PCA plot (Fig. 4a) clearly shows that penetrometer measurements did not represent the sensory textural attributes perceived by humans and thus cannot accurately predict consumer preference.

5.2.2.2 Individual assessment as predictor of eating quality liking.

The preference of the consumer group could not be predicted by hedonic preference ratings or eating quality attributes assessed by the individual assessor. Poor correlations between individually assessed attributes and consumer liking could be ascribed to the temporal difference between *ind* assessment and consumer preference analysis and sensory fatigue of the individual assessor (as discussed earlier). Hampson *et al.* (2000) similarly showed that a single assessor cannot readily predict the preference of a larger group. An individual assessor cannot represent consumers from diverse consumer segments with different preference patterns (Chapter 4). It is inevitable that his/her personal preferences reflect in the selection of potentially successful seedlings. If the assessor prefers sweet tasting apples, sour apples that may be preferred by a consumer group with different preferences may be underrepresented in new breeding selections. Therefore, the individual assessor should be acquainted with the preferences of all consumer segments (viz. Chapter 4) and assisted by small (2-4) groups of expert assessors who objectively quantify fruit quality attributes in the early evaluation phases.

5.2.2.3 Trained panel assessment as predictor of eating quality liking

The methodologies used to predict consumer preference by DSA of fruit quality, whereby these analyses were conducted within the same time period, showed that trained panel analysis provides a more accurate prediction of consumer preference than instrumental measurement and individual assessment. Higher correlations between consumer preference and trained panel assessment of quality attributes were obtained despite underrepresentation of the variability within the seedling trees, suggesting that the methods currently applied in the evaluation of a breeding programme could be optimised. Despite the increased interest in DSA in the analysis of fruit quality for breeding purposes, germplasm evaluation is currently mainly based on analysis by an individual or small teams of tasters (Oraguzie *et al.*, 2009). Results from the current study, and those obtained by other authors (King *et al.*, 2000; Hampson *et al.*, 2000), have shown that panels trained in DSA could successfully be used for the analysis of a large (30+) number of genotypes from a breeding programme in a formalised sensory laboratory during the advanced evaluation phases.

The current study showed that sensory textural and taste attributes explained the largest part of the variability in the data on PC1 and PC2, respectively, similar to studies by Daillant-Spinnler *et al.* (1996) and Harker *et al.* (2008). However, Jaeger *et al.* (1998) and Seppä *et al.* (2012) found attributes ranging from “sweet” to “sour” on PC1 and from “juicy, crispy” to “floury” on PC2. Even though sensory textural attributes showed poor to intermediate correlations with consumer preference, they were better predictors of consumer preference than instrumental texture measurement. Juiciness, an important driver of liking for a large proportion of consumers (Daillant-Spinnler *et al.*, 1996; Chapter 4), showed stronger correlations with consumer preference in the current study ($r=0.66$; $P<0.0001$ the highest) than crispness, hardness and crunchiness, which strongly associated with each other (Fig. 4a) and were equally good predictors of consumer preference. Extensive analysis of crispness, hardness and crunchiness would not necessarily increase the precision with which consumer preference can be predicted and analysis could be limited to only one of these attributes in addition to juiciness. In accordance with results from the literature (Jaeger *et al.*, 1998), mealiness was a strong negative driver of consumer preference

(Fig. 4a) and also for a large proportion of the consumer group in Chapter 4, but could not be accurately predicted by instrumental measurements. Sensory mealiness is associated with floury, coarse, dry and soft texture in apples (Andani *et al.*, 2001) and is the result of sunburn, over maturity and storage conditions (Harker *et al.*, 1997a). PC2 showed a contrast between sweet and sour tastes (Fig. 4a). Trained panel analysis of sweetness reflects the integrated perception of sweet and sour tastes, which was a relatively good predictor of consumer preference. High sour taste ratings may be acceptable or unacceptable, depending on the sweetness level (Hampson *et al.*, 2000). The positioning of apple flavour towards the centre of Figure 4a and its association with consumer preference showed that it was an important driver of consumer liking, even though it could only explain a limited amount of the variability in the data.

Consumers' degree of liking for overall apple eating quality is simultaneously determined by several attributes that cannot accurately be studied in isolation. Texture has an overriding effect on flavour perception (Carr *et al.*, 1996), shown by the association between apple flavour and juiciness, crispness, hardness and crunchiness (Fig. 4a). Linkage perception complicates the identification of single drivers of liking. Hampson *et al.* (2000) reported that sweet and sour tastes explained only about half of the variation in flavour liking. In the current study, consumers generally disliked genotypes with high levels of mealiness, despite high sensory sweetness (Table 6). Similarly, Harker *et al.* (2008) found that apples below a certain firmness threshold did not gain consumer acceptance despite increased sweetness. Thirdly, although mean preference scores were used in the statistical analysis in the current study, consumers have divergent preferences for apple eating quality, i.e. one consumer group have a preference for sour taste, while another group is sour aversive (Daillant-Spinnler *et al.*, 1996; Carbonell *et al.*, 2008; Chapter 4). Non-significant correlations in the current study could have resulted from mean preference values calculated for the total consumer group that constituted sub-groups with diverse preferences. Individual preference differences are taken into account in consumer segmentation, i.e. a statistical method that identifies consumer segments with similar preference patterns (Carbonell *et al.*, 2008), as was conducted in Chapter 4. Stronger correlations between consumer preference and quality attributes might result if determined for each of the consumer segments independently, however, this was not the purpose of this chapter. Multivariate statistical techniques, such as PCA that was used in the current study, can be used to gain a better understanding of the relative importance of attributes in driving consumer preference and how these attributes relate to each other.

6. CONCLUSIONS

The aim of this study was to investigate ways to increase the efficiency of the ARC apple breeding programme. We set out to determine the extent to which instrumental measurements can be used to predict sensory attributes assessed by an individual assessor or by a panel trained in DSA. We also investigated the extent to which instrumental measurements, DSA or individual assessment of fruit quality attributes can predict consumer preference. The procedures used by the ARC apple breeding programme to assess fruit from breeding families were followed for logistic and practical reasons, and also to assess the validity of the current protocol.

We could not accurately answer the questions relating to the validity of individual and instrumental assessment as predictors of sensory quality parameters or consumer preference due to a time delay between instrumental measurements and individual assessment (conducted after harvest and prior to cold storage) and DSA and consumer preference tests (conducted after cold storage) that could have caused quality differences. The availability of a limited number of fruit for different assessments may also have decreased correlations between the various measurements since fruit from seedling trees may have varied considerably in quality attributes. It would have been better to use cultivars to accurately answer these questions.

Despite the limitations inherent in using breeding material, we were, however, able to answer and make recommendations regarding some questions. Instrumental measurements in the current study could not predict the sensory attributes that they characterised, as analysed by the individual assessor. TSS/TA, but not TSS that is often used, might be a valuable measurement in predicting the sensory perception of sweetness, which drives preference for a large proportion of consumers (Chapter 4). Visual assessment of colour attributes provided a better prediction of consumers' preference for peel colour compared to instrumental colour measurements and can be assessed by an expert breeder.

Texture (crispness, crunchiness, or hardness in addition to juiciness), apple flavour and sweet taste as quantified by a panel trained in DSA and instrumental measurement of TA and TSS/TA should be used to analyse breeding families where funds and fruit size/numbers are limited, due to the ability of these parameters to predict consumers' responses.

DSA and consumer preference tests could be conducted simultaneously as a once-off analysis to determine drivers of liking in the early evaluation phase. Existing cultivars can be used for this goal as done in Chapters 3 and 4. Here after the particular sensory profiles of all breeding families, as analysed by a small team (2-4) of expert assessors during the first and second evaluation phases, should be projected onto the preference space to ensure the selection of potential cultivars with high consumer appeal. Potential cultivars should then be subjected to DSA and consumer preference testing in the advanced evaluation phases to ensure cultivar success when it is released to the market. Individual assessment prior to cold storage as is practised by the ARC apple breeding programme does not seem to be a reliable method to predict consumers' preference for the eating quality and appearance of seedlings in a breeding population and does not seem to accurately predict the preference of a larger consumer group that constitute consumer segments with diverse preference patterns (see Chapter 4 for a description of these segments). However, we acknowledge that an experienced apple breeder may fare better in assessing the potential consumer acceptance of a specific genotype than the comparatively inexperienced individual taster employed in this study.

With hindsight, we could have kept all fruit in cold storage in order to conduct quality analyses and consumer preference tests at the same time. The potential drawback of storing fruit prior to assessments is that storability is factored into the assessment of potential new cultivars, which would eliminate some of the very early selections. Early apple cultivars are known to have a much shorter storage life than cultivars with a longer development period.

On a multivariate level, principal component analysis were used to illustrate association of different types of analyses, and to determine possible predictors of quality or drivers of liking. However, it might be worthwhile to consider a more advanced, robust approach by using multi-block analysis. In multi-block analysis there are different blocks of data where each block is a collection of related attributes. The main objective of multi-block analysis is to find common and unique components among a number of data blocks to improve the interpretation of models and ultimately determine the most valid predictors of quality and/or consumer liking (Mage *et al.,* 2012).

Outcomes from this part of the research and recommendations on the optimisation of fruit quality analysis in a breeding programme will be discussed further in Chapter 8.

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Table 1 The measuring scale of attributes as quantified by the individual assessor

Attribute description	Scale/Unit
Coloured area	0-100; uncoloured - full coloured
Incidence of stripeness	0-100; no striped - full coloured
Visual lightness of the overall colour	0-100; dark - light
Visual brightness of the over-colour	0-100; dull - bright
Visual brightness of the background colour	0-100; muddy - bright
Sour taste	0-100; low - high
Sweet taste	0-100; low - high
Apple flavour	0-100; low - high
Juiciness	0-100; dry - juicy
Hardness	0-100; mealy - crisp

Table 2 Photographs of the parental genotypes and control samples presented for consumer preference analysis of apple appearance for three consecutive harvesting seasons (2008-2010), i.e. 'Royal Gala' control (RG), 'Anna' (F1P1), 'Scarlet Gala' (F1P2), 'Prima' (F2P1), 2B-19-22 (F2P2), 'Treco Red' (F3P1), 'Golden Delicious' (F3P2), 8F-8-6 (F4P1) and 'Cripps' Pink' (F4P2)

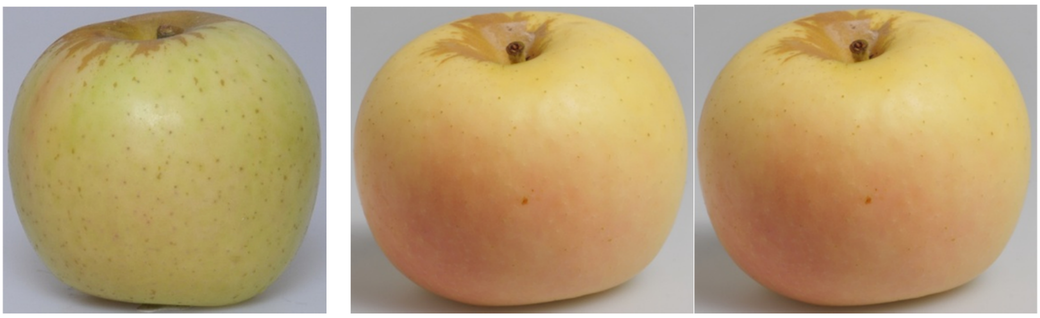
	2008	2009	2010
F1P1			
F1P2			
F2P1			

F2P2

F3P1

F3P2

F4P1



F4P2

RG

Table 3 Pearson's correlation coefficients for families 1 and 2 (F1 & F2), as well as families 3 and 4 (F3 & 4) in 2008-2010 between instrumental and sensory attributes analysed by the trained panel (*tp*) and the individual assessor (*ind*). Instrumental measurements included fruit firmness (TEXT), total soluble solids (TSS), titratable acidity (TA) and TSS/TA. Sensory attributes included crispness, hardness, crunchiness, juiciness, mealiness, texture, sweet taste and sour taste. Values in bold correlated significantly (P≤0.05).

Quality parameter	**F1&F2 - 2008**	**F1&F2 - 2009**	**F1&F2 - 2010**	**F3&F4 - 2008**	**F3&F4 - 2009**	**F3&F4 - 2010**
TEXT & texture *(ind)*	r=−0.04; P=0.7831	**r=0.34; P=0.0001**	**r=0.65; P<0.0001**	**r=0.28; P=0.0277**	**r=0.37; P=0.0036**	**r=0.52; P<0.0001**
TEXT & juiciness *(ind)*	r=−0.23; P=0.0663	**r=−0.20; P=0.0281**	**r=0.55; P<0.0001**	**r=−0.28; P=0.0290**	**r=0.35; P=0.0064**	**r=0.50; P<0.0001**
TSS & sweet taste *(ind)*	r=−0.06; P=0.6656	**r=0.26; P=0.0034**	**r=0.34; P=0.0092**	r=0.14; P=0.2749	r=0.26; P=0.0560	r=0.18; P=0.1508
TA & sour taste *(ind)*	**r=0.56; P<0.0001**	**r=0.57; P<0.0001**	**r=0.70; P<0.0001**	**r=0.66; P<0.0001**	**r=0.42; P=0.0007**	**r=0.64; P<0.0001**
TSS/TA & sweet taste *(ind)*	r=−0.08; P=0.5826	**r=0.27; P=0.0035**	**r=0.52; P<0.0001**	r=0.08; P=0.6073	r=0.16; P=0.2559	r=0.20; P=0.0950
Sweet & sour taste *(ind)*	r=0.10; P=0.4441	r=−0.06; P=0.5099	**r=−0.47; P=0.0001**	r=0.05; P=0.6826	r=−0.01; P=0.9431	r=0.05; P=0.7008
TEXT & crispness *(tp)*	r=0.07; P=0.6111	**r=0.34; P<0.0001**	**r=0.61; P<0.0001**	**r=0.53; P=0.0001**	**r=0.61; P<0.0001**	**r=0.53; P<0.0001**
TEXT & hardness *(tp)*	r=0.01; P=0.9316	**r=0.43; P<0.0001**	**r=0.62; P<0.0001**	**r=0.52; P=0.0001**	**r=0.67; P<0.0001**	**r=0.57; P<0.0001**
TEXT & crunchiness *(tp)*	r=0.03; P=0.8048	**r=0.42; P<0.0001**	**r=0.64; P<0.0001**	**r=0.51; P=0.0002**	**r=0.66; P<0.0001**	**r=0.55; P<0.0001**
TEXT & juiciness *(tp)*	r=−0.01; P=0.9383	r=0.13; P=0.1519	**r=0.48; P=0.0003**	**r=0.34; P=0.0178**	r=0.20; P=0.1231	r=0.22; P=0.0722
TEXT & mealiness *(tp)*	r=−0.12; P=0.3711	**r=−0.19; P=0.0367**	**r=−0.63; P<0.0001**	r=−0.23; P=0.1133	r=−0.09; P=0.5005	**r=−0.50; P<0.0001**
TSS & sweet taste *(tp)*	**r=0.30; P=0.0336**	**r=0.30; P=0.0008**	r=0.16; P=0.2641	**r=0.41; P=0.0033**	r=0.16; P=0.2212	**r=0.28; P=0.0187**
TA & sour taste *(tp)*	**r=0.65; P<0.0001**	**r=0.68; P<0.0001**	**r=0.41; P=0.0029**	**r=0.74; P<0.0001**	**r=0.72; P<0.0001**	**r=0.79; P<0.0001**
TSS/TA & sweet taste *(tp)*	**r=0.51; P=0.0006**	**r=0.65; P<0.0001**	**r=0.30; P=0.0329**	**r=0.71; P<0.0001**	**r=0.64; P<0.0001**	**r=0.38; P=0.0015**
Sweet & sour taste *(tp)*	**r=−0.88; P<0.0001**	**r=−0.53; P<0.0001**	**r=−0.83; P<0.0001**	**r=−0.81; P<0.0001**	**r=−0.74; P<0.0001**	**r=−0.59; P<0.0001**

Table 4 Overall means of sensory textural attributes measured on a 100 mm line scale during descriptive sensory analysis for the parental genotypes and seedlings of the four breeding families and the control for three consecutive harvesting seasons (2008-2010), i.e. 'Royal Gala' control (RG); 'Anna' (F1P1) x 'Scarlet Gala' (F1P2) for family 1 (F1); 'Prima' (F2P1) x 2B-19-22 (F2P2) for family 2 (F2); 'Treco Red' (F3P1) x 'Golden Delicious' (F3P2) for family 3 (F3); 8F-8-6 (F4P1) x 'Cripps' Pink' (F4P2) for family 4 (F4). Means (±SD) with different alphabetical letters in the same column differ significantly. The least significant difference for each sensory attribute is indicated at the 5% level of significance

	Crispness			**Hardness**			**Crunchiness**		
Family	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
RG	46.8 ± 8.21^{cd}	48.9 ± 3.65^{bc}	54.0 ± 4.90^{ab}	41.5 ± 5.60^{b}	40.4 ± 3.22^{de}	50.3 ± 6.95^{ab}	42.0 ± 5.49^{c}	40.2 ± 3.01^{de}	53.1 ± 5.61^{a}
F1P1	29.9 ± 3.77^{f}	27.1 ± 7.89^{f}	36.2 ± 5.96^{ef}	27.1 ± 2.96^{d}	23.6 ± 7.09^{g}	35.0 ± 6.61^{de}	24.5 ± 4.51^{de}	23.9 ± 8.36^{g}	35.2 ± 5.98^{de}
F1P2	62.7 ± 6.67^{a}	58.1 ± 4.34^{a}	58.4 ± 5.12^{a}	53.9 ± 6.50^{a}	50.1 ± 3.62^{ab}	56.2 ± 5.09^{a}	52.7 ± 7.40^{ab}	51.0 ± 3.09^{ab}	57.1 ± 5.61^{a}
F1	49.2 ± 9.21^{cd}	45.1 ± 11.37^{cd}	41.7 ± 8.73^{cde}	42.9 ± 8.39^{b}	40.8 ± 10.37^{cde}	41.2 ± 9.31^{cd}	42.2 ± 8.95^{c}	40.7 ± 10.66^{d}	41.6 ± 9.28^{bc}
F2P1	48.9 ± 15.3^{cd}	56.4 ± 4.16^{ab}	52.3 ± 4.81^{b}	43.2 ± 13.09^{b}	50.6 ± 3.45^{ab}	52.3 ± 5.38^{a}	41.8 ± 14.46^{c}	50.3 ± 3.19^{abc}	51.6 ± 5.49^{a}
F2P2	18.6 ± 2.42^{g}	20.5 ± 2.74^{f}	24.4 ± 3.12^{g}	17.3 ± 1.98^{e}	18.4 ± 2.61^{g}	22.6 ± 2.96^{f}	16.4 ± 2.41^{e}	17.6 ± 2.38^{g}	23.3 ± 3.69^{f}
F2	35.4 ± 10.92^{ef}	37.5 ± 12.83^{e}	39.9 ± 8.78^{def}	31.9 ± 9.53^{cd}	33.8 ± 11.84^{ef}	38.5 ± 9.06^{cd}	29.7 ± 9.93^{d}	33.4 ± 11.56^{ef}	38.8 ± 8.43^{cd}
F3P1	44.4 ± 8.47^{cde}	54.4 ± 4.02^{ab}	45.5 ± 2.67^{cd}	42.2 ± 5.50^{b}	46.3 ± 4.05^{abcd}	41.8 ± 2.14^{c}	41.8 ± 5.78^{c}	45.3 ± 4.68^{bcd}	42.5 ± 3.42^{bc}
F3P2	46.0 ± 6.18^{cd}	50.6 ± 3.01^{bc}	44.3 ± 3.83^{cd}	43.9 ± 5.42^{b}	42.7 ± 3.77^{cd}	39.7 ± 3.37^{cd}	43.0 ± 5.44^{c}	42.9 ± 3.87^{d}	42.1 ± 4.21^{bc}
F3	52.2 ± 15.91^{bc}	54.5 ± 6.57^{ab}	45.9 ± 7.20^{c}	47.2 ± 13.00^{ab}	47.5 ± 7.49^{abc}	43.7 ± 7.26^{c}	46.9 ± 13.03^{abc}	47.2 ± 7.01^{abcd}	44.5 ± 7.70^{bc}
F4P1	41.3 ± 10.91^{de}	39.4 ± 11.24^{de}	34.6 ± 6.20^{f}	39.2 ± 8.86^{bc}	33.3 ± 8.07^{f}	32.1 ± 5.06^{e}	39.0 ± 9.00^{c}	31.9 ± 8.73^{f}	32.1 ± 5.41^{e}
F4P2	61.7 ± 4.37^{ab}	60.4 ± 3.18^{a}	58.8 ± 2.19^{a}	55.2 ± 3.23^{a}	51.5 ± 1.84^{a}	54.3 ± 1.92^{a}	54.8 ± 3.27^{a}	52.9 ± 1.85^{a}	56.9 ± 1.68^{a}
F4	50.6 ± 16.19^{cd}	50.3 ± 9.57^{bc}	46.5 ± 6.95^{c}	45.4 ± 12.72^{b}	43.9 ± 9.57^{bcd}	44.5 ± 8.13^{bc}	45.5 ± 13.48^{bc}	43.5 ± 9.77^{cd}	45.1 ± 7.79^{b}
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Family	Juiciness			Mealiness		
	2008	2009	2010	2008	2009	2010
RG	56.5 ± 7.73^{abc}	57.2 ± 3.02^{abc}	55.0 ± 4.11^{a}	0.8 ± 1.04^{ef}	1.4 ± 2.19^{d}	1.3 ± 1.42^{e}
F1P1	43.6 ± 3.51^{e}	33.9 ± 6.83^{g}	42.5 ± 6.30^{d}	23.4 ± 6.98^{b}	17.3 ± 8.59^{a}	11.7 ± 5.40^{bcd}
F1P2	59.6 ± 3.89^{a}	57.9 ± 3.24^{abc}	57.5 ± 5.22^{a}	2.7 ± 2.64^{ef}	0.2 ± 0.38^{d}	0.8 ± 0.97^{e}
F1	49.5 ± 6.12^{d}	46.5 ± 8.93^{de}	41.3 ± 7.04^{d}	7.2 ± 7.90^{de}	4.4 ± 8.18^{d}	11.7 ± 9.46^{cd}
F2P1	52.4 ± 8.37^{bcd}	52.6 ± 1.97^{cd}	49.5 ± 4.41^{bc}	11.9 ± 14.59^{cd}	0.1 ± 0.15^{d}	2.8 ± 1.62^{e}
F2P2	35.1 ± 4.78^{f}	37 ± 5.641^{fg}	33.7 ± 5.79^{e}	43.4 ± 8.76^{a}	17.9 ± 2.43^{a}	31.6 ± 8.50^{a}
F2	43.0 ± 7.73^{e}	42.8 ± 10.23^{ef}	41.2 ± 7.67^{d}	18.2 ± 13.81^{bc}	9.8 ± 9.99^{bc}	14.6 ± 11.90^{bc}
F3P1	48.5 ± 2.52^{de}	60.0 ± 3.09^{ab}	48.0 ± 1.44^{bc}	1.8 ± 1.68^{ef}	2.4 ± 2.60^{d}	5.0 ± 2.40^{e}
F3P2	52.2 ± 3.48^{bcd}	54.3 ± 3.14^{bc}	44.8 ± 2.08^{cd}	0.5 ± 0.38^{ef}	4.1 ± 3.67^{d}	6.3 ± 2.24^{de}
F3	54.1 ± 7.72^{cd}	53.4 ± 6.16^{c}	43.2 ± 5.09^{d}	2.7 ± 5.72^{ef}	4.3 ± 4.88^{d}	6.4 ± 5.60^{de}
F4P1	48.1 ± 5.78^{de}	44.7 ± 10.07^{e}	36.0 ± 6.86^{e}	2.2 ± 3.25^{ef}	10.8 ± 8.24^{b}	17.6 ± 7.21^{b}
F4P2	57.6 ± 2.34^{ab}	61.3 ± 2.15^{a}	50.1 ± 2.62^{b}	0.2 ± 0.20^{f}	2.9 ± 2.89^{d}	1.1 ± 1.02^{e}
F4	49.5 ± 7.27^{d}	52.5 ± 7.76^{c}	42.8 ± 4.18^{d}	3.8 ± 7.52^{ef}	5.1 ± 4.11^{cd}	6.1 ± 5.14^{de}

P-value	<0.0001	<.0001	<0.0001	<0.0001	<0.0001	<0.0001

SD = Standard Deviation

Table 5 Means of measured maturity indexes firmness, total soluble solids (TSS) and titratable acidity (TA) and calculated ratio of total soluble solids and titratable acidity (TSS/TA) for the parental genotypes and seedlings of the four breeding families and the control for three consecutive harvesting seasons (2008-2010), i.e. 'Royal Gala' control (RG); 'Anna' (F1P1) x 'Scarlet Gala' (F1P2) for family 1 (F1); 'Prima' (F2P1) x 2B-19-22 (F2P2) for family 2 (F2); 'Treco Red' (F3P1) x 'Golden Delicious' (F3P2) for family 3 (F3); 8F-8-6 (F4P1) x 'Cripps' Pink' (F4P2) for family 4 (F4). Means (±SD) with different alphabetical letters in the same column differ significantly. The least significant difference for each sensory attribute is indicated at the 5% level of significance

	Firmness (N)			**TSS (ºBrix)**		
Family	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
RG	64.7 ± 0.54^{e}	62.7 ± 0.60^{bcd}	64.7 ± 0.33^{cde}	12.9 ± 0.56^{d}	13.4 ± 0.93^{e}	13.3 ± 0.68^{c}
F1P1	45.1 ± 0.89^{f}	66.6^{abc*}	44.1 ± 0.28^{f}	14.2 ± 1.72^{bc}	15.3^{bcd*}	14.1 ± 3.39^{bcd}
F1P2	85.3 ± 0.80^{b}	68.6 ± 0.32^{abc}	68.6 ± 0.57^{bcd}	13.5 ± 1.29^{cd}	14.0 ± 0.29^{de}	14.8 ± 0.32^{abc}
F1	138.2 ± 1.51^{a}	79.4 ± 2.00^{a}	73.5 ± 2.03^{abc}	8.5 ± 1.70^{e}	16.5 ± 2.34^{b}	15.7 ± 1.49^{a}
F2P1	69.6 ± 1.36^{cde}	52.9 ± 1.00^{cde}	55.9 ± 2.10^{e}	13.5 ± 0.87^{cd}	16.3 ± 1.73^{bc}	15.3 ± 1.51^{ab}
F2P2	35.3 ± 0.40^{g}	50.0 ± 0.89^{de}	41.2 ± 1.35^{f}	13.7 ± 1.25^{cd}	16.5 ± 1.81^{b}	15.2 ± 0.79^{ab}
F2	138.2 ± 1.55^{a}	70.6 ± 1.68^{ab}	66.6 ± 1.60^{cde}	7.3 ± 1.74^{f}	16.3 ± 1.34^{bc}	15.2 ± 1.82^{ab}
F3P1	79.4 ± 0.72^{bc}	71.5 ± 0.68^{ab}	74.5 ± 0.59^{abc}	13.7 ± 0.94^{bcd}	16.4 ± 1.04^{b}	14.8 ± 0.71^{abc}
F3P2	66.6 ± 1.05^{de}	61.7 ± 0.72^{bcd}	60.8 ± 0.51^{de}	14.4 ± 0.91^{bc}	16.4 ± 1.08^{b}	16.0 ± 0.46^{a}
F3	85.3 ± 1.35^{b}	83.3 ± 1.98^{a}	82.3 ± 1.55^{a}	15.5 ± 1.59^{a}	18.4 ± 1.18^{a}	16.1 ± 1.18^{a}
F4P1	44.1 ± 1.53^{f}	41.2 ± 0.93^{e}	57.8 ± 0.29^{de}	13.0 ± 0.61^{d}	14.7 ± 0.94^{cde}	12.9 ± 0.85^{c}
F4P2	74.5 ± 0.36^{cd}	82.3 ± 0.33^{a}	84.3 ± 0.41^{a}	14.1 ± 0.59^{bc}	14.0 ± 0.65^{de}	13.8 ± 0.39^{cd}
F4	75.5 ± 1.62^{cd}	66.6 ± 1.75^{abc}	79.4 ± 1.68^{ab}	14.7 ± 1.50^{ab}	16.3 ± 1.51^{bc}	15.5 ± 1.42^{a}
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	TA (% malic acid)			**TSS/TA**		
RG	0.33 ± 0.10^{cd}	0.29 ± 0.04^{e}	0.25 ± 0.03^{f}	41.0 ± 9.28^{abcd}	46.6 ± 4.41^{abc}	53.2 ± 5.65^{a}
F1P1	0.52 ± 0.12^{ab}	0.61^{b*}	0.41 ± 0.12^{cdef}	28.3 ± 7.94^{e}	25.1^{ef*}	39.3^{abcd}
F1P2	0.39 ± 0.15^{bcd}	0.23 ± 0.01^{e}	0.27 ± 0.03^{ef}	38.0 ± 12.2^{bcde}	61.1 ± 3.39^{a}	52.8 ± 6.85^{a}
F1	0.32 ± 0.14^{cd}	0.55 ± 0.22^{bcd}	0.40 ± 0.21^{cdef}	34.2 ± 18.22^{cde}	37.0 ± 21.18^{bcde}	48.4 ± 24.16^{ab}
F2P1	0.61 ± 0.31^{a}	0.51 ± 0.07^{bcd}	0.69 ± 0.25^{ab}	29.2 ± 15.39^{e}	32.3 ± 5.91^{cdef}	29.5 ± 20.53^{bcd}
F2P2	0.33 ± 0.09^{cd}	0.40 ± 0.08^{cde}	0.30 ± 0.06^{ef}	47.3 ± 13.83^{ab}	42.3 ± 5.77^{bc}	55.4 ± 12.37^{a}
F2	0.64 ± 0.24^{a}	0.85 ± 0.21^{a}	0.72 ± 0.21^{a}	14.5 ± 10.39^{f}	20.3 ± 5.14^{f}	23.0 ± 7.84^{d}
F3P1	0.43 ± 0.13^{bc}	0.41 ± 0.07^{cde}	0.34 ± 0.05^{def}	35.0 ± 9.16^{cde}	41.6 ± 8.91^{bcd}	44.5 ± 6.88^{abcd}
F3P2	0.42 ± 0.05^{bc}	0.37 ± 0.06^{de}	0.32 ± 0.01^{def}	35.5 ± 5.18^{cde}	45.3 ± 7.56^{abc}	49.6 ± 2.43^{ab}
F3	0.45 ± 0.19^{bc}	0.49 ± 0.22^{bcd}	0.42 ± 0.2^{cde}	41.5 ± 19.9^{abc}	48.3 ± 28.15^{abc}	47.6 ± 22.71^{abc}
F4P1	0.26 ± 0.05^{d}	0.30 ± 0.04^{e}	0.36 ± 0.05^{def}	50.0 ± 5.17^{a}	49.1 ± 7.17^{ab}	36.8 ± 3.74^{abcd}
F4P2	0.40 ± 0.04^{bc}	0.56 ± 0.07^{bc}	0.55 ± 0.05^{bc}	35.4 ± 5.14^{cde}	25.6 ± 3.32^{def}	25.3 ± 2.19^{cd}
F4	0.52 ± 0.13^{ab}	0.55 ± 0.16^{bcd}	0.46 ± 0.17^{cd}	30.2 ± 9.42^{de}	33.6 ± 12.74^{bcdef}	40 ± 25.84^{abcd}
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

SD = Standard Deviation

*Only one sample of fruit was harvested in 2009

Table 6 Overall means of sensory taste and flavour attributes measured on a 100 mm line scale during descriptive sensory analysis for the parental genotypes and seedlings of the four breeding families and the control for the parental genotypes and seedlings of the four breeding families and the control for three consecutive harvesting seasons (2008-2010), i.e. 'Royal Gala' control (RG); 'Anna' (F1P1) x 'Scarlet Gala' (F1P2) for family 1 (F1); 'Prima' (F2P1) x 2B-19-22 (F2P2) for family 2 (F2); 'Treco Red' (F3P1) x 'Golden Delicious' (F3P2) for family 3 (F3); 8F-8-6 (F4P1) x 'Cripps' Pink' (F4P2) for family 4 (F4). Means (±SD) with different alphabetical letters in the same column differ significantly. The least significant difference for each sensory attribute is indicated at the 5% level of significance

Family	Sour Taste 2008	Sour Taste 2009	Sour Taste 2010	Sweet Taste 2008	Sweet Taste 2009	Sweet Taste 2010
RG	41.5 ± 6.90[cde]	48.3 ± 2.49[cd]	44.9 ± 2.75[cd]	53.1 ± 5.08[abc]	63.7 ± 3.88[a]	58.7 ± 2.02[a]
F1P1	55.6 ± 3.96[ab]	42.2 ± 8.61[de]	44.3 ± 6.60[cd]	48.8 ± 3.70[bcd]	50.4 ± 4.22[ghi]	44.9 ± 2.65[d]
F1P2	48.1 ± 4.88[bc]	34.9 ± 5.44[ef]	35.1 ± 5.23[ef]	55.3 ± 4.21[a]	55.3 ± 3.69[def]	57.4 ± 3.10[a]
F1	40.7 ± 9.96[cde]	42.5 ± 15.49[de]	41.8 ± 14.93[cde]	55.5 ± 5.36[a]	54.3 ± 5.73[efg]	51.3 ± 8.28[bc]
F2P1	61.0 ± 5.65[a]	58.3 ± 5.97[ab]	59.7 ± 6.31[a]	47.9 ± 2.68[cd]	47.4 ± 2.48[hi]	45.2 ± 4.90[d]
F2P2	39.2 ± 7.90[cde]	30.1 ± 3.09[f]	32.4 ± 3.78[f]	56.5 ± 3.35[a]	59.1 ± 4.70[bcd]	47.9 ± 4.60[cd]
F2	59.9 ± 11.94[a]	58.5 ± 10.66[ab]	56.7 ± 10.92[ab]	46.1 ± 5.43[d]	47.2 ± 4.57[i]	44.1 ± 5.25[d]
F3P1	33.9 ± 3.72[def]	46.4 ± 2.35[d]	45.9 ± 1.99[cd]	48.6 ± 4.43[bcd]	63.1 ± 2.27[ab]	55.0 ± 2.53[ab]
F3P2	32.5 ± 7.70[ef]	47.8 ± 2.81[cd]	38.4 ± 4.32[def]	54.4 ± 2.86[a]	60.8 ± 3.52[abc]	51.9 ± 2.45[bc]
F3	34.9 ± 15.67[def]	49.0 ± 10.50[cd]	47.1 ± 12.17[b]	53.4 ± 10.12[ab]	61.5 ± 7.63[abc]	51.5 ± 4.95[bc]
F4P1	27.1 ± 6.85[f]	43.1 ± 4.44[d]	44.0 ± 4.88[cd]	48.0 ± 3.53[cd]	58.4 ± 4.94[cde]	50.2 ± 2.81[c]
F4P2	42.1 ± 5.76[cd]	63.5 ± 4.52[a]	57.9 ± 3.88[ab]	47.7 ± 5.03[d]	51.6 ± 2.91[fgh]	51.3 ± 3.58[bc]
F4	46.3 ± 11.83[c]	55.1 ± 9.47[bc]	50.23 ± 10.56[bc]	46.7 ± 6.95[d]	57.4 ± 4.47[cde]	50.8 ± 4.11[bc]
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Family	Apple Flavour 2008	Apple Flavour 2009	Apple Flavour 2010	Astringency 2008	Astringency 2009	Astringency 2010
RG	47.9 ± 4.72[abc]	58.3 ± 1.50[a]	56.2 ± 2.46[a]	0.1 ± 0.16[d]	2.0 ± 2.79[de]	0.09 ± 0.15[d]
F1P1	47.0 ± 2.76[abc]	46.3 ± 3.83[f]	41.1 ± 3.57[f]	0.5 ± 0.91[bcd]	2.4 ± 2.17[d]	0.02 ± 0.05[d]
F1P2	49.7 ± 3.33[ab]	49.9 ± 1.73[de]	49.1 ± 3.59[bc]	0.8 ± 1.05[bcd]	3.5 ± 1.74[cd]	0.39 ± 0.72[bcd]
F1	44.4 ± 3.42[cd]	48.5 ± 5.57[ef]	43.4 ± 4.85[f]	1.0 ± 1.08[bc]	4.1 ± 2.84[c]	1.61 ± 1.77[b]
F2P1	49.8 ± 3.25[ab]	48.5 ± 2.41[ef]	47.6 ± 3.24[bcd]	1.3 ± 1.24[ab]	6.4 ± 1.60[a]	1.57 ± 1.33[bc]
F2P2	45.6 ± 3.88[cd]	48.5 ± 3.81[ef]	37.2 ± 5.14[g]	0.5 ± 0.66[bcd]	2.6 ± 1.30[cd]	0.30 ± 0.59[cd]
F2	44.3 ± 3.72[cd]	47.7 ± 3.94[ef]	43.1 ± 5.23[f]	1.9 ± 2.07[a]	5.4 ± 2.31[ab]	3.32 ± 2.58[a]
F3P1	45.3 ± 4.11[cd]	56.1 ± 1.69[ab]	51.0 ± 1.63[b]	0.2 ± 0.16[cd]	0.0 ± 0.04[f]	0.02 ± 0.03[d]
F3P2	50.2 ± 5.67[a]	54.3 ± 1.98[bc]	44.2 ± 2.69[def]	0.3 ± 0.19[cd]	0.0 ± 0.00[f]	0.05 ± 0.03[d]
F3	46.3 ± 7.08[bc]	53.1 ± 4.84[bcd]	44.1 ± 4.23[def]	0.4 ± 0.28[cd]	0.7 ± 1.05[ef]	1.56 ± 1.57[bc]
F4P1	42.1 ± 3.65[d]	52.8 ± 4.52[bcd]	44.2 ± 3.43[def]	0.3 ± 0.16[cd]	0.0 ± 0.09[f]	0.02 ± 0.03[d]
F4P2	44.2 ± 4.51[cd]	52.4 ± 1.79[cd]	47.6 ± 2.01[bcd]	0.4 ± 0.19[cd]	0.5 ± 0.56[ef]	0.16 ± 0.14[d]
F4	47.3 ± 4.29[abc]	54.1 ± 4.45[bc]	46.1 ± 4.00[cde]	0.4 ± 0.28[cd]	0.5 ± 0.72[ef]	1.13 ± 1.53[bcd]
P-value	0.0004	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

SD = Standard Deviation

Table 7 Socio-demographic breakdown of consumers that partook in the study in 2008, 2009 and 2010, indicated as percentage of the total group for each year

	2008	2009	2010
Gender			
Male	25	26	30
Female	75	74	70
Consumption of apples			
2 x month	15	16	11
1 x week	28	25	28
3-4 x week	34	37	40
5-7 x week	23	22	21
Age			
18-21	43	43	38
22-30	39	40	40
31-40	9	10	10
40+	9	7	12

Table 8 Means of instrumental colour attributes for the parental genotypes and seedlings of the four breeding families and the control for three consecutive harvesting seasons (2008-2010), i.e. 'Royal Gala' control (RG); 'Anna' (F1P1) x 'Scarlet Gala' (F1P2) for family 1 (F1); 'Prima' (F2P1) x 2B-19-22 (F2P2) for family 2 (F2); 'Treco Red' (F3P1) x 'Golden Delicious' (F3P2) for family 3 (F3); 8F-8-6 (F4P1) x 'Cripps' Pink' (F4P2) for family 4 (F4). Colour measurements included lightness (TOPL), chroma (TOPC), hue angle (TOPH) of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively; and the lightness (BACKL), chroma (BACKC) and hue angle (BACKH) of the background colour. Means (±SD) with different alphabetical letters in the same column differ significantly. The least significant difference (LSD) for each sensory attribute is indicated at the 5% level of significance

	TOPL			TOPC			TOPH		
Family	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
RG	40.6 ± 16.62^{ef}	44.4 ± 6.02^{e}	41.4 ± 2.97^{ef}	42.9 ± 1.46^{ab}	38.8 ± 6.87^{de}	42.2 ± 4.31^{c}	28.2 ± 2.68^{def}	29.6 ± 5.18^{de}	29.5 ± 4.11^{ef}
F1P1	38.5 ± 6.49^{efg}	*	41.5 ± 3.70^{ef}	39.2 ± 4.64^{b}	*	42.0 ± 2.16^{c}	28.6 ± 7.58^{def}	*	28.5 ± 4.04^{ef}
F1P2	37.8 ± 1.72^{efg}	47.8 ± 6.16^{de}	39.9 ± 1.95^{ef}	45.0 ± 1.90^{a}	44.0 ± 1.69^{abc}	46.3 ± 3.25^{bc}	23.7 ± 1.86^{ef}	30.0 ± 4.34^{de}	29.0 ± 5.94^{ef}
F1	41.4 ± 5.85^{def}	36.1 ± 4.45^{d}	37.9 ± 5.70^{f}	42.3 ± 3.42^{ab}	39.8 ± 5.38^{cde}	41.7 ± 5.29^{c}	24.2 ± 4.28^{ef}	27.2 ± 34.41^{def}	22.3 ± 4.23^{ef}
F2P1	32.7 ± 2.45^{g}	32.4 ± 10.23^{fg}	36.2 ± 3.83^{f}	32.2 ± 4.83^{c}	33.8 ± 3.45^{f}	35.4 ± 3.36^{d}	22.1 ± 3.35^{ef}	25.1 ± 15.09^{def}	25.8 ± 11.12^{ef}
F2P2	35.6 ± 3.20^{fg}	29.0 ± 2.94^{g}	37.1 ± 4.56^{f}	33.4 ± 5.10^{c}	27.8 ± 5.91^{g}	33.4 ± 4.14^{d}	25.1 ± 6.34^{ef}	13.0 ± 3.37^{f}	20.0 ± 7.10^{f}
F2	34.0 ± 4.43^{g}	30.6 ± 3.95^{fg}	36.3 ± 4.46^{f}	33.3 ± 6.06^{c}	31.1 ± 7.00^{fg}	35.6 ± 6.14^{d}	19.3 ± 5.73^{f}	16.6 ± 6.07^{ef}	22.4 ± 7.58^{ef}
F3P1	43.8 ± 2.09^{de}	43.2 ± 3.33^{e}	44.9 ± 2.18^{de}	45.3 ± 1.95^{a}	45.8 ± 1.24^{a}	48.3 ± 1.70^{ab}	30.2 ± 4.53^{de}	30.8 ± 4.51^{de}	31.5 ± 3.24^{ef}
F3P2	71.1 ± 2.95^{a}	74.7 ± 3.22^{a}	68.7 ± 9.45^{a}	45.1 ± 3.99^{a}	45.0 ± 4.04^{a}	51.7 ± 14.36^{a}	94.8 ± 14.47^{a}	94.0 ± 8.01^{a}	88.8 ± 7.64^{a}
F3	52.9 ± 13.59^{bc}	55.9 ± 12.24^{c}	57.8 ± 11.30^{b}	43.4 ± 8.11^{a}	45.5 ± 6.76^{a}	44.5 ± 5.92^{bc}	47.7 ± 23.41^{bc}	52.7 ± 20.39^{bc}	54.7 ± 20.78^{bc}
F4P1	57.8 ± 11.99^{b}	66.6 ± 7.53^{b}	66.9 ± 5.62^{a}	39.4 ± 3.54^{b}	35.6 ± 3.10^{ef}	31.0 ± 2.00^{d}	55.3 ± 21.77^{b}	62.4 ± 19.02^{b}	62.4 ± 15.20^{b}
F4P2	46.9 ± 4.51^{cd}	52.4 ± 4.23^{cd}	49.7 ± 4.30^{cd}	39.5 ± 2.00^{b}	40.3 ± 3.39^{bcd}	41.3 ± 3.00^{c}	38.4 ± 8.80^{cd}	38.5 ± 8.19^{cd}	33.7 ± 10.10^{de}
F4	53.5 ± 14.30^{b}	54.5 ± 14.43^{cd}	54.3 ± 11.76^{bc}	44.2 ± 6.07^{a}	44.5 ± 6.89^{ab}	43.7 ± 5.89^{bc}	49.1 ± 23.38^{b}	49.4 ± 24.87^{bc}	43.6 ± 20.73^{cd}
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

	BACKL			BACKC			BACKH		
Family	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
RG	67.6 ± 5.11^{cde}	72.8 ± 5.76^{ab}	64.1 ± 6.57^{def}	36.2 ± 2.89^{d}	33.9 ± 1.24^{e}	41.2 ± 2.43^{bc}	70.0 ± 14.11^{ef}	80.9 ± 11.98^{c}	66.0 ± 10.47^{f}
F1P1	64.9 ± 6.63^{e}	*	67.3 ± 6.70^{cde}	47.9 ± 4.67^{a}	*	47.5 ± 2.38^{a}	77.1 ± 22.54^{de}	*	91.3 ± 14.50^{abcd}
F1P2	58.8 ± 6.74^{fg}	77.5 ± 3.34^{a}	66.7 ± 6.80^{cde}	36.2 ± 3.37^{d}	41.5 ± 4.44^{cd}	46.1 ± 3.48^{a}	58.2 ± 13.14^{f}	86.4 ± 28.15^{bc}	74.4 ± 15.06^{def}
F1	71.9 ± 6.86^{abc}	60.7 ± 9.03^{cde}	62.4 ± 10.24^{ef}	38.6 ± 4.53^{cd}	41.9 ± 4.43^{cd}	41.1 ± 5.13^{bc}	82.6 ± 16.84^{cd}	56.8 ± 15.47^{de}	61.9 ± 23.06^{f}
F2P1	66.2 ± 5.53^{de}	63.3 ± 11.39^{bcd}	66.8 ± 8.76^{cde}	41.6 ± 4.77^{bc}	50.8 ± 16.15^{a}	47.0 ± 6.22^{a}	90.0 ± 9.40^{c}	80.6 ± 30.82^{c}	93.3 ± 10.72^{abc}
F2P2	63.5 ± 8.85^{ef}	49.0 ± 11.49^{f}	58.6 ± 7.47^{f}	38.1 ± 3.13^{d}	41.3 ± 3.20^{cd}	40.0 ± 6.34^{cd}	76.4 ± 20.21^{de}	39.0 ± 21.83^{f}	66.4 ± 19.56^{f}
F2	58.0 ± 7.63^{g}	52.8 ± 11.80^{ef}	60.7 ± 9.76^{ef}	38.7 ± 3.69^{cd}	38.1 ± 5.55^{de}	39.2 ± 4.52^{cd}	65.1 ± 21.81^{ef}	46.2 ± 20.80^{ef}	70.0 ± 27.44^{de}
F3P1	70.6 ± 4.39^{abcd}	55.3 ± 11.63^{def}	66.2 ± 2.74^{de}	35.4 ± 4.86^{d}	41.3 ± 3.00^{cd}	41.0 ± 2.54^{bc}	76.5 ± 10.99^{de}	61.4 ± 11.89^{d}	62.0 ± 6.15^{f}
F3P2	73.2 ± 2.40^{ab}	71.1 ± 4.50^{ab}	70.0 ± 11.23^{bcd}	47.4 ± 2.41^{a}	45.1 ± 1.98^{bc}	47.2 ± 2.64^{a}	107.3 ± 2.23^{a}	105.4 ± 1.50^{a}	102.4 ± 2.01^{ab}
F3	68.7 ± 9.43^{bcde}	63.7 ± 12.05^{bc}	73.8 ± 7.07^{abc}	44.8 ± 6.92^{ab}	48.1 ± 6.70^{ab}	44.6 ± 5.16^{ab}	82.5 ± 17.94^{cd}	82.1 ± 17.01^{c}	85.7 ± 15.54^{bcde}
F4P1	74.6 ± 9.15^{a}	70.7 ± 15.87^{ab}	81.0 ± 0.93^{a}	42.3 ± 5.01^{b}	39.7 ± 3.11^{d}	36.6 ± 4.36^{d}	94.8 ± 17.35^{bc}	98.8 ± 2.40^{ab}	104.4 ± 3.00^{a}
F4P2	74.5 ± 5.66^{a}	68.0 ± 16.02^{abc}	70.0 ± 3.67^{bcd}	46.53 ± 2.56^{a}	41.8 ± 2.12^{cd}	41.2 ± 3.11^{bc}	104.5 ± 3.20^{ab}	105.3 ± 2.39^{a}	98.4 ± 6.72^{abc}
F4	74.6 ± 6.29^{a}	65.8 ± 15.01^{bc}	75.2 ± 8.94^{ab}	42.6 ± 4.11^{b}	42.1 ± 5.55^{cd}	41.2 ± 5.50b^{c}	90.5 ± 13.69^{c}	78.0 ± 23.27^{c}	85.1 ± 22.16^{cde}
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

SD = Standard Deviation

*Indicates that an insufficient number of fruit was harvested for instrumental analysis

Table 9 Pearson's correlation coefficients for families 1 and 2 (F1 & F2), as well as families 3 and 4 (F3 & 4) in 2008-2010 of consumer preference with instrumental and sensory attributes analysed by the trained panel (*tp*) and the individual assessor (*ind*). Instrumental measurements included fruit firmness (TEXT), total soluble solids (TSS), titratable acidity (TA) and TSS/TA. Sensory attributes included crispness, hardness, crunchiness, juiciness, mealiness, texture, sweet taste, sour taste and apple flavour. Values in bold correlated significantly (P≤0.05).

Attribute correlating with consumer preference	F1&F2 - 2008	F1&F2 - 2009	F1&F2 - 2010	F3&F4 - 2008	F3&F4 - 2009	F3&F4 - 2010
TEXT	r=0.11; P=0.4078	r=0.10; P=0.2709	r=0.17; P=0.1895	r=0.07; P=0.6395	r=−0.06; P=0.6707	r=−0.12; P=0.3356
TSS	**r=0.30; P=0.0193**	r=0.03; P=0.7499	r=0.17; P=0.2185	r=−0.02; P=0.8850	r=−0.21; P=0.1168	r=−0.05; P=0.7088
TA	r=−0.28; P=0.0529	**r=−0.49; P<0.0001**	**r=−0.37; P=0.0044**	**r=−0.32; P=0.0418**	r=−0.13; P=0.3117	r=−0.02; P=0.8583
TSS/TA	r=0.08; P=0.6178	**r=0.23; P=0.0096**	**r=0.35; P=0.0079**	r=0.06; P=0.7306	r=0.01; P=0.9426	r=−0.13; P=0.3042
Juiciness *(ind)*	**r=0.30; P=0.0472**	**r=0.30; P=0.0007**	r=0.18; P=0.1705	r=0.17; P=0.2200	r=0.21; P=0.1229	r=−0.09; P=0.4606
Texture *(ind)*	**r=0.28; P=0.0309**	**r=0.26; P=0.0042**	r=0.20; P=0.1290	**r=0.47; P=0.0003**	r=0.12; P=0.3617	r=−0.03; P=0.7887
Sweet taste *(ind)*	r=0.01; P=0.4643	r=0.11; P=0.2424	**r=0.27; P=0.0405**	r=0.07; P=0.6039	r=0.08; P=0.5680	r=−0.05; P=0.7008
Sour taste *(ind)*	**r=−0.39; P=0.0019**	**r=−0.20; P=0.0251**	**r=−0.37; P=0.0038**	**r=−0.27; P=0.0458**	r=0.04; P=0.7840	r=0.08; P=0.5283
Apple flavour(*ind*)	r=0.00; P=0.9799	r=0.14; P=0.1217	r=−0.02; P=0.9002	r=0.09; P=0.5398	**r=0.34; P=0.0090**	r=−0.02; P=0.8949
Crispness *(tp)*	**r=0.64; P<0.0001**	**r=0.60; P<0.0001**	**r=0.30; P=0.0207**	**r=0.38; P=0.0033**	**r=0.30; P=0.0135**	r=0.03; P=0.8328
Hardness *(tp)*	**r=0.62; P<0.0001**	**r=0.57; P<0.0001**	**r=0.29; P=0.0246**	**r=0.39; P=0.0023**	**r=0.28; P=0.0211**	r=−0.07; P=0.5634
Crunchiness *(tp)*	**r=0.62; P<0.0001**	**r=0.60; P<0.0001**	**r=0.30; P=0.206**	**r=0.39; P=0.0021**	**r=0.28; P=0.0232**	r=0.03; P=0.7844
Juiciness *(tp)*	**r=0.62; P<0.0001**	**r=0.66; P<0.0001**	**r=0.27; P=0.0361**	**r=0.50; P<0.0001**	**r=0.55; P<0.0001**	r=0.21; P=0.0876
Mealiness *(tp)*	**r=−0.50; P=0.0001**	**r=−0.51; P=0.0001**	r=−0.21; P=0.1152	**r=−0.40; P=0.0017**	**r=−0.42; P=0.0004**	r=−0.06; P=0.6047
Sweet taste *(tp)*	**r=0.44; P=0.0010**	**r=0.55; P<0.0001**	**r=0.32; P=0.0148**	**r=0.42; P=0.0009**	**r=0.31; P=0.0104**	r=0.15; P=0.2260
Sour taste *(tp)*	**r=−0.33; P=0.0170**	**r=−0.20; P=0.0235**	**r=−0.30; P=0.0226**	r=−0.20; P=0.1204	r=0.00; P=0.9885	r=−0.09; P=0.4748
Apple flavour(*tp*)	**r=0.42; P=0.0017**	**r=0.52; P<0.0001**	r=0.06; P=0.6418	**r=0.61; P<0.0001**	**r=0.63; P<0.0001**	r=0.16; P=0.1845

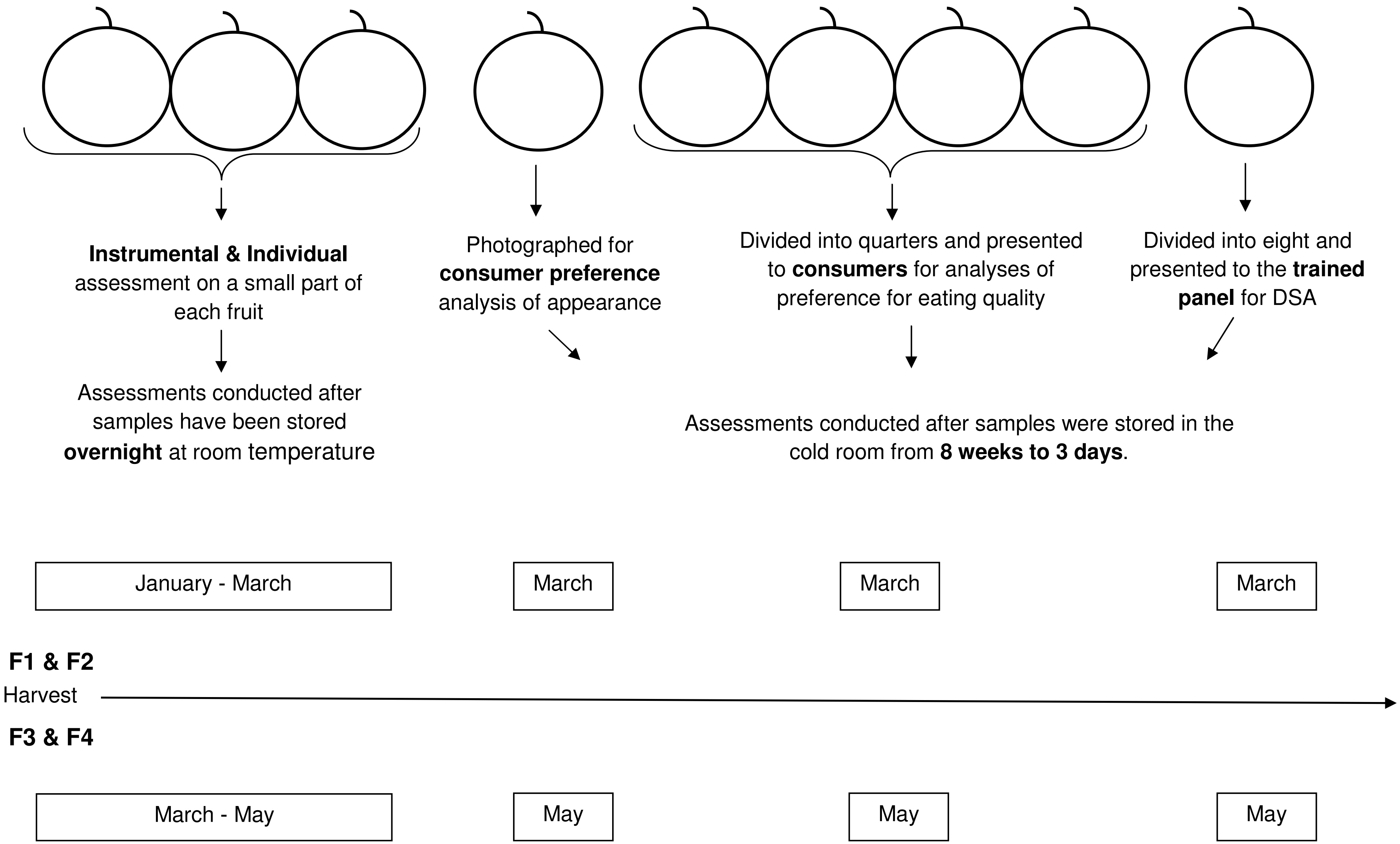


Figure 1 Illustration of the experimental design applied for the individual assessment, instrumental measurements, consumer preference tests and DSA (descriptive sensory analysis) of the early bearing F1 and F2 (families 1-2) and later bearing F3 and F4 (families 3-4) in 2008-2010.

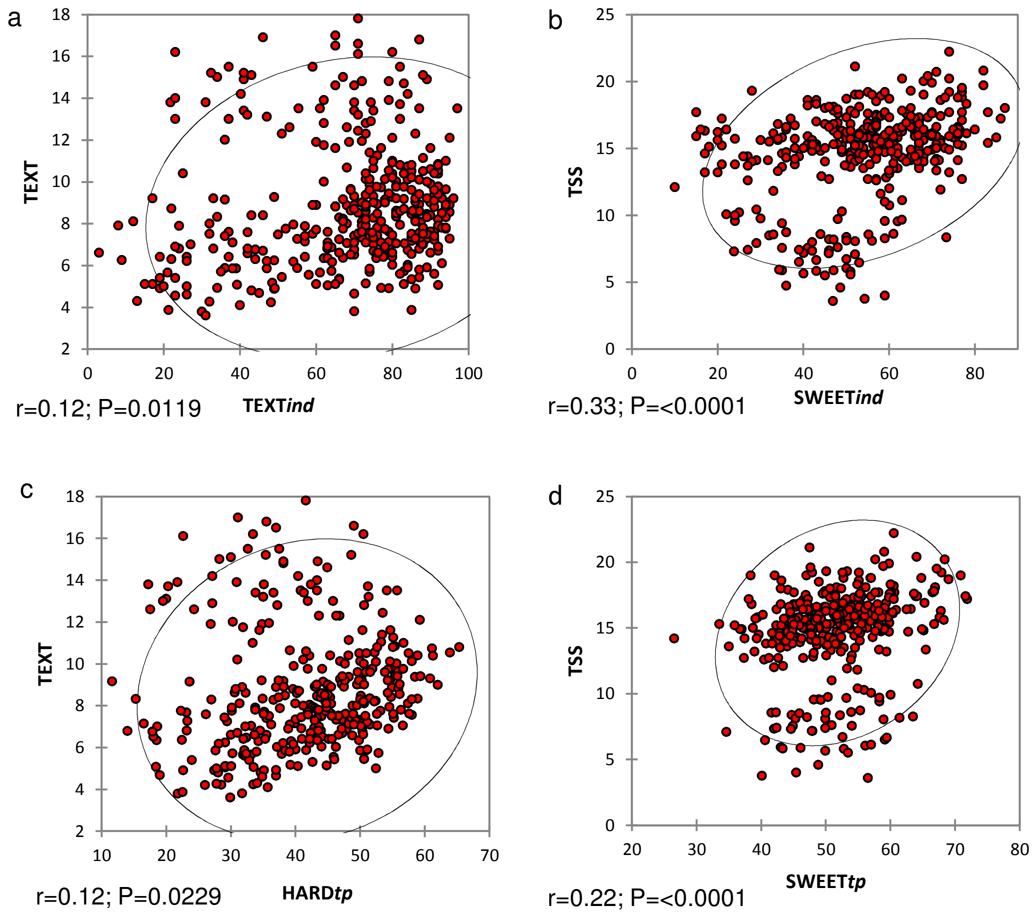


Figure 2 Scatterplots showing the relationship between sensory and instrumental measurement of quality attributes for all families across all years, i.e. families 1-4 for 2008-2010: a) Penetrometer firmness (TEXT) and individually assessed texture (TEXT*ind*); b) total soluble solids (TSS) and individually assessed sweetness (SWEET*ind*); c) TEXT and trained panel hardness (HARD*tp*); d) TSS and trained panel sweetness (SWEET*tp*).

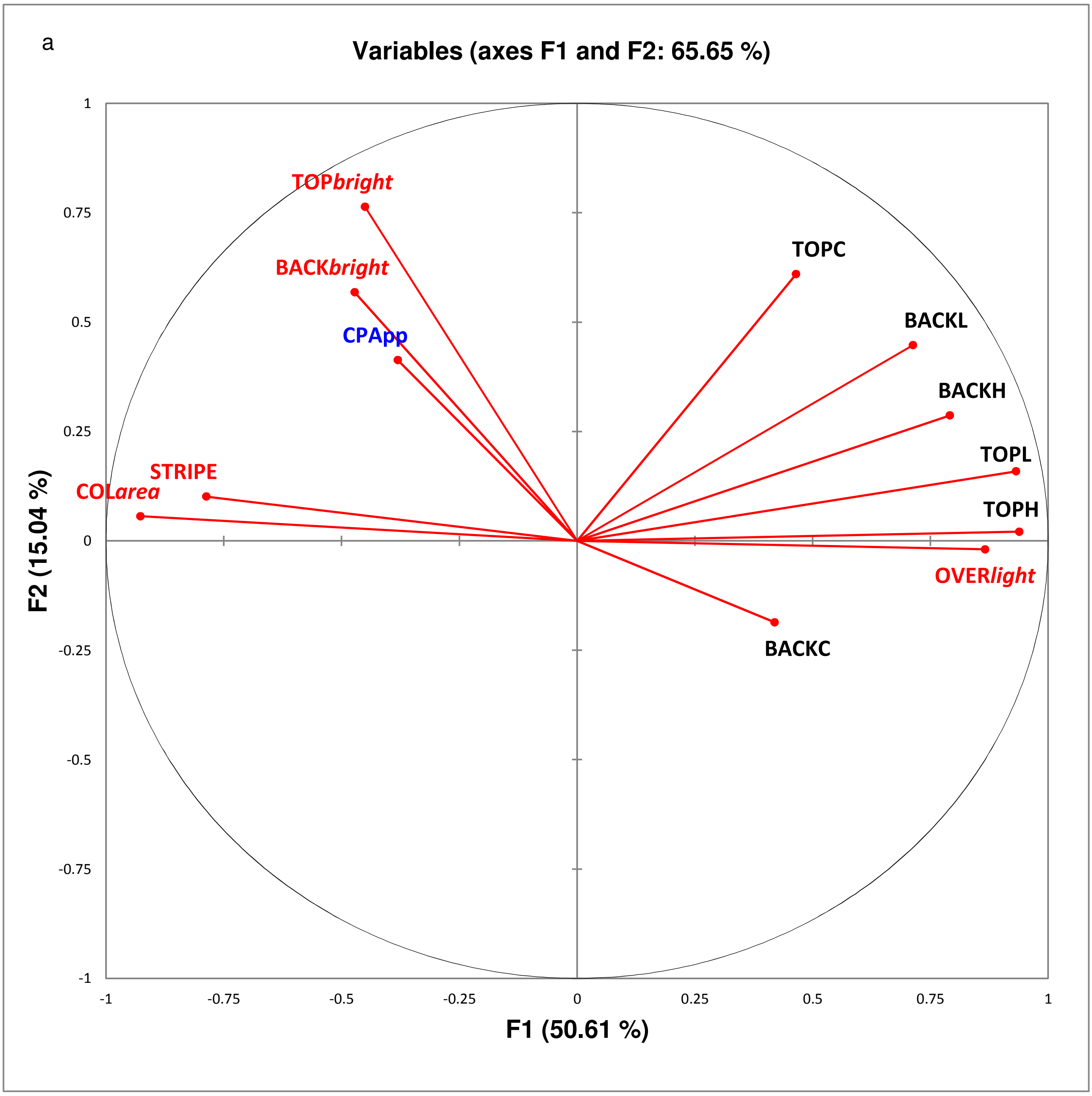


Figure 3a Principal component analysis loadings plot indicating the position of consumers' preference for overall appearance (CPApp) in relation to sensory and instrumental measures of fruit quality. The sensory measurements analysed by the individual assessor included visual brightness of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively (TOP*bright*), brightness of the background colour (BACK*bright*), coloured area (COL*area*), stripeness intensity (STRIPE) and lightness of the overall colour (OVER*light*). Instrumental measurements included lightness (TOPL), chroma (TOPC), hue angle (TOPH) of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively; and the lightness (BACKL), chroma (BACKC) and hue angle (BACKH) of the background colour.

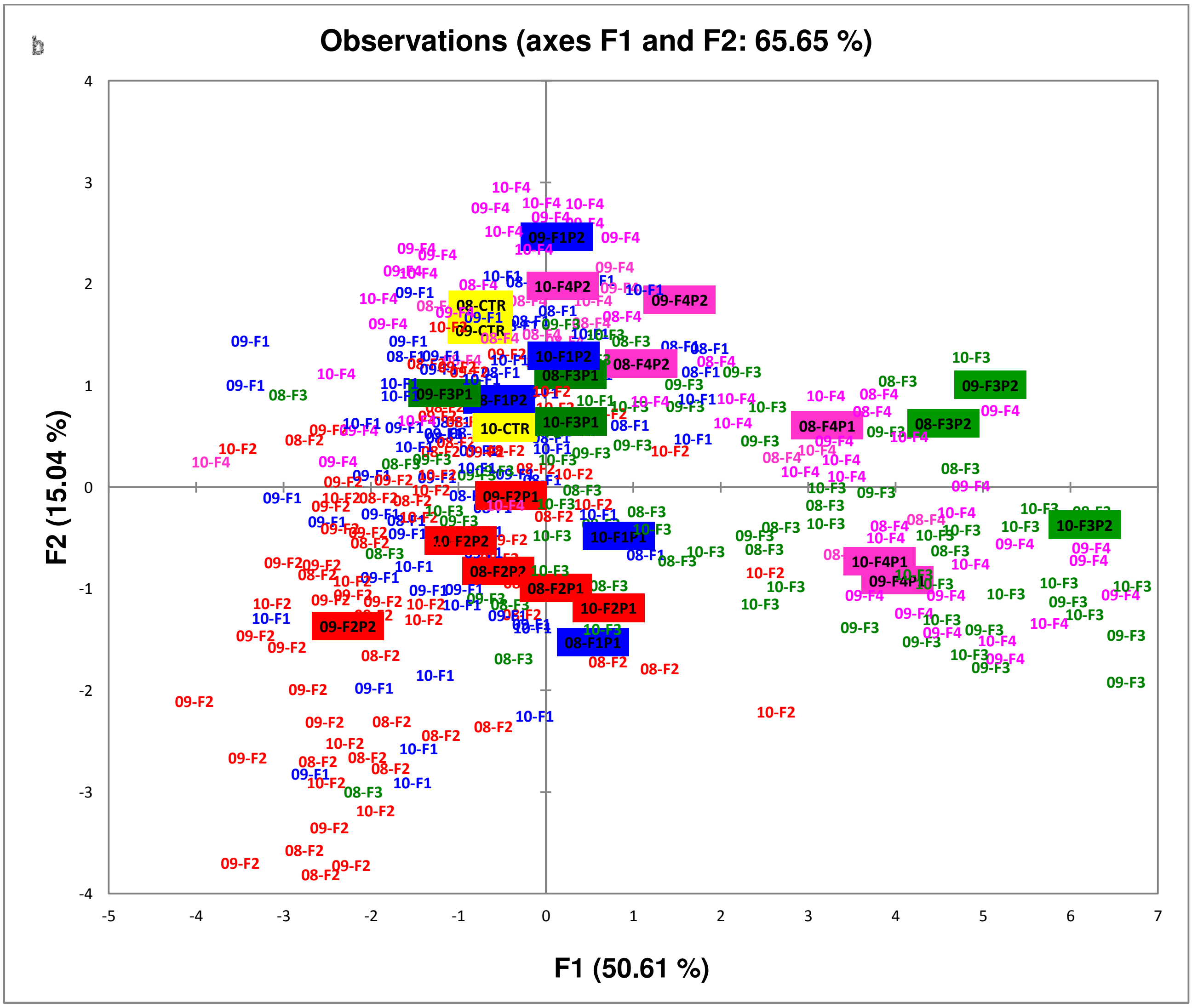


Figure 3b Principal component analysis scores plot indicating the position of the control, four breeding families and parental genotypes in relation to each other, measured by individual assessment of visual brightness of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively, brightness of the background colour, coloured area, stripeness intensity and lightness of the overall colour. Instrumental measurements included lightness, chroma, hue angle of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively; and the lightness, chroma and hue angle of the background colour. The samples were ‘Royal Gala’ control (RG; yellow), ‘Anna’ (F1P1; blue), ‘Scarlet Gala’ (F1P2; blue), family 1 (F1; blue), ‘Prima’ (F2P1; red), 2B-19-22 (F2P2; red), family 2 (F2; red), ‘Treco Red’ (F3P1; pink), ‘Golden Delicious’ (F3P2; pink), family 3 (F3; pink), 8F-8-6 (F4P1; green), ‘Cripps’ Pink’ (F4P2; green) and family 4 (green) for 2008 (08), 2009 (09) and 2010 (10).

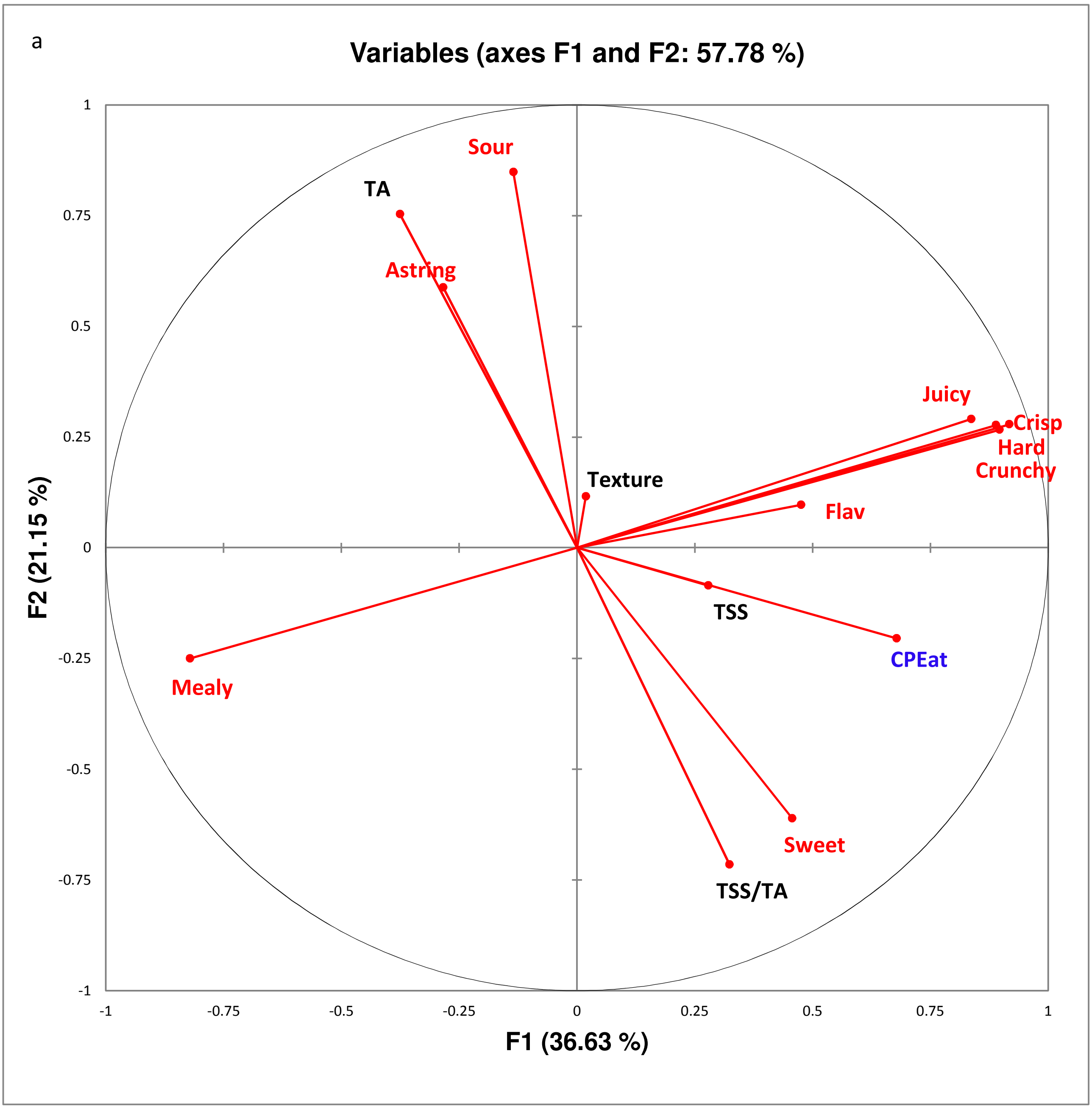


Figure 4a Principal component analysis loadings plot indicating the position of consumers' preference for overall eating quality (CPEat) in relation to sensory and instrumental measures of fruit quality. The sensory measurements analysed by the trained panel included crunchiness (crunchy), crispness (crisp), hardness (hard), juiciness (juicy), overall apple flavour (flav), sweet taste (sweet), sour taste (sour) mealiness (mealy) and astringency (astrin). Instrumental measurements were total soluble solids (TSS), titratable acidity (TA), penetrometer firmness (texture) and the relation of TSS to TA (TSS/TA).

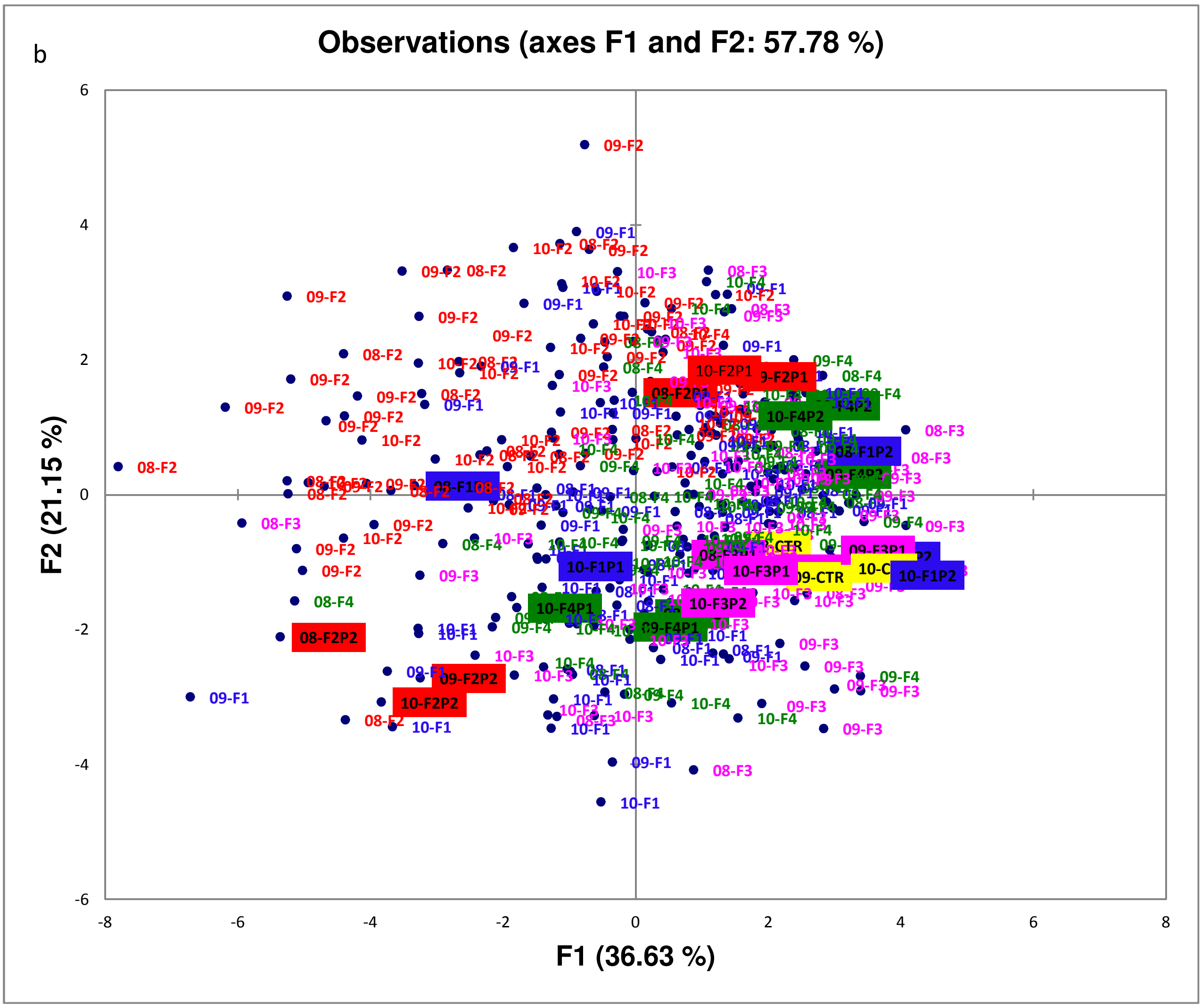


Figure 4b Principal component analysis scores plot indicating the position of the control, four breeding families and parental genotypes in relation to each other, measured by trained panel analysis of crunchiness, crispness, hardness, juiciness, overall apple flavour, sweet taste, sour taste mealiness and astringency. Instrumental measurements were total soluble solids, titratable acidity, penetrometer firmness and the relation of TSS to TA. The samples were ‘Royal Gala’ control (RG; yellow), ‘Anna’ (F1P1; blue), ‘Scarlet Gala’ (F1P2; blue), family 1 (F1; blue), ‘Prima’ (F2P1; red), 2B-19-22 (F2P2; red), family 2 (F2; red), ‘Treco Red’ (F3P1; pink), ‘Golden Delicious’ (F3P2; pink), family 3 (F3; pink), 8F-8-6 (F4P1; green), ‘Cripps’ Pink’ (F4P2; green) and family 4 (green) for 2008 (08), 2009 (09) and 2010 (10).

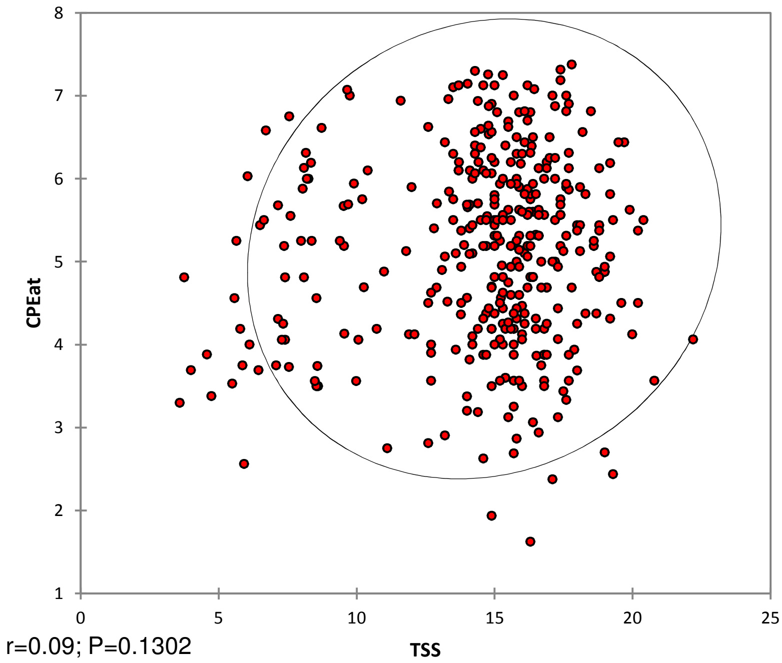


Figure 5 Scatterplot showing the relationship between consumer preference for eating quality (CPEat) and total soluble solids (TSS).

CHAPTER 7

Genotypic variation and heritability of fruit quality attributes within and between apple breeding families

4.7 Principal component analysis

5. DISCUSSION

5.1 Eating quality attributes

5.2 Appearance attributes

6. CONCLUSIONS

7. REFERENCES

1. ABSTRACT

Attributes relating to eating quality and appearance in apple (*Malus x domestica* Borkh.) parental genotypes and seedlings from four breeding families were subjected to instrumental analyses, individual assessment by a trained assessor and descriptive sensory analysis (DSA) by a trained panel. A quantitative genetic analysis of the data was carried out in order to quantify within- and between-family variation using analysis of variance (ANOVA), variance components and broad-sense heritability estimates. Principal component analysis (PCA) was conducted to identify the attributes that explain the largest part of the variation between seedlings. Correlation analysis was applied to investigate possible associations between attributes. ANOVA detected significant variation between families for attributes relating to colour and acidity, while attributes such as sweetness, total soluble solids (TSS) and apple flavour did not show variation between families. In general, colour attributes showed strong genetic control, illustrated by high broad-sense heritability estimates. Crossing of 'Treco Red' (TR) and 'Golden Delicious' (GD), and 8F-8-6 (8F) and 'Cripps' Pink' (CP) resulted in progenies with varying levels of colour brightness, lightness and red colour coverage. Complicated inheritance mechanisms for TA in apple were evident. 'Prima' (PR) was identified as a parental genotype that induces high titratable acidity (TA) in its progeny. Phenotypic correlations between sweet and sour tastes showed that human perception tends to integrate the sensorial experience of these attributes. In addition, integration of apple flavour with other flavour attributes also led to difficulties in objective flavour quantification. Year*family interaction effects and year to year variation support evidence that most attributes investigated are inherited quantitatively. Results confirmed that selection pressure may have played a role in the inheritance and expression of russet and fruit size, resulting in higher levels of russet expression and lower mean weight in progenies compared to parental genotypes. PCA showed that attributes relating to colour explained the largest part of variability in the breeding families. Although a proper experimental design was not applied to test trained panel versus individual assessment, repeatability estimates generated from trained panel data were generally higher than from data generated by the individual assessor. Results indicate that measurements should be repeated for calculation of heritability estimates and proper sensory evaluation during the selection process. The expertise of a trained panel is recommended to verify the potential of selections in the advanced evaluation phases.

Keywords Fruit breeding, fruit quality, descriptive sensory analysis, genotypic variation, heritability estimates, *Malus* x *domestica* (Borkh.).

2. INTRODUCTION

Breeding and selection of new, high-quality apple cultivars that can replace existing cultivars and meet consumer demands are time-consuming, expensive and challenging. It can take between 20 and 25 years before a selection can be released as a new cultivar (Kellerhals & Meyer, 1994). The process of breeding is complicated by a large number of breeding aims that has to be taken into consideration, such as resistance to pests and diseases, a shortened juvenile phase, selection against alternate fruit bearing and a range of fruit quality attributes such as appearance, size, colour, firmness, flavour and sugar and acid balance. Fast selection of these attributes in apple breeding is hampered by self-incompatibility, a long juvenile phase and the complex nature of inheritance of attributes (Liebhard *et al.*, 2003). The simultaneous improvement of desired attributes can be further complicated by genetic correlation between attributes and polygenic control of most of the important attributes (Kouassi *et al.*, 2009).

The focus of the Breeding and Evaluation Division of Agricultural Research Council (ARC) Infruitec-Nietvoorbij is the identification of promising new apple cultivars with ripening dates varying from early to late in the season, good marketing potential, external and internal fruit quality that appeal to local and international consumers and adaptability to an adverse, Mediterranean-type South African climate (Labuschagné, 2012). Breeding and evaluation of apple cultivars in the ARC breeding programme can be divided into four phases: 1) During the first phase, visual and sensory evaluation of seedlings are conducted by an individual breeder in order to select the most promising genotypes; 2) during the second phase, these selections are again subjected to visual and sensory evaluation by the individual breeder, including pre- and post-storage assessments; 3) during the third phase, these selections are given a semi-commercial status and are properly evaluated by postharvest specialists before and after cold storage where fruit are collected from regions with varying climatic conditions; and 4) after evaluation in the third phase, exceptional cultivars are released to the industry.

Genetic parameters are applied to understand the genetic systems that control the inheritance of desirable attributes, such as good flavour, colour and texture, and the genetic and environmental factors that influence their expression (Rowan *et al.*, 2009). Parameters such as variance components, heritabilities and genotypic and phenotypic correlations among desirable attributes are useful to make predictions of genetic progress among offspring, especially when parental genotypes are selected based on their own performance (Falconer & Mackay, 1996). The total variance within a population (in this study the term “family” is applied) is the variance of phenotypic values inclusive of all seedlings in the test family. Variance components assign the relative importance of sources of variation as a proportion of the total variance. The magnitudes of these components allow the breeder to estimate the extent of hereditary factors versus environmental influences. When the phenotypic variance is assigned into within-family and between-family variance, the latter component as a proportion of the total variance expresses the degree of resemblance between individuals and is known as the intraclass correlation coefficient (Falconer & Mackay, 1996). Heritability expresses the relative importance of heredity in determining phenotypic values and is a property of the genetic variation within a family, the environmental conditions to which the individuals are subjected and the method of phenotypic measurement (Falconer & Mackay, 1996; Kouassi *et al.*, 2009). High heritability values are favourable and should guarantee the efficiency of mass selection in the field (Durel *et al.*, 1998). Heritability in the narrow sense (or simply heritability) expresses the extent to which phenotypes are determined by the genes transmitted from the parents and can be defined as the ratio of the breeding value to the total phenotypic value (Falconer & Mackay, 1996). The breeding value, or that part of an individual's genotypic value that is due to additive and transmittable gene effects, provides an indication of the value of an individual genotype as a breeding parent, thereby enabling the selection of superior breeding parents (breeding values were not assessed during this study). Broad-sense heritability is expressed as the extent to which the individual's phenotypes are determined by the genotypes or as the ratio of genotypic variance to phenotypic variance. Here genotypic variance refers to total genetic variance including additive, dominance and epistatic components (Falconer & Mackay, 1996).

Heredity of fruit quality parameters may not be independent of each other, and relationships among them should therefore be studied to increase the efficiency of breeding for selected attributes (Cantín *et al.*, 2010). Genetic correlations are of interest in determining how improvements in one attribute may affect another attribute, and in choosing attributes for indirect selection (Alspach & Oraguzie, 2002). It is therefore valuable for predicting the level of expression of an attribute without measuring the attribute directly. Genetic correlations between two studied attributes could result from pleiotropic effects, whereby a gene affects two or more attributes, or from genetic linkage between the different genes (Falconer & Mackay, 1996; Kouassi *et al.*, 2009). Phenotypic correlation (the correlation between phenotypic values) is a non-additive combination of both genetic and environmental correlations (De Souza *et al.*, 1998) and shows the total relationship between attributes (Rowan *et al.*, 2009).

Several studies have examined the phenotypic diversity and relationships of fruit quality attributes in apple (Durel *et al.*, 1998; Liebhard *et al.*, 2003; Kumar *et al.*, 2010). Oraguzie *et al.* (2001) recorded the first estimation of genetic parameters of tree and agronomic attributes with a broad-based population in apple breeding, but did not report on the heritability of sensory attributes. King *et al.* (2000) conducted quantitative genetic analysis over a period of two years on sensory attributes relating to apple texture, which is an important driver of liking for a large proportion of consumers (Chapter 4). Rowan *et al.* (2009) determined heritabilities and phenotypic and genetic correlations for 23 flavour volatiles. Alspach and Oraguzie (2002) used variance components, heritability estimates, and genetic and phenotypic correlations on sensory data to analyse the genetic variability in breeding families. Kouassi *et al.* (2009) estimated genetic parameters of instrumental and sensory attributes using pedigreed genotypes from several European breeding programmes for three years of data collection.

Most studies referred to in the literature only used heritability data from one or two years, whereas three or more years' data collection provides more accurate heritability results (King *et al*., 2000; Kouassi *et al*., 2009). The aim of this study was to assess the genotypic diversity between and within four apple breeding families developed in the ARC apple breeding programme to optimise breeding potential. The specific objectives included: 1) Quantification of the variation, interaction and year effects; 2) estimation of variance components and broad-sense heritabilities in an attempt to explain the genetic control of important attributes; 3) investigation of possible phenotypic correlations between attributes; 4) assessment of possible association between data obtained from sensory and instrumental evaluation and 5) comparison of evaluation protocols performed by an individual researcher and a trained panel in order to optimise selection efficiency. Data sets were accumulated over a period of three years, collected from one location. The experimental design allowed comparison of instrumental measurements with subjective sensory perceptions.

3. MATERIALS AND METHODS

3.1 Plant material

The plant material used as progenitors in this study included six commercial cultivars and two experimental genotypes from the ARC apple breeding programme. Families were identified from controlled crosses performed for the purpose of selecting individual seedlings with good fruit attributes with no attention to any specific mating design. The progenies used were derived from four sets of crosses. These crosses included two early families [family 1 (F1): 'Anna' (AN) x 'Scarlet Gala' (SG) and family 2 (F2): 'Prima' (PR) x 2B-19-22 (2B)] and two late families [family 3 (F3): 'Treco Red' (TR) x 'Golden Delicious' (GD) and family 4 (F4): 8F-8-6 (8F) x 'Cripps' Pink' (CP)]. The resulting seedlings were budded on M25 rootstocks and one tree per genotype was established. Seedlings were planted in a seedling evaluation orchard at the ARC Drostersnes experimental farm in the Vyeboom area, Western Cape Province of South Africa (latitude 34°4'S; longitude 19°4'E). Trees were grown under standard conditions of fertilisation, irrigation and pest and disease control.

3.2 Planting design

Sibling seedlings within each family were planted adjacently in progeny rows in four randomised blocks. The parents used in the crosses were planted within their progeny rows. In the case where these trees did not bear sufficient fruit, parental fruit were harvested from adjacent blocks on the farm, or from another experimental farm in the area, as was the case with parental trees of 8F and CP. Approximately 150 seedlings from each of the four breeding families were harvested for three consecutive seasons. Fruit were harvested from approximately sixteen trees of each parent.

3.3 Data collection

The fruit were harvested when maturity (based on appearance, texture and flavour) was judged to be optimal and at a stage where the fruit were eat-ripe (70% to 90% starch breakdown). This was done by weekly testing and harvesting during the January to May 2008, 2009 and 2010 harvest seasons. During the first year fruit were erroneously judged to be eat-ripe and harvested at a slightly earlier stage (70% to 80% starch breakdown). For each year, a representative three-fruit sample from each seedling tree was subjected to instrumental measurement and individual sensory assessment. In some cases poor fruit set resulted in sampling of two fruit. A sub-selection of thirty-two seedlings was selected for trained panel analysis from each of the four families to represent the largest genotypic variation within each family, as described in Chapter 6.

3.4 Extractions and analyses

Individual (ind) and instrumental analyses were conducted at room temperature (21 ºC) on a three-fruit sample per seedling tree and on sixteen replications of the parent trees, where sufficient fruit were available. These analyses (with the exception of titratable acidity [TA] measurements, which have been conducted at the Department of Horticultural Science, Stellenbosch University, South Africa) were conducted one day after harvest at the fruit analysis laboratory of the ARC experimental farm, Bien Donne, South Africa in 2008 and 2009 and for the early bearing families of 2010. The later bearing families of 2010 were kept in cold storage (–0.5 ºC) at the fruit analysis laboratory of the Department of Horticultural Science, where it was instrumentally and individually analysed once all parental genotypes and seedlings were harvested. One fruit per seedling tree and eight fruit of each parent were selected for trained panel analysis and were kept in cold storage (–0.5 ºC) at ARC Bien Donne for up to eight weeks until analysis commenced. “Trained panel analysis” refers to descriptive sensory analysis (DSA) that was carried out by a trained panel (tp) during March and May 2008, 2009 and 2010 in the sensory research laboratory of the Department of Food Science, Stellenbosch University.

3.4.1 Individual assessment

“Individual assessment” refers to a set of sensory evaluations that was carried out by the individual researcher. This assessor was trained in sensory evaluation practices at the sensory research laboratory, Department of Food Science, Stellenbosch University. The individual assessor was also given a training course by an expert breeder with specific reference to the sensory analysis of apples and the evaluation methods typically used for the assessment of a breeding programme. Unstructured line scales were used for intensity analysis of several visual, taste, flavour and textural attributes (Table 1).

3.4.2 Instrumental analysis

Instrumental analysis included measurement of weight (WEIGHT), diameter (DIAM), fruit firmness (TEXT), total soluble solids (TSS) concentration and TA. WEIGHT (g) and DIAM (mm) were recorded by the individual assessor. TEXT (N) was determined as the maximum force required to push an 11 mm diameter probe with a convex tip into the flesh after peeling two equatorial sites using a motorised penetrometer (Guss Instruments, Stellenbosch, South Africa). The remaining flesh and peel of the three fruit were juiced together and analysed for TSS with a digital refractometer (Atago, Tokyo, Japan). The remaining juice was kept frozen until titration with 0.1 M NaOH (719S Titrino autotitrator, Metrohm 50, Herisau, Switzerland) up to pH 8.1. Results were expressed in gram-equivalents of malic acid per litre of juice, i.e. TA. The TA/TSS ratio was calculated for all samples. External fruit colour was measured on the composite three-fruit samples with a chromameter (NR-3000; Nippon Denshoku, Tokyo, Japan), where lightness (L), chroma (C) and hue angle (H) were recorded on the overcolour (TOPL, TOPC and TOPH, respectively) and on the background colour (BACKL, BACKC and BACKH, respectively). “Overcolour” is used in this study to describe the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively. Normal standardisation protocols were followed on a white tile (L^*=92.30, a^*=0.32 and b^*=0.33). Sixteen replications were performed on each parent.

3.4.3 Descriptive sensory analysis

Panellist training was conducted using the consensus method and analyses were performed according to “Generic Descriptive Analysis”, as described by Lawless and Heymann (2010). The panel consisted of eight female judges and was tested for consistency. During training, samples were chosen to represent the sensory variation in the seedlings to calibrate the panel for the sensory attributes. Unstructured line scales were used for attribute intensity analysis, ranging from 0 (lowest intensity) to 100 (highest intensity). The judges agreed on a consensus list of attributes for describing apple taste, flavour and texture of the peeled samples, viz. sour taste (SOUR*tp*), sweet taste (SWEET*tp*), apple flavour (FLAV*tp*), crispness (CRISP*tp*), hardness (TEXT*tp*) and juiciness (JUICY*tp*). The subset of thirty-two seedlings of each of the four families and all parents were analysed during eight replicate sessions. The sample set included four parents and eight seedlings. Apples were cut into eight slices from stem end to calyx end. Panellists received 12 cut, unpeeled slices of the same seedling per replication, presented on Petri dishes (Kimix, South Africa). Panellists had to peel the samples prior to analysis. Samples were coded with three-digit random codes and served in a complete randomised order, balanced to minimise order and carry-over effects. Data were collected manually via paper questionnaires in 2008 and 2009 and electronically in 2010 using Compusense® Five data collection software (Version 4.2, Compusense Inc., Guelph, Ontario, Canada). Distilled water and water biscuits (Woolworths, South Africa) were provided as a palate cleanser between samples. Profiling was conducted in tasting booths with standardised artificial daylight lighting and temperature control (21 ºC).

3.5 Statistical procedures

Data were analysed using SAS statistical software (SAS, Version 9, 1999, Cary, North Carolina, USA). Individual, trained panel and instrumental data sets were subjected to the Shapiro-Wilk test to test for non-normality (Shapiro & Wilk, 1965). If there was strong evidence for outliers, they were identified and removed from the dataset until the residuals were symmetrically distributed (Glass *et al.*, 1972). Trained panel data were averaged across replicates and panellists per seedling (Johansen *et al.*, 2010). Basic descriptive statistics were calculated for all attributes of all the fruit studied and included maximum and minimum values, means, mean standard errors and standard deviations. Analysis of variance (ANOVA) was performed on all attributes for each year and on a joint analysis for the 3 years to test for year*family (Y*F) interaction effects. The seedling-within-families mean square was used to compare between families if Y*F interaction was not significant, i.e. differences between family means were compared with differences between seedlings within families. In cases where significant Y*F interaction was found, the mean square for Y*F interaction was used as error term in the ANOVA (Kempthorne, 1957). Variance components and intraclass correlation coefficients were calculated using the SAS Variance Component Estimation procedure. Variance components were calculated for attributes measured instrumentally or assessed by an individual assessor and trained panel in order to quantify the variance contribution made by family, seedlings within family, year, Y*F interaction and error to the total variance. A subset of thirty-two seedlings was analysed by the trained panel compared to approximately 150 seedlings per family analysed by the individual assessor. Variance components for instrumental and individually assessed attributes were computed on the same subset of thirty-two seedlings in an independent analysis in order to compare variance components for trained panel, individual and instrumental assessment. Phenotypic correlation analyses were performed using the SAS Correlation procedure and according to Falconer and Mackay (1996). In this study, estimations of broad-sense heritabilities were calculated from variance components as described by Falconer and Mackay (1996). The variance structure was applied according to Labuschagné *et al.* (2002). Principal component analysis (PCA) was performed with XLSTAT software on parental means over three years and individual seedling values for each year's assessment (Addinsoft, Version 2007, Paris, France).

4. RESULTS

4.1 Between- and within-family variation

4.1.1 Eating quality attributes

ANOVA did not detect significant levels of variation between families for TSS and SWEET*ind* (Tables 2 & 3), but differences between families were significant for SWEET*tp* (P=0.0321; Table 4). Accordingly, intraclass correlation coefficients indicated low between-family variation for TSS and SWEET*ind* (Tables 5 & 6). Seedling-within-family variance was low (3.4%) compared to the variance contributed by other factors to the total variance for TSS (Table 5). Average TSS values ranged from 13.2 ºBrix for F2 to 17.0 ºBrix for F3 (Table 7). SWEET*ind* and SWEET*tp* values were significantly lower in F2 (45.1 and 45.3, respectively) compared to F3 (56.3 and 55.5, respectively) (Tables 8 & 9). Progeny means were lower than parental means for TSS of F1 and F2, but were higher than parental means for TSS in F3 and F4 (Table 7). Average SWEET*ind* values were higher in CP (65.9) compared to the other parental genotype for F4 (8F=53.3) and their progeny (54.3) (Table 10). Families were ranked in a slightly different order for SWEET*ind* compared to TSS (Tables 7 and 8).

ANOVA detected significant levels of variation between and within families for TA (P<0.0001) and between families for SOUR*tp* (P<0.0001) and SOUR*ind* (P=0.0034) (Tables 2, 3 & 4). Accordingly, the intraclass correlation coefficients for TA (0.32) and SOUR*ind* (0.20) indicated higher between-family variation compared to other eating quality attributes (Tables 5 & 6). Families were ranked in a similar order for SOUR*ind*, SOUR*tp* and for TA measurements (Tables 7, 8 & 9). SOUR*ind*, SOUR*tp* and TA values were significantly higher in F2 compared to other families, while values for F4 were higher than F3 and F1 (Tables 7, 8 and 9). Progeny means were higher than parental means for TA of all families. This was especially seen in the high progeny means of F2 (0.75) compared to the parental means (0.46) (Table 7). PR (0.58) and CP (0.50) were dominant in inducing higher TA in F2 (Fig. 1a) and F4 (Fig. 1b), respectively, compared to 2B (0.33) and 8F (0.31) (Table 11). TA progeny means for F1 (Fig. 1c) and F3 (Fig. 1d) were lower compared to F2 and F4.

The TSS/TA ratio differed significantly between and within families (P<0.0001) (Table 2). Clear genotypic differences for this attribute were thus shown between all families and family variance consequently contributed to 23% of the total variance (Table 5). TSS/TA values ranged from 19.5 for F2 to 50.9 for F3 (Table 7). Considering the low TSS/TA values and the low within-family variance for F2 (69.8), only a limited number of seedlings in F2 had a high TSS/TA ratio (Table 7). Accordingly, the TSS/TA distribution for F2 was skewed towards lower values. Within-family variance was high for TSS/TA of F3 and the wide distribution was skewed towards higher values. SG had a higher TSS/TA (52.3) compared to AN (28.8) for F1 (Table 11).

FLAV*tp* values differed significantly between families (P<0.0001) (Table 4). Mean FLAV*tp* values for all families were intermediate, but higher in F4 and F3 compared to F1 and F2 (Table 9). FLAV*ind* did not differ significantly between the families (Table 3) and the intraclass correlation coefficient was 0.00 (Table 6).

PEEL*ind* did not differ significantly between families (Table 3). The peel of parental genotypes was on average less tough than in seedlings (Table 8). Peel of AN (82.4) was significantly softer than SG (56.9) (Table 10), which indicate that SG might have had a dominant influence over die peel toughness in F1 (53.14) (Table 8).

TEXT did not differ significantly between families (Table 2), but significant levels of variation for TEXT*ind* (P=0.0067) and TEXT*tp* (P<0.0001) were shown (Tables 3 & 4). Parental means for TEXT were lower than progeny means for all families, but larger differences were reported between parental and progeny means of F1 (60.1 and 101.1 N, respectively) and F2 (50.0 and 93.5 N, respectively) (Table 7). CP (79.3 N) induced higher TEXT in the progeny of F4 (80.6 N) compared to 8F (47.4 N) (Tables 7 & 11). Measurement of TEXT and TEXT*ind* resulted in different ranking orders among families. 2B had the lowest TEXT (38.2 N) among all parents (Table 11). F4 (72.8), F3 (70.0) and F1 (67.5) had significantly higher TEXT*ind* than F2 (56.8) (Table 8). Similar to TEXT*ind*, TEXT*tp*, CRISP*tp* and JUICY*tp* measurements were significantly lower for F2 compared to other families (Table 9).

4.1.2 Appearance attributes

Russet was measured on a scale where high RUS values corresponded to low levels of russet and low RUS values represented high russet levels on the fruit. Significant levels of between-family and within-family variation were found for RUS (P<0.0001) (Table 3). Within-family variance contributed to 32.6% of the total variance for RUS (Table 6). Russet expression was lower and RUS values were significantly higher in F2 (77.7), F4 (77.4) and F1 (70.8) compared to F3 (54.3) (Table 8). F3 showed a high within-family variance (760.4) (Table 8) and value distribution, but tended to segregate into seedlings with high and low RUS (Fig. 2a). Distributions for F1 (Fig. 2b), F2 and F4 were skewed towards higher RUS values and thus lower expression of russet.

The scale that was used to assess LENT conspicuousness corresponded to small or non-significant occurrence of lenticels at the higher end and high conspicuousness at the low end. ANOVA detected significant levels of variation between and within families (P<0.0001) (Table 3). LENT values were significantly lower in F3 (54.9) and in F1 (51.32) compared to F4 (61.9) and F2 (72.7), indicating lower lenticel conspicuousness in the latter two families (Table 8). Progeny means for LENT were lower than parental means for F2, F3, and F4 (Table 8). High variance of LENT within F3 (784.9) and F4 (956.3) was shown (Table 8). 8F (70.6) induced higher LENT values in F4 compared to CP (39.0) and GD (47.00) induced lower values (thus a higher incidence of lenticels in F3 compared to TR (80.6) (Table 10).

ANOVA did not indicate significant levels of variation for DIAM and WEIGHT between families (Table 2). Intraclass correlation coefficients for between-family variation were thus low for DIAM (0.00) and WEIGHT (0.04) (Table 5). WEIGHT for F1 (Fig. 3a) and F2 (Fig. 3b) showed non-normal distribution, while DIAM and WEIGHT for F4 (Fig. 3c) and F3 (Fig. 3d) were normally distributed. SG (106.9 g) induced a lower mean WEIGHT in F1 (110.6 g) than AN (139.1 g) (Tables 7 & 11). The WEIGHT range found among seedlings from F1 (14.0 g – 241.0 g) resulted in the larger variance (1163.2) for F1 (Table 7, Fig. 3a). 2B had a significantly lower WEIGHT and DIAM (80.5 g, 59.4 mm) than all other parental genotypes and probably induced lower values in F2 (94.9 g, 61.6 mm) compared to PR (121.8 g, 67.1 mm) (Tables 7 & 11, Fig. 3b).

COL*area* was used to measure the percentage of colour coverage sensorially, while hue angles measured the proportion of red or green colour instrumentally. High values for COL*area* represented full red-coloured fruit, while blushed or uncoloured fruit generated low values. Higher proportions of red and green colour were represented by low and high hue angles, respectively. For the visual (OVER*light*) and instrumental (TOPL and BACKL) assessment of lightness, a low lightness value corresponded to a dark colour, while lighter colours were indicated by higher lightness values. COL*area*, TOPH, BACKH, TOPL, OVER*light*, TOPC (P<0.0001), BACKL (P=0.0045) and TOP*bright* (P=0.0088) varied significantly between families (Tables 2 & 3). Genotypic variation for COL*area* within families (53.2%) was higher than between families (29.5%) (Table 6). The intraclass correlation coefficient for COL*area* was higher than for the other visually assessed colour attributes. Progeny means for COL*area* were higher than parental means for all families (Table 8). Between-family (43.7%) and within-family variance (43.8%) contributed to the largest part of the total variance for TOPH (Table 5). The intraclass correlation coefficient for TOPL (0.50) revealed higher between-family variation than for the other instrumentally measured colour attributes (Table 5). Significantly higher mean values for TOPH, BACKH, TOPL, OVER*light*, TOPC and lower values for Col*area* in F3 and F4 compared to F1 and F2 showed redder, darker fruit with lower chroma among F1 and F2 progenies (Tables 7 & 8). Fruit of F1 (61.6) had a significantly higher TOP*bright* than F2 (52.1) and F3 (48.4), while F4 (58.2) was comparable to F1 and F2

(Table 8). SG (77.7) and CP (87.5) induced higher TOP*bright* in the progeny of F1 and F4, respectively, when compared with AN (40.1) and 8F (44.0) (Table 10). Hue angles indicated that F3 involved TR with a red overcolour (30.8) on a yellow-green background (66.0) and GD with a full green colour (TOPH= 92.7 and BACKH=105.3), where the percentage of coloured area in TR (95.1) was significantly higher compared to GD (17.3) (Tables 10 & 11). F4 involved parents with light red (8F=59.6) and pink (CP=37.3) blush on a yellow-green (8F=98.3) and green (CP=103.4) background (Table 11). Large variances and wide distribution densities for TOPH and COL*area* shown by F4 (Fig. 4a, b) and F3 indicated that seedlings of these families included non-red as well as blushed fruit (Tables 7 & 8). F4 (Fig. 4a) showed segregation into groups with high and low TOPH and COL*area*, with higher peaks at values that represented redder fruit. Distributions for F1 (Fig. 4c, d) and F2 were skewed towards lower TOPH and BACKH values (thus more red) and higher COL*area* values that represented more full coloured red fruit and higher percentages of coloured peel. BACKH for F3 and F4 showed a skewed distribution towards higher values (thus greener). The higher variances in F1 (450.2) and especially F2 (627.3) indicate that various seedlings from the early families also revealed areas with green background colour (Table 7). F3 (71.2), F4 (70.6) and F1 (65.5) showed significantly higher BACKL values compared to F2 (57.4) (Table 7). BACKC for F3 (44.5) was significantly higher compared to other families (Table 7). SG (69.6) and CP (78.0) induced higher BACK*bright* values in the progenies of F1 (56.6) and F4 (55.6), respectively, than AN (35.9) and 8F (57.1) (Tables 8 & 10).

STRIPE was measured as the percentage of stripe coverage from low (stripes far apart) to high (stripes almost fully covering fruit) on the red part of the fruit. Hundred per cent stripeness could refer to either full red-coloured fruit, or a solid blush on a non-red background. STRIPE did not differ significantly between families (Table 3). F1, F2 and F4 showed skewed distributions towards higher STRIPE, while F3 showed segregation into high and low ranges (not shown). F3 (802.0) and F4 (1090.4) showed larger variation for STRIPE than F1 (175.2) and F2 (96.9) (Table 8).

4.2 Year*family interaction

4.2.1 Eating quality attributes

Y*F interaction effects accounted for 34.5% of the total variance for TSS (Table 5). Cross-over effects were observable for TSS concentrations of F1 and F2, which were significantly lower in 2008 (8.8 and 7.4 ºBrix) compared to 2009 (17.5 and 16.9 ºBrix) and 2010 (15.6 and 15.7 ºBrix) (Table 12). SWEET*ind* and SWEET*tp* Y*F rankings were comparable and showed minor cross-over effects. Apart from SWEET*ind* for F1, F1 and F2 seedlings did not taste significantly sweeter in 2009 and 2010 compared to 2008 (Tables 13 & 14). Significant Y*F interaction for TA (P=0.0088) was explained by differences between F1 and F3 that were only significant in 2008

(Table 12). Measurements of acidity (TA, SOUR*ind* and SOUR*tp*) gave more consistency than measurements of sweetness (TSS, SWEET*ind* and SWEET*tp*). A small cross-over effect explained significant (P<0.0001) Y*F interaction between F4 and F1 (2008) for TSS/TA (Tables 2 & 12). Significant Y*F interaction for FLAVtp (P=0.0014) was explained by differences between F1 and F3 that were only significant in 2009 (Table 14).

Y*F interaction effects contributed to 44.4% of the total variance for TEXT (Table 5). F1 and F2 were subjected to large yearly differences and showed significantly higher TEXT in 2008 (141.8 and 141.6 N) compared to 2009 (81.2 and 74.0 N) and 2010 (76.2 and 63.8 N) (Table 12). F4 was subjected to ranking differences and was significantly firmer in 2010 (85.7 N) compared to 2008 (76.67 N) and 2009 (74.7 N) (Table 12). Y*F interactions were significant for TEXT*tp* (P=0.0021), CRISP*tp* (P=0.0006) and JUICY*tp* (P<0.0001) (Table 4), but cross-over effects were only shown for F3 and F4 in 2010 (Table 14).

4.2.2 Appearance attributes

COL*area*, TOPH, BACKH, TOPL and OVER*light* (P<0.0001) showed significant Y*F interactions (P<0.0001) (Tables 2 & 3). F1 showed greener, lighter fruit (higher TOPH, BACKH, TOPL and OVER*light*) with less colour coverage in 2008 compared to 2009 and 2010. TOPH, BACKH and TOPL values for F2 were higher in 2008 and 2010 compared to 2009, but COL*area* did not differ significantly (Tables 12 & 13). TOPC for F1 and F2 was lower in 2009 (39.9 and 30.9) compared to 2010 (41.9 and 33.3) and 2008 (42.1 and 32.6) (Table 12). F3 showed comparable TOPL and OVER*light* in 2008 (53.6 and 36.9) and 2009 (54.7 and 38.6), but fruit were significantly lighter in 2010 (56.5 and 43.8). F4 fruit were redder and higher percentages of colour coverage were shown in 2010 compared to 2008 and 2009 (Tables 12 & 13). TOPL for F4 was comparable in 2009 (54.2) and 2010 (54.1), but lower in 2008 (52.6) (Table 12). BACKC (P=0.0046) showed significant Y*F interaction effects (Table 2) and showed higher values for F1 and F3 in 2009 (41.7 and 46.0) compared to 2010 (40.5; 44.0) and 2008 (39.5; 43.5) (Table 12). BACKC for F4 was higher in 2008 (42.4) and 2009 (42.0) compared to 2010 (40.2) and BACKH was higher in 2008 (90.1) compared to 2010 (84.1) and 2009 (80.1) (Table 12). Cross-over effects were observed for BACKL of F1, F3 and F4, while F2 constantly had the lowest BACKL (Table 12). Cross-over effects were observed for STRIPE of F4, which showed the highest values among families in 2008 (86.0), but changed ranking position in 2009 (49.7) and 2010 (76.1) (Table 13).

4.3 Year to year variation

4.3.1 Eating quality attributes

Yearly means across families for TSS (P=0.0266) and SWEET*ind* (P=0.0178) differed significantly (Tables 2 & 3). The effect of year on TSS, expressed as a percentage of the total variance, made a larger contribution (43.8%) compared to the other components (Table 5). TSS means were significantly higher in 2009 (17.2) and 2010 (16.0) compared to 2008 (11.1) (Table 12). SWEET*ind* values were higher in 2009 (62.1) compared to 2008 (51.9) and 2010 (47.2) (Table 13). Although year contributed only 3.3% to the total variance for TA, yearly means across families differed significantly (P<0.0001) (Tables 2 & 5). Mean TA was significantly higher in 2009 (0.60) compared to 2008 (0.53), which was significantly higher than in 2010 (0.51) (Table 12). Family means for TSS/TA were significantly higher in 2010 (41.1) compared to 2009 (35.5) and 2008 (26.4) (Table 12). ANOVA indicated significant levels of variation between years for FLAV*ind* (P=0.0002) and FLAV*tp* (P<0.0001) (Tables 3 & 4). The year effect made the largest contribution to the total variance for FLAV*ind* (60.1%) (Table 6). FLAV*ind* and FLAV*tp* were significantly higher in 2009 (75.5 and 50.9) than in 2008 (64.3 and 45.7) and 2010 (37.3 and 44.3) (Tables 13 & 14). Year did not have a significant effect on PEEL*ind*, TEXT, TEXT*ind*, JUICY*ind* and TEXT*tp* of families, but differences in yearly means across families were significant for CRISP*tp* (P=0.0276) and JUICY*tp* (P<0.0001) (Tables 2, 3 & 4). Yearly means for CRISP*tp* and JUICY*tp* were significantly higher in 2008 (47.1 and 48.6) and 2009 (46.8 and 48.7) compared to 2010 (43.7 and 42.2) (Table 14).

4.3.2 Appearance attributes

Year did not have a significant effect on DIAM, but yearly means for WEIGHT differed significantly (P=0.0492) (Table 2). WEIGHT was significantly higher in 2009 (114.2 g) than in 2010 (95.1 g), but these values were comparable to 2008 (109.5 g) (Table 12). Family means for RUS (P<0.0001) and LENT (P=0.0159) differed between years (Table 3). Family means for RUS were the highest in 2009 (80.9), significantly lower in 2008 (70.8) and the lowest in 2010 (63.3). LENT means across families were significantly higher in 2008 (62.6) than in 2010 (58.8) (Table 13). Yearly means across families differed significantly for COL*area*, TOPL and OVER*light* (P<0.0001) (Tables 2 & 3). Family means for COL*area* were significantly higher in 2009 (75.7) compared to 2008 (73.1) and 2010 (72.7) (Table 13). Progenies were lighter in 2010 compared to 2009 and 2008, indicated by significantly higher TOPL and OVER*light* means in 2010 (Tables 12 & 13). BACKH, BACKC (P<0.0001), BACK*bright* (P=0.0057) and BACKL (P=0.0026) differed significantly between years (Tables 2 & 3). BACKH values showed greener fruit in 2008 (81.3) compared to 2010 (76.4) and 2009 (68.2) (Table 12). Family means for BACKL and BACKC were significantly lower and higher, respectively, in 2009 compared to 2008 and 2010 (Table 12). BACK*bright* showed significantly higher values in 2009 (60.0) and 2008 (56.7) compared to 2010 (43.9) (Table 13).

4.4 Intraclass correlation coefficients and broad-sense heritabilities

4.4.1 Eating quality attributes

Broad-sense heritability estimates calculated according to intraclass correlation coefficients were low for TSS (0.21) (Table 5). The low intraclass correlation coefficient for SWEET*ind* (0.11) could be explained by a large error component (57.3% of total variance) that contributed primarily to the variation (Table 6). Intermediate broad-sense heritability estimates were calculated for TA (0.55) and TSS/TA (0.64). Seedling-within-family variation accounted for the largest part of the variation for TA (35.2%) and TSS/TA (44.3%), reflecting high heterozygosity for these attributes (Table 5). The broad-sense heritability for SOUR*ind* was low (0.29) and error contributed to the largest part of the variance (51.3%) (Table 6). FLAV*ind* (0.05) showed a very low heritability estimate and year effects contributed to the largest part of the variance (60.1%) (Table 6). The broad-sense heritability estimate was low for TEXT (0.30) and Y*F interaction (44.4%) made the largest contribution to the total variance (Table 5). JUICY*ind* (0.17) and TEXT*ind* (0.15) had low heritability estimates, with high error components (75.9%) (Table 6).

4.4.2 Appearance attributes

WEIGHT and DIAM showed intermediate broad-sense heritabilities (0.46 and 0.47), with high error variances (42.5 and 45.6%) that made the largest contribution to the total variance (Table 5). An intermediate broad-sense heritability was calculated for russet (0.45), with large contributions made by error (40.3%) and seedling-within-family variance (32.6%) to the total variance component (Table 6). Lenticel conspicuousness showed an intermediate broad-sense heritability (0.42), with the error term (50.9%) contributing to the largest part of the variation (Table 6).

Broad-sense heritabilities for TOPH (0.79) and COL*area* (0.77) were high, while BACKH had an intermediate heritability (0.46) (Table 5). TOPL was shown to be highly heritable (0.78), OVER*light* was intermediately heritable (0.59) and BACKL showed a lower broad-sense heritability estimate (0.39) (Tables 5 & 6). Seedling-within-family variation (45.6%), error (39.6%) and family (49.9%) made the largest contributions towards the total variance for OVER*light*, BACKL and TOPL, respectively, indicating high between-family variation for TOPL (Tables 5 & 6). Intermediate broad-sense heritability estimates were calculated for TOPC (0.42), BACKC (0.39) and TOP*bright* (0.45), while BACK*bright* showed a low heritability estimate (0.23) caused by large contributions made by error (64.7%) (Tables 5 & 6). Heritability for STRIPE was low (0.30) with a large variance contributed by error (49.2%) (Table 6).

4.5 Variance components on seedling subset

Variance components were used to calculate repeatability estimates on trained panel data recorded as a measurement of consistent individual differences (Falconer & Mackay, 1996). Here we do not imply that repeatability estimates set the upper limit to heritability, due to differences in measurement and quantification between trained panel and individual assessor. Instrumental measurement of acidity (TA^{32}) (0.47) calculated to a higher repeatability estimate than SOUR*tp* (0.33) and SOUR*ind*^{32} (0.16) (Table 15). The percentage of the total variance contributed to error [seedling(Y*F) error] was larger for SOUR*ind*^{32} (60.6%) than for SOUR*tp* (44.0%) and TA^{32} (32.3%). Sweetness was more influenced by sources of error compared to acidity and consequently showed lower repeatability estimates: TSS^{32} (0.23), SWEET*tp* (0.24) and SWEET*ind*^{32} (0.09) (Table 15). Larger year effects were found for TSS^{32} (43.6%), compared to SWEET*tp* (10.1%) and SWEET*ind*^{32} (9.6%). TSS/TA^{32} (0.65) showed an intermediate repeatability estimate and high seedling-within-family variation was reported (46.4%) (Table 15). FLAV*tp* (0.28) calculated to a higher repeatability estimate than FLAV*ind*^{32} (0.03) (Table 15). Repeatability estimates for TEXT*tp* (0.46) were higher than for TEXT*ind*^{32} (0.18) and TEXT^{32} (0.34) (Table 15). Y*F interaction (41.1%) and year (29.3%) contributed greatly to the total variance for TEXT^{32}, while the error component contributed primarily to the total variance for TEXT*ind*^{32} (77.7%). JUICY*tp* (0.36) showed higher consistency in measurement compared to JUICY*ind*^{32} (0.10), which was subjected to a large contribution of the error component (86.5%). Repeatability estimates for CRISP*tp* (0.40) were slightly higher than for JUICY*tp* and MEALY*tp* (0.35) (Table 15). Larger year effects were found for TEXT^{32} (29.3%) compared to TEXT*ind*^{32} (0.4%) and TEXT*tp* (0.0%).

4.6 Correlation analyses

4.6.1 Phenotypic correlations between instrumental and individually assessed attributes

Low negative phenotypic correlations were observed between SWEET*ind* and SOUR*ind* (r=−0.15; P<0.0001). TA and TSS were not significantly correlated. TA and SOUR*ind* showed a stronger correlation (r=0.57; P<0.0001) compared to TSS and SWEET*ind* (r=0.28; P<0.0001). Low correlations were found between TSS/TA and SWEET*ind* (r=0.17; P<0.0001), SWEET*ind* and JUICY*ind* (r=0.16; P<0.0001) and FLAV*ind* and JUICY*ind* (r=0.15; P<0.0001). SWEET*ind* and FLAV*ind* (r=0.52; P<0.0001) were intermediately correlated. COL*area* showed a strong negative correlation with OVER*light* (r=−0.78; P<0.0001) and TOPL in general (r=−0.86; P<0.0001), but correlation coefficients between COL*area* and TOPL were higher in F3 and F4 (r=−0.75 and −0.80, respectively; P<0.0001) compared to F1 and F2 (r=−0.43 and −0.41, respectively; P<0.0001). Although the effect of TOPH on TOPL was significant among all families (r=0.96; P<0.0001), this effect was family dependant and higher in F3 and F4 (r=0.96 and 0.96; P<0.0001) compared to F1 and F2 (r=0.83 and 0.77, respectively; P<0.0001). OVER*light* among all families showed a strong positive correlation with TOPL (r=0.79; P<0.0001), TOPH (r=0.80; P<0.0001) and an intermediate correlation with BACKL (r=0.57; P<0.0001). A stronger correlation was found between TOP*bright* and BACK*bright* (r=0.52; P<0.0001) compared to TOPC and BACKC (r=0.36; P<0.0001).

4.6.2 Phenotypic correlations between instrumental, trained panel and individual attributes

Intermediate negative phenotypic correlations were observed between SWEET*tp* and SOUR*tp* (r=−0.59; P<0.0001), but SWEET*ind*^{32} and SOUR*ind*^{32} did not correlate significantly. FLAV*tp* and JUICY*tp*, FLAV*tp* and SWEET*tp*, and FLAV*ind*^{32} and SWEET*ind*^{32} were intermediately correlated (r=0.56, 0.43 and 0.52, respectively; P<0.0001). TA^{32} correlated intermediately with SOUR*tp* and SOUR*ind*^{32} (r=0.61 and 0.53, respectively; P<0.0001). TSS/TA^{32} showed a stronger correlation with SWEET*tp* (r=0.45; P<0.0001) than TSS^{32} with SWEET*tp* and with SWEET*ind*^{32} (r=0.24 and 0.34, respectively; P<0.0001). SWEET*tp* and SWEET*ind*^{32}, SOUR*tp* and SOUR*ind*^{32}, and FLAV*tp* and FLAV*ind*^{32} showed poor to intermediate correlations (r=0.32, 0.46 and 0.39, respectively, P<0.0001). Strong correlations were observed between trained panel analysis of texture measurements relating to firmness for all seedlings: CRISP*tp* and HARD*tp*, JUICY*tp* and TEXT*tp*, and JUICY*tp* and CRISP*tp* (r=0.96, 0.74 and 0.82, respectively; P<0.0001). Strong negative correlations were observed between MEALY*tp* and CRISP*tp*, MEALY*tp* and HARD*tp*, and MEALY*tp* and JUICY*tp* (r=−0.77, −0.76 and −0.74, respectively; P<0.0001).

4.7 Principal component analysis

The PCA bi-plot (Fig. 5) illustrated that 37.8% of the observed variance could be explained by the first two principal components. The first (PC1) and second principal components (PC2) explained 27.3% and 10.5%, respectively, of the total variability in the data. Table 16 shows the correlations between the original attribute loadings and PC1 and PC2. Although seedlings from all families could be observed in all four quadrants, there was a general tendency for F1 and F2 seedlings to group together on the left side of the bi-plot, while F3 and F4 seedlings associated on the right side of the bi-plot.

Component loadings on PC1 mainly explained the colour differences between seedlings, viz. TOPL, TOPH, COL*area*, OVER*light*, BACKH, BACKL and STRIPE (Table 16). Seedlings that were situated on the right side of PC1 associated with TOPH, TOPL, BACKH, BACKL and OVER*light* and included mostly F3 and F4. Their association with higher lightness values (thus lighter colours) and higher hue values (thus greener fruit) indicate that these seedlings were either uncoloured (green), or had a light pink/red blush on a green background. Seedlings situated on the left side of the bi-plot and far from TOPH, TOPL, BACKH and BACKL associated with STRIPE and COL*area*. These seedlings had darker colours, with lower hue values (more red), higher STRIPE and higher colour coverage that associated mostly with F1 and F2. Several F4 seedlings on the top left part of the bi-plot associated with BACK*bright* and TOP*bright*.

PC2 represented mainly differences in WEIGHT, JUICY*ind*, TEXT, DIAM and FLAV*ind* (Table 16). Seedlings situated on the positive end of PC2 associated with bigger fruit (higher WEIGHT and DIAM) and also had a higher firmness. Several F1, F3 and F4 seedlings associated with these attributes. Although exceptions for F2 seedlings were observed, these seedlings were mostly situated opposite TEXT and JUICY*ind* and close to SOUR*ind* and TA, indicating softer textures or higher acidity.

5. DISCUSSION

Quantification of genotypic diversity between and within breeding families, estimation of genetic parameters (e.g. variance components and broad-sense heritabilities) and knowledge about the relationships between attributes can provide useful information about genetic control, which will enable breeders to determine the most efficient design for mating and seedling evaluation (Liebhard *et al.*, 2003; Kouassi *et al.*, 2009). If several attributes have to be improved simultaneously for new cultivars in a breeding programme, it is important to know how these attributes are related and to determine the strength of their heritability. Variance components and genetic parameters are dependent on several factors such as family size, genetic relationship between families, selection intensity, degree of inbreeding and environmental effects (Kouassi *et al.*, 2009). The accuracy of these parameters and the quality of the data that are generated are further determined by repeated measures over harvest seasons and the protocols for attribute evaluation (Falconer & Mackay, 1996; King *et al.*, 2000; Kouassi *et al.*, 2009). Comparisons of results from the literature present several discrepancies for variance components and heritability estimates of apple quality attributes.

Repeatability estimates calculated for trained panel analysis were mostly higher than broad-sense heritability estimates computed for the individual assessor, possibly due to differences in sample size, measurement and quantification methodology: Individual fruit were subjected to repeated measures by eight trained panellists. Trained panel data were thus generated by computing mean values of 8 measurements of 1 fruit per seedling tree per year. Individual assessment data were generated by computing mean values for three fruits per seedling, where each fruit was assessed once on a small proportion of the entire fruit. Trained panel assessment generated 8 datapoints per seedling, thereby reducing the variation within one single seedling fruit, while the one datapoint that was allocated for each seedling during individual assessment accounted for variation between different fruit from the same seedling tree. Variability within fruit and variation between fruit within a tree are important sources of variation (Dever *et al.*, 1995; Plotto *et al.*, 1997; Thaipong & Boonprakob, 2005).

5.1 Eating quality attributes

Although variation in the flavour of apples is predominantly determined by the balance between sugars and acids (Liebhard *et al.*, 2003), apple flavour also comprise of flavour volatiles (Rowan *et al.*, 2009). The ratio between TSS and TA that is often used as an indication of the flavour intensity in apple (Oraguzie *et al.*, 2009) was therefore a poor predictor of the sensory perception of apple flavour, as also seen in Chapter 6. Although FLAV*tp* was highly variable between families, FLAV*ind* did not show significant variance. The complexity of measuring apple flavour (Janick *et al.*, 1996; Harker *et al.*, 2003; Seppä *et al.*, 2012) impeded the accurate quantification of genotypic diversity among families by the individual assessor, who was possibly not able to accurately distinguish between different levels of apple flavour. Narrow-sense heritabilities for sensory apple flavour reported by Kouassi *et al.* (2009) (ranging from 0.09 to 0.15 for three different storage times) and by Durel *et al.* (1998) (0.39) were higher than in the current study for the individual assessor (0.05) but comparable to the trained panel (0.28). Since apple flavour is a driver of consumers' preference for apple eating quality (Chapter 6), it is essential to accurately quantify and estimate the variability and heritability of apple flavour by distinguishing different apple flavours more effectively. Various flavours in apple can range from grassy, fresh, soapy, pear-like, peardrops (the flavour associated with peardrops candy), watery, plum/cherry, spicy, musty and flowery (Watada *et al.*, 1983; Daillant-Spinnler *et al.*, 1996).

The total sugar concentration as well as the proportion of the main sugars present in apple, viz. fructose, sucrose and glucose, have shown wide variation between different cultivars in previous studies (Brown & Harvey, 1971). However, a low level of genetic variability for TSS and SWEET*ind* was shown between the families used in the current study. Low between-family variations could partly be ascribed to low level differences of TSS ratings in parental genotypes. These results further suggest the impact of environmental effects on TSS concentration in the apple breeding families used in the present study, as was also suggested by Kenis *et al.* (2008). Lower TSS for F1 and F2 in 2008 compared to 2009 and 2010 probably caused the significant contributions that were made by year and Y*F interaction effects to the total variation for TSS. Low TSS for the early families in 2008 could be ascribed to the low sugar concentrations in immaturely harvested fruit (Visser *et al.*, 1968). Immature harvesting is a result of the difficulties involved in determining optimum maturity of red fruit when background colour is not revealed (Willson & Whelan, 1990), especially among seedlings that are subjected to variations in ripening dates. The effect of too early harvesting was also prevalent in other attributes, which will be discussed later. Parental genotypes of F4 were effective in inducing higher TSS in their progeny, while parents of F2 induced a low TSS.

The large contribution of the error component to the total variance for SWEET*ind* (57.3%) and the low broad-sense heritability estimate computed in the current study (0.11) could partly be ascribed to the complexity of sweetness and tasting fatigue involved in the sensory assessment of sweet taste (Oraguzie *et al.*, 2009). A similarly low narrow-sense heritability estimate (0.12) was obtained by Alspach and Oraguzie (2002) for data collected in a breeding programme. TSS in the current study generally computed to higher heritability estimates compared to individual sensory assessment of sweet taste. Similarly, narrow-sense heritability estimates obtained by Kouassi *et al.* (2009) were lower for sweet taste compared to TSS and ranged from 0.25 to 0.29 and from 0.49 to 0.55, respectively, for different storage times. Year and Y*F interaction effects that were caused by too early harvesting contributed to lower broad-sense heritability estimates for TSS (0.21) in the current study, but were not pronounced for sensory assessment of sweet taste.

Between- and within-family variance that contributed largely to the total variance for TA and SOUR*ind* is indicative of a wider genetic variability between the parental genotypes and segregants. The significant effect of year on TA could be ascribed to environmental factors. Although TA decrease in fruit is a product of maturity, the effect of maturity is more pronounced for TSS than for TA in maturing apples (Visser *et al*., 1968). Similar to findings obtained by Kouassi *et al.* (2009), the present study showed that heritability of instrumentally measured TA was higher compared to sensory evaluated SOUR*ind* and SOUR*tp*. Broad-sense heritability of SOUR*ind* (0.29) in the current study was higher than the narrow-sense heritabilities (0.07 and 0.11 for two sublines in a breeding programme) computed by Alspach and Oraguzie (2002). However, the broad-sense heritability estimates obtained by Kouassi *et al.* (2009) for SOUR*ind* (ranging from 0.52 to 0.63 for three different storage times) and TA (ranging from 0.79 to 0.81 for four different storage times) were considerably higher than the values obtained in the present study. It is important to consider the method of quantification and assessment when comparing these results.

Between- and within-family variance contributed largely to the total variance for TSS/TA, indicating strong genetic control for this attribute. The high TSS/TA of F1 (40.5) could be ascribed to the high TSS (17.0) of this family, while the low TSS/TA for F2 (19.5) resulted from its high TA (0.75). Parental genotypes for F2 are not considered as good breeding parents for a programme that aims to increase the TSS/TA value of the progeny. Conversely, GD and TR effectively induced a higher TSS/TA in F3 and SG induced higher TSS/TA in F1. The wide, skewed distribution towards higher TSS/TA for F3 indicated that numerous seedlings with high to very high TSS/TA ratios could be selected from this family. Limited information on the heritability of TSS/TA is available from the literature.

It is vital to understand the mechanisms that explain the genetic control of acidity and sweetness, which are important attributes in driving consumers' preference for apple eating quality (Daillant-Spinnler *et al.*, 1996; Hampson *et al.*, 2000; Chapters 3 & 4). The hypothesis of independent inheritance for sugar and acid content in apple fruit (Visser *et al.*, 1968; Janick *et al.*, 1996; Kouassi *et al.*, 2009) were supported by non-significant phenotypic correlations between TSS and TA obtained in the current study. However, the strong negative phenotypic correlation between SWEET*tp* and SOUR*tp* found in the current study suggests that factors other than genetic and environmental effects may be involved in the directly observable association between these attributes (Falconer & Mackay, 1996). This association can be ascribed to "linkage perception", a concept described earlier by King *et al.* (2000) as "perceptual interaction". The perception of acid taste in the mouth does not only depend on the acid concentration, but also on the concentration and type of sugars present, suggesting that other factors are involved in the subjective quantification of sour taste (Visser *et al.*, 1968). Higher acidity thus leads to the perception of lower sweetness (Oraguzie *et al.*, 2009) and the selection for seedlings with high SWEET*tp* would consequently result in selection against high SOUR*tp*. The intermediate to high negative genetic correlations between the sensory assessment of sweetness and sourness reported previously ($r=-0.74$ and $r=-0.63$; $P<0.01$) (Kouassi *et al.*, 2009; Kumar *et al.*, 2010) again provide evidence for the hypothesis that the sensory perception of these attributes are linked. Linkage perception was more pronounced in trained panel assessment compared to individual assessment, i.e., phenotypic correlations between SOUR*tp* and SWEET*tp* ($r=-0.59$; $P<0.0001$) were intermediate, but were low between SOUR*ind* and SWEET*ind* and non-significant between SOUR*ind*^{32} and SWEET*ind*^{32}. The complexity of measurement that resulted from these perceptual interactions, as was also found in trained panel analyses by Seppä *et al.* (2012) and Poinot *et al.* (2011), could have resulted in the lower heritability estimates for sensory measured sweetness and sourness.

Poor correlations and associations between TSS, SWEET*ind* and SWEET*tp* that were found in the current study and in literature (Hampson *et al.*, 2000; Harker *et al.*, 2002a) illustrated that TSS is a poor predictor of sensory perception of sweetness. Linkage perception and the effect of sour taste on sweet taste probably caused these poor correlations. Quantification of genetic variation for these attributes in seedlings should be specified. SWEET*tp* was better predicted by TSS/TA^{32} ($r=0.45$; $P<0.0001$) than by TSS^{32} ($r=0.24$; $P<0.0001$), because the influence of acidity on sweet taste perception is accounted for in TSS/TA measurement. Lower phenotypic correlations between sensory assessment of sweet and sour taste for the individual assessor compared to the trained panel suggests that the latter was more effected by linkage perception. TA was better able to predict sensory assessment of sour taste.

In accordance with results from previous studies, the present study also showed a polygenic and / or quantitative mode of inheritance for sugar (Visser *et al.*, 1968; Brown & Harvey, 1971). TSS is attributed to five genomic regions on different linkage groups (Liebhard *et al*., 2003). Two patterns are superimposed in the inheritance of malic acid, the main acid in apple fruit: A mechanism of polygenic and / or quantitative inheritance; and a single gene control mechanism, where medium to high acid is dominant over the very low acid type (Visser *et al*., 1968; Janick *et al*., 1996; Liebhard *et al*., 2003). The variability for TA contributed by genotype can be almost fully explained by two QTL's (quantitative trait loci) on two linkage groups, of which one is known to carry the dominant *Ma* gene for malic acid (Liebhard *et al*., 2003). Most cultivars are of the heterozygous *Ma/ma* type (Brown & Harvey, 1971). For control by a single gene, 25% of the progeny of a cross with *Ma/ma* parents will be homozygous (*ma/ma*) and 75% would have a high acidity and contain the heterozygotes (*Ma/ma*) and homozygous high acid (*Ma/Ma*) genotypes (Visser *et al*., 1968; Liebhard *et al*., 2003). When polygenic and single gene inheritance patterns are superimposed, a wide distribution (typical of polygenic control) with skewness towards higher values (typical of single gene dominance) could result, which could explain TA inheritance in F3 in the current study (Fig. 1d). A Chi square test (P=0.7278) showed a clear 3:1 distribution ratio and a group (approximately 25%) with low TA could clearly be distinguished. TA for TR and GD (F3) did not differ significantly, providing evidence for the hypothesis that both these parents were heterozygous (*Ma/ma*). The wide distribution of the seedlings with higher acid fruit that may have inherited the dominant gene could be ascribed to the superimposed quantitative inheritance pattern described by Janick *et al.* (1996). Although F4 showed a normal distribution (typical of polygenic control), the higher family mean compared to mid-parent value was not typical of quantitative inheritance (Fig. 1b). The single gene control mechanism for F4 could be explained by a homozygous recessive (*ma/ma*) and heterozygous (*Ma/ma*) parent. Due to the fact that 8F showed a significantly lower TA than CP, it is suggested that 8F was homozygous for low acid. All F2 seedlings were of the high acid type (Fig. 1a). The only hypothesis that would explain the dominance of the high acid gene would include a parent of the homozygous acid type (*Ma/Ma*). Due to the high acidity of PR and lower acidity of 2B, it is suggested that these parents were homozygous acid (*Ma/Ma*) and homozygous recessive (*ma/ma*), respectively. Progeny TA means that were higher than parental means could be attributed to selection pressure against sourness in previous generations (Visser & Verhaegh, 1978). The TA segregation pattern of F1 could not be explained (Fig. 1c) and here gene interactions may have complicated inheritance patterns (Visser *et al*., 1968).

The genetic control of apple texture has been described to four QTLs (Liebhard *et al*., 2003). Although penetrometer measurement did not show significant levels of variation between families, sensory assessment of textural attributes showed between-family variation. The large contribution made by Y*F interaction effects (44.4%) to the total variance for TEXT resulted from significantly lower TEXT values of the F1 and F2 fruit that were harvested too early in 2008. The effect of immature harvesting was more pronounced in the instrumental assessment of texture.

Considerably smaller Y*F interactions were shown for the sensory textural attributes. CP induced firmer texture in its progeny and is recommended as a parent for breeding families with high instrumental and sensory firmness. The low phenotypic correlations between individually and instrumentally assessed texture (r=0.20; P<0.0001) could partly be ascribed to individual assessment of a small part of the fruit and instrumental assessment on the blushed as well as shaded side of the fruit. Harker *et al.* (2002b) found that texture variability in apple could pertain to measurement on the specific side of the fruit (blushed versus shaded). Gálvez-López *et al.* (2010) found a stronger correlation between penetrometer measurements and sensory assessment of firmness, but a poor correlation was reported between penetrometer measurements and juiciness (r=0.46 and 0.21, respectively; P<0.0001).

Similar to the current study, Kouassi *et al.* (2009) found that penetrometer measurements of texture showed higher heritability estimates compared to sensory measurements. The broad-sense heritability estimate for TEXT in the current study (0.30) was lower than narrow-sense heritabilities reported by Kouassi *et al.* (2009) (0.57-0.71 for three different harvest dates) and by Gálvez-López *et al.* (2010) (0.63-0.66 for two harvest dates). TEXT*ind* heritabilities reported by Kouassi *et al.* (2009) ranged from 0.14-0.20 and were similar to the TEXT*ind* obtained for the current study (0.15). Gálvez-López *et al.* (2010) reported higher broad-sense heritabilities for sensory textural attributes (ranging from 0.73 to 0.80 for juiciness and from 0.85 to 0.89 for crispness) for a family consisting of 141 seedlings. JUICY*ind* (0.34) and TEXT*ind* (0.33) (Durel *et al*., 1998) and JUICY*ind* reported by Gálvez-López *et al.* (2010) (0.35-0.38) were higher than for the current study (0.17). Alspach and Oraguzie (2002) used a 0-9 categorical scale to measure firmness, crispness and juiciness. Heritabilities for firmness (0.36) were higher than in the current study, but juiciness heritability was lower (0.14 and 0.06 for two sublines). Lower heritabilities for JUICY*ind* and TEXT*ind* in the current study could partly be ascribed to the high error components for these attributes. Repeated measures on individual fruit by the trained panel [JUICY*tp* (0.36) and TEXT*tp* (0.46)] would have reduced the error component included in the seedling(Y*F) error term, whereas single measurements by the individual assessor would have inflated the error term, leading to lower heritability estimates. The effect of assessor that is included in the error term is expected to be smaller for trained panel compared to individual assessment and a lower error component and higher heritability estimates were therefore expected and seen for the trained panel. Quantification differences occurred when trained panel assessment of texture (TEX*tp*) measured the intensity of hardness on a scale from 0-100, while individual assessment of texture (TEXT*ind*) was measured on a continuous scale ranging from mealy (low values) to crisp (high values).

Strong positive correlations between trained panel measurements of texture (CRISP*tp* and TEXT*tp*) that were found in the current study were in accordance with results obtained in Chapter 6 and by Daillant-Spinnler *et al.* (1996) that these attributes are used to measure similar textural differences. However, Harker *et al.* (2002b) indicated that juiciness can be applied to measure textural structures other than crispness, hardness and crunchiness. Similar to the negative correlation between mealiness and crispness, hardness and crunchiness, Jaeger *et al.* (1998) found that the perception of mealiness indicates low levels of crispness, hardness and crunchiness. Positive correlations between JUICY*ind* and FLAV*ind* and SWEET*ind* and FLAV*ind* could also result from *linkage perception*. Durel *et al.* (1998) reported phenotypic correlations between FLAV*ind* and JUICY*ind* of 0.47 and Kouassi *et al.* (2009) a range of 0.23-0.28 for three different harvest dates. A mechanism proposed by Hampson *et al.* (2000) whereby a high juice content provides carriers for flavour components and increases the perception of apple flavour adds to our definition of "linkage perception", i.e., humans tends to over- or underestimate the intensity of a sensory attribute in the presence of another attribute that has shown to have an integrated effect on perception.

5.2 Appearance attributes

Significant between- and within-family differences illustrated a wide genetic diversity induced by parental genotypes for expression of russet. The broad-sense heritability estimate of russet in the present study (0.45) was higher than narrow-sense heritability estimates reported by Durel *et al.* (1998) (0.36) and Alspach and Oraguzie (2002) (0.36 and 0.37 for two breeding sublines). Durel *et al.* (1998) used a 1-4 point scale and Alspach and Oraguzie (2002) a 0-9 point grading scale that could lead to reduced precision compared to the continuous scale used in the present study.

Russet expression is controlled by several genes with different effects that do not follow the same inheritance patterns, in addition to external factors such as low temperature, high humidity during early fruit development and chemical spray damage (Janick *et al.*, 1996). Results from the current study suggest that the group of genes involved with russet expression follows an inheritance behaviour that is similar to that of single gene control where rusetting is controlled in a recessive manner. Distribution for F1 (Fig. 2b), F2 and F4 were skewed towards seedlings with low russet expression. Progeny means showed a higher incidence of russet compared to parental means (except for F1), suggesting that selection pressure for low russet expression during the development of the parents could have influenced the inheritance pattern of russet in their progeny. A group with low and another group with higher russet scores that were shown for F3 (Fig. 2a) indicated the possibility of dominance and single gene control. However, data cannot be supported by either a 1:1 or 3:1 ratio, which indicates that russetting is not easily explained by Mendelian genetics. GD is known to be particularly susceptible to russet (Janick *et al.*, 1996). The high within-family variance and wide distribution of F3 indicated that GD and TR positively contributed towards a family from where low russet seedlings or seedlings free of russet can also be selected, even though the high mean values suggest unacceptable levels (Fig. 2a). F1 however, showed a clear 1:3 distribution ratio according to a Chi square test (P=0.3984) (Fig. 2b). Due to higher levels of russet expression in SG fruit, it is proposed that AN was homozygous recessive and SG heterozygous for this attribute.

Size is one of the most important attributes in the selection of apple seedlings. Seedlings that fail to attain the required size should not be considered further in a breeding programme (Janick *et al.*, 1996). Fruit size can be expressed by objective measurement of diameter (mm) or by fruit weight (grams), which in combination can give an indication of fruit shape. Visual assessment of fruit size constitutes measurement on categorical scales, ranging from small to big fruit sizes. The broad-sense heritability estimates for weight (0.46) and diameter (0.47) in the current study were slightly lower than narrow-sense heritability estimates for fruit weight obtained by Alspach and Oraguzie (2002) (0.51 and 0.61 for two breeding sublines) and Oraguzie *et al.* (2001) (0.56). Higher heritabilities were reported by Kumar *et al.* (2010) for weight of four sublines grown on different sites (0.51->1). Lower heritabilities found for fruit size by Durel *et al.* (1998) (0.33) could be ascribed to subjectivity of assessment on a three point grading scale that is less precise than a continuous quantitative assessment used in the current study.

It is known from the literature that fruit size is polygenically controlled, but that the contribution made by parents is complex and that the normal distribution would therefore not be around the parental means (Janick *et al.*, 1996). A small percentage of seedlings in a progeny might have larger fruit than the larger parent, while 50% of the seedlings may be smaller than the smaller parent (Janick *et al.*, 1996), which was clearly illustrated in the current study for F4 (Fig. 3c) and F3 (Fig. 3d). However, non-normal distributions for weight was shown by F1 (Fig. 3a) and F2 (Fig. 3b). Progeny means for weight and diameter that were lower than parental means for all four families could be ascribed to several factors: Smaller progenies could result from extreme selection pressure over many generations where selection was always towards the extreme end of the curve, i.e., there has been a strong selection away from small-sized fruits over generations, resulting in progeny means toward the middle range. Mating large and small apples frequently produce hybrids with fruit size closer to the small parent, suggesting dominance for small fruit size (Janick *et al.*, 1996). Dominance of smaller fruit size is proposed for F2, where 2B was significantly smaller than PR and had a dominant effect on the progeny size. It should be mentioned that smaller progeny means for fruit size could also be attributed to early harvest compared to parental genotypes, as discussed earlier. Furthermore, seedlings in the juvenile phase often bear a small amount of fruit and of small size (Janick *et al.*, 1996). In order to obtain the necessary amount of fruit, small fruit were often used in the current study. Bigger crop loads on mature trees ensure sufficient fruit of acceptable size. The bias towards sampling of bigger fruits in the mature parental trees also contributed to larger parental means compared to progeny means. As seen for F3 and F4, the proportion of seedlings of acceptable size, increase in accordance with the fruit size of the parents. It is thus suggested that large-fruited genotypes should be used as breeding parents in order to ensure a larger proportion of seedlings with an acceptable fruit size (Janick *et al*., 1996). It was found that family means were significantly smaller in 2008 compared to 2009, which could either be attributed to early harvesting in the first year of the experiment (as discussed earlier), environmental factors, or a combination of both.

Fruit colour can be measured subjectively by the human eye, or objectively by a chromameter where H, C and L values indicate hue angle, chroma and lightness, respectively. Hue angle is the attribute of visual perception relating to the proportion of red, yellow, green and blue colour and is measured on a scale ranging from green (values above 110 º) through yellow (lower values) to red (lowest values, but >0 º). Chroma is an indication of the relative colourfulness and measures the amount of hue that an area exhibits, where higher chroma values correspond to higher colourfulness (Hunt & Pointer, 2011). The study of the mechanisms involved in fruit colour inheritance is complicated, because colour expression is affected by fruit maturity, climatic conditions, nutrition, cultural factors and the microenvironment within the area of the tree (Saure, 1990; Telias *et al*., 2011). Overall fruit colour in apple is primarily determined by the ground colour of the peel and secondly by the superimposed anthocyanin pigmentation (Lancaster, 1992). An attractive bright red colour is produced when anthocyanin is superimposed on a ground colour that is almost white or light yellow, whereas a green ground colour could result in the perception of a dull, brown-red colour.

Correlations between instrumental and sensory measurements were stronger for colour attributes compared to flavour attributes. An advantage relating to subjective colour measurements is that assessors are not subjected to similar fatigue that would result from measurements relating to eating quality. In the case of the non-significant correlation and poor association on the PCA bi-plot for TOPC and TOP*bright*, these seemingly related measurements did not measure equivalent attributes, i.e., TOPC measured colourfulness, while TOP*bright* measured brightness. Another reason for differences between TOPC and TOP*bright* is that the overall brightness of the overcolour is taken into consideration during visual assessment when a score is computed that considers the variation in the colouring of the fruit peel within a sample, while instrumental assessment relies on the measurement of small peel regions (average value obtained by measuring two 3 mm diameter spots) (Telias *et al*., 2011).

The genetic control of attributes relating to fruit colour (i.e. TOPH, BACKH and COL*area*) can be studied by examining the regulatory mechanisms involved in anthocyanin expression. High between-family variation found in the current study for these attributes are supported by results from the literature that colour inheritance is under strong genetic control and should be readily easy to breed and select for. F1 and F2 seedlings with either full red or striped red parents associated with higher STRIPE, COL*area* and OVER*light*. The positions of these families opposite TOPH, BACKH, TOPL and BACKL on the PCA bi-plot (Fig. 5) confirmed that seedlings from F1 and F2 generally had darker and redder peel compared to F3 and F4. The negative correlation between COL*area* and TOPL and the positive correlation between TOPH and TOPL showed that higher colour coverage pertained to darker peel that tended towards hue angles from the redder side of the scale. High correlations found between TOPL and TOPH and between OVER*light* and COL*area* illustrated the variability in fruit colour for F3 and F4 seedlings. More uniformly coloured fruit and lower correlations occurred in the early families. It is suggested that environmental factors contributed to year effects for TOPL, OVER*light* and COL*area*.

Anthocyanin biosynthesis is a complex process that is primarily influenced by light, but also by other environmental factors such as temperature and nutrient supply (Honda *et al.*, 2002; Xu *et al.*, 2011). The structural genes that control anthocyanin synthesis exist in all cultivars, but genes in red-fruited genotypes are more easily expressed than genes in yellow and green genotypes that can produce anthocyanin under more specific conditions (Telias *et al.*, 2011). At least five tightly linked structural genes are co-ordinately expressed during anthocyanin expression, which follows a heritability behaviour similar to a single gene that is dominant for red (Honda *et al.*, 2002; Telias *et al.*, 2011), as shown in the current study.

Full red (AN and SG) and full striped red (PR and 2B) fruit were crossed to deliver F1 and F2, respectively. Considering that the majority of the seedlings for F1 (Fig. 4c, d) and F2 were highly coloured and mostly red, all parents for the early families were homozygous for dominant anthocyanin. However, the variance in colouration among the red fruited progeny showed that groups of structural genes were inherited according to a single gene mechanism. The variation that resulted from this heritability behaviour could be ascribed to different levels of expression of the associated genes and regulatory genes that control anthocyanin synthesis (Honda *et al.*, 2002).

Striped (TR) and uncoloured (GD) parental genotypes were crossed to deliver F3 and blushed parental genotypes (CP and 8F) were crossed to develop F4. Parental genotypes for F3 and F4 produced a few non-red seedlings, but most seedlings showed more than 50% coloured area. The wide distribution and the segregation into groups with high and low COL*area* and TOPH for F3 and F4 (Fig. 4a, b) indicated that uncoloured, blushed and full coloured fruit could be selected from these families. It is proposed that these parental genotypes may be heterozygous for the dominant group of genes that controlled anthocyanin production and directed towards a higher proportion of red and coloured fruit. Higher progeny means than parental means for COL*area* could further be ascribed to greater anthocyanin expression caused by exposure to the sun (Janick *et al.*, 1996), which would explain why Chi square tests did not detect clear 3:1 distributions ($P>0.0001$). High variances for coloured area and stripeness illustrated by distribution graphs for STRIPE, COL*area*, and TOPH for F3 and F4 (Fig. 4a, b) indicated large genetic variation and high selection efficiency. A wide distribution range of TOP*bright* for F3 and wide segregation towards high and low values for F4 indicate that these progenies constituted both dull and bright coloured seedlings. F4 fruit that showed a brighter, darker and redder blush colour probably resulted from genes carried by CP, while those seedlings at the lower end of the scale expressed the genes that induced less brightness that may be carried by 8F. This is in agreement with evaluation results showing that red colouration on 8F becomes dull during cold storage (Labuschagné, 2012). The same tendencies were seen in the distribution graphs of BACK*bright*. CP and also SG are efficient parents to use in a breeding programme aiming towards increasing overall brightness and colourfulness. When crossing blushed apples, their progeny will normally be either blushed or non-pigmented, but not striped (Janick *et al.*, 1996). The segregation for F4 at high and low STRIPE, TOPH (Fig. 4a) and COL*area* (Fig. 4b) values therefore indicate that the type of blush that was present in the progeny was mostly full coloured (solid blush), or absent (uncoloured fruit).

As apple fruit mature, the green colour of the immature fruit fades, until the ground colour will be in the white range or white to very pale cream or light yellow to deep yellow; or the green may partially fade, in which case ground colours in the greenish-yellow to yellowish-green range are produced; or the green colour might not fade at all and leave a green ground colour (Janick *et al.*, 1996). The intensity and extent of coloration that develops during maturity in red fruited apple cultivars are important factors in the timing of fruit harvesting (Reay & Lancaster, 2001). However, it is more difficult to determine optimum harvest time for red fruited apples that exhibit minimal colour changes during the later stages of maturity. A higher incidence of fruit with a green background, or less anthocyanin pigmentation in the background areas found in the red fruited early families (F1 and F2) in 2008, could thus be ascribed to too early harvesting of these progenies. Large variances of these families for BACKH values that ranged from low values (≈10) to high values (≈110) illustrated that numerous seedlings were full red or revealed green background areas.

For F3 and F4, it was clearly seen that the distribution was skewed towards higher BACKH values, indicating a higher proportion of seedlings with a green background. These greener backgrounds were expected, considering that less colour development and a higher incidence of blushed or uncoloured fruit occurred in the later families. BACKL showed skewed distributions towards higher lightness values, indicating that seedlings had a lighter ground colour. The ground colour of the peel is polygenically controlled and the yellow and green ranges are independently controlled from the ground colour (Janick *et al.*, 1996). There is limited information available from the literature regarding heritability estimates for ground colour intensity.

6. CONCLUSIONS

Despite the importance of accurate quantification of genotypic diversity of fruit quality attributes for the identification of breeding parents and the optimisation of breeding potential, there is no universally agreed methodology in the literature to objectively compare and apply results. Differences in quantification methods (instrumental, individual researcher and / or breeder and trained panel), measurements (categorical, hedonic and continuous scales), the number of years for data collection, sensory profiling conducted by varying numbers of assessors, plant material (breeding populations and cultivars), orchard management, sampling methodologies (possible bias towards sampling of bigger or more attractive fruit) and differences in storage times possibly caused discrepancies in values related to genotypic quantification and heritability estimates reported in the literature. It is unclear from literature whether the statistical analysis of data generated by groups of assessors are treated as repeated measurements or whether mean values are calculated for seedlings from group assessment.

Differences in measurements between the individual assessor and trained panel in the current study resulted in smaller broad-sense heritability estimates for attributes analysed by the individual researcher compared to repeatability estimates by the trained panel. It should also be considered that repeatability estimates for trained panel assessment was computed on a sub sample of fruit from thirty-two seedlings, while individual assessment was conducted on approximately 150 seedlings per family. The large sample size that was assessed by the individual researcher could have resulted in assessor fatigue (Oraguzie *et al.*, 2009) that may have led to higher error variance components. The effect of the evaluation protocols applied by the individual assessor versus trained panel was evident in the variance component analyses and contribution towards the error components. The error component for trained panel assessment accounted for within-fruit variation, while the error component for individual assessment accounted for different fruit from the same tree. Within-fruit (blush/non-blush, top/bottom) variation has shown significant effects on quality parameters (Dever *et al.*, 1995), while repeated measures have been proven as the best way to overcome the between-fruit influence of heterogeneous material (Williams & Carter, 1977). The variation caused by trained panels or small groups of expert breeders is expected to be smaller compared to assessor variance of an individual researcher, which is currently the mainstay of evaluation in the first phase of the ARC apple breeding programme. A comparison between the broad-sense heritability estimates and repeatability estimates is not viable and the variance contributed by assessors (tp versus ind) could therefore not be quantified. Care should thus be taken in the interpretation of these results. However, results in the current study are used to demonstrate differences between the applied methods of evaluation.

It was shown that instrumental and sensory assessment of attributes can measure and reflect different underlying genetic factors. Linkage perception that contributed to differences in sensory and instrumental measurements that aimed to measure the same parameters should be taken into consideration during the quantification of genotypic diversity or the estimation of heritability. Human perception tends to integrate or link the sensory sensations caused by several attributes, as was evident from the phenotypic correlation between sweet and sour taste. This correlation resulted in the improved ability of TA to predict sour taste compared to the ability of TSS to predict sweet taste. TSS/TA was a better predictor of sweet taste than TSS.

The possible interaction effects of groups of genes that control TA complicate the identification and selection of parents in a breeding programme that aims to increase acidity in the progenies. Considering that TSS in apple is under quantitative genetic control, it is difficult to estimate a measurable benchmark for genetic gain for apple taste and flavour. Instrumental and sensory quantification of attributes relating to taste and flavour in apple is a high priority, partly due to the complexities involved with the inheritance and the combination and interaction of attributes that determine apple flavour, but also due to the high importance of these attributes in driving consumer liking (Chapters 3 & 4). Flavour attributes could be better quantified if panellists are trained in the objective assessment of more accurately defined attributes enabling them to discriminate between attributes that are subjected to strong linkage perception.

Results from the present study indicated high genotypic diversity and broad-sense heritabilities among families for attributes related to colour, indicating that selection for these characteristics could result in high genetic gain in a breeding programme. The agreement between sensory and instrumental measurements relating to colour is indicative of the relative ease and simplicity in measuring these attributes sensorially. The influence of groups of genes in inheritance and expression of anthocyanin was also evident in the present study.

This study showed that PCA analysis can be successfully used to identify attributes that explain a significant percentage of the variability in the breeding stock, by simplifying the visualisation of the complete data set from individual and instrumental assessment in a reduced dimensional plot. It was seen that seedlings from different families mostly grouped together on PC1 and PC2. Novel seedlings could be selected from the outer level of the PCA bi-plots that would constitute a combination of attributes distinguishable from other seedlings. Associations between attributes could be visualised. Close association on the PCA bi-plot and strong correlation coefficients for attributes such as TOPL, BACKL, TOPH and BACKH indicate that selection for each of these attributes would also result in higher levels of the associated attributes in a progeny.

Heritability estimates for attributes subjected to sensory and instrumental measurements in the present study were mostly lower than values reported in the literature. Although instrumentally measured attributes mostly showed higher broad-sense heritability estimates compared to sensorially attributes analysed by the individual assessor, instrumental measurements cannot substitute sensory assessment in all cases. Higher heritability estimates for instrumentally measured attributes would therefore not necessarily result in increased breeding efficiency and to develop progenies with improved flavour or consumer acceptance. Heritability estimates should thus be considered independently for instrumentally and sensorially measured attributes.

From the present study it is suggested that universal methodologies for the quantification of genetic parameters should be developed and applied in apple breeding and selection programmes. Data from measurements for more than two years should be used to increase accuracy. Considering the large amount of fruit that has to be assessed during the first evaluation phase, seedlings that show obvious defects and poor fruit quality (for example, visually unattractive fruit, very small fruit, poor texture or unacceptable levels of acidity) could be eliminated from selection by individual breeders. The remaining seedlings should be assessed by small groups (2-4) of assessors during the first and second evaluation phases. Individual assessment could be optimised by repeated measurements, instead of estimating a single score for a composite sample of fruit. Assessors should use continuous bi-polar scales to quantify the attributes relating to eating quality and appearance. Means computed by the proposed method could lead to smaller error components contributed by within-fruit variability, variability between fruit from the same tree and between assessors. It is recommended that formal sensory analyses by trained panellists should commence in the third evaluation phase. Considering the importance of sensory attributes in driving consumer liking, it is important that assessors of a breeding programme do not rely only on their own judgement to quantify sensory attributes, but incorporate trained panellists to obtain a more accurate estimation of the genotypic variation and heritability values.

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Table 1 Descriptions of attributes measured by individual assessor and abbreviations applied in text

Abbreviation	Attribute description	Scale/Unit
COL*area*	Coloured area	0-100; uncoloured - full coloured
STRIPE	Incidence of stripeness	0-100; no striped - full coloured
OVER*light*	Visual lightness of the overall colour	0-100; dark - light
TOP*bright*	Visual brightness of the overcolour	0-100; dull - bright
BACK*bright*	Visual brightness of the background colour	0-100; muddy - bright
RUS	Russetting of the fruit peel	0-100; high visibility- low visibility
LENT	Lenticel conspicuousness	0-100; conspicuous - inconspicuous
PEELind	Thoughness of the fruit peel	0-100; tough - soft
SOUR*ind*	Sour taste	0-100; low - high
SWEET*ind*	Sweet taste	0-100; low - high
FLAV*ind*	Apple flavour	0-100; low - high
JUICY*ind*	Juice content of the fruit flesh	0-100; dry - juicy
TEXT*ind*	Sensory texture of the fruit flesh	0-100; mealy - crisp

Table 2 Analysis of variance (ANOVA) for instrumentally measured quality attributes in four apple breeding families. Data were recorded on seedling trees during three years (2008, 2009 and 2010). Quality attributes included weight of the fruit (WEIGHT), diameter (DIAM), titratable acidity (TA), total soluble solids (TSS), TSS/TA and instrumental texture (TEXT). Colour measurements included lightness (TOPL), chroma (TOPC), hue angle (TOPH) of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively; and the lightness (BACKL), chroma (BACKC) and hue angle (BACKH) of the background colour

Atttribute and source of variation	***df***	***MS***	***F***	***P***
WEIGHT* (g)				
Year	2	66457.239	5.19	0.0492
Family	3	26602.648	2.08	0.2048
Y*F interaction	6	12809.961		
Error=Seedling(Y*F)	1834	735.950		
DIAM* (mm)				
Year	2	2730.909	4.57	0.0621
Family	3	346.143	0.58	0.6494
Y*F interaction	6	596.940		
Error=Seedling(Y*F)	1837	39.347		
TA (% malic acid)				
Family	3	8.677	146.47	<0.0001
Seedling(Family)	911	0.059	3.23	<0.0001
Year	2	1.013	55.24	<0.0001
Y*F interaction	6	0.053	2.88	0.0088
Error	741	0.018		
TSS* (ºBrix)				
Year	2	5418.698	7.61	0.0226
Family	3	973.302	1.37	0.3398
Y*F interaction	6	712.306		
Error=Seedling(Y*F)	1774	2.529		
TSS/TA				
Family	3	66909.787	103.98	<0.0001
Seedling(Family)	895	643.496	4.26	<0.0001
Year	2	12719.158	84.18	<0.0001
Y*F interaction	6	1623.181	10.74	<0.0001
Error	686	151.093		
TEXT* (N)				
Year	2	2802.860	3.50	0.0982
Family	3	237.247	0.30	0.8270
Y*F interaction	6	800.071		
Error=Seedling(Y*F)	1775	3.138		
TOPL				
Family	3	52607.981	298.29	<0.0001
Seedling(Family)	931	176.363	7.56	<0.0001
Year	2	484.466	20.77	<0.0001
Y*F interaction	6	363.839	15.60	<0.0001
Error	882	23.328		

TOPC				
Family	3	13994.513	311.35	<0.0001
Seedling(Family)	930	44.947	2.38	<0.0001
Year	2	50.214	2.65	0.0709
Y*F interaction	6	105.077	5.55	<0.0001
Error	881	18.920		
TOPH				
Family	3	111234.361	217.99	<0.0001
Seedling(Family)	931	510.263	7.93	<0.0001
Year	2	139.473	2.17	0.1150
Y*F interaction	6	704.080	10.94	<0.0001
Error	881	64.338		
BACKL*				
Year	2	9752.411	7.05	0.0266
Family	3	18653.177	13.49	0.0045
Y*F	6	1382.827		
Error=Seedling(Y*F)	1816	105.470		
BACKC				
Family	3	2365.046	57.03	<0.0001
Seedling(Family)	931	41.468	2.28	<0.0001
Year	2	396.368	21.80	<0.0001
Y*F interaction	6	57.289	3.15	0.0046
Error	882	18.186		
BACKH				
Family	3	52112.446	92.28	<0.0001
Seedling(Family)	933	564.718	2.65	<0.0001
Year	2	35082.141	164.57	<0.0001
Y*F interaction	6	3462.740	16.24	<0.0001
Error	882	213.174		

* Y*F interaction was used as error term in ANOVA for marked attributes

Table 3 Analysis of variance (ANOVA) for quality attributes assessed by the individual researcher in four apple breeding families. Data were recorded on seedling trees during three years (2008, 2009 and 2010). Attributes included coloured area (COL*area*), stripeness (STRIPE), visual brightness of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively (TOP*bright*), lightness of the overall colour (OVER*light*), brightness of the background colour (BACK*bright*), russetting (RUS), lenticel conspicuousness (LENT), toughness of the fruit peel (PEEL*ind*), sour taste (SOUR*ind*), sweet taste (SWEET*ind*), apple flavour (FLAV*ind*), juiciness (JUICY*ind*) and perceived texture (TEXT*ind*)

Attribute and source of variation	*df*	*MS*	*F*	*P*
SOUR*ind**				
Year	2	11092.807	3.66	0.0915
Family	3	45295.108	14.94	0.0034
Y*F interaction	6	3032.380		
Error=Seedling(Y*F)	1807	343.396		
SWEET*ind**				
Year	2	35020.072	8.48	0.0178
Family	3	13519.647	3.28	0.1007
Y*F interaction	6	4127.550		
Error=Seedling(Y*F)	1811	187.190		
FLAV*ind**				
Year	2	253528.597	50.89	0.0002
Family	3	2373.346	0.48	0.7102
Y*F interaction	6	4981.621		
Error=Seedling(Y*F)	1810	220.629		
JUICY*ind**				
Year	2	2593.473	0.68	0.5414
Family	3	12795.713	3.36	0.0964
Y*F interaction	6	3809.378		
Error=Seedling(Y*F)	1803	502.762		
TEXT*ind**				
Year	2	2611.057	1.27	0.3473
Family	3	23625.604	11.47	0.0067
Y*F interaction	6	2059.532		
Error=Seedling(Y*F)	1797	531.182		
PEEL*ind**				
Year	2	24803.544	3.19	0.1137
Family	3	5845.272	0.75	0.5598
Y*F interaction	6	7769.212		
Error=Seedling(Y*F)	1804	673.348		
RUS				
Family	3	54344.892	78.99	<0.0001
Seedling(Family)	934	688.030	2.85	<0.0001
Year	2	26584.922	110.21	<0.0001
Y*F interaction	6	5772.449	23.93	<0.0001
Error	879	241.227		

LENT				
Family	3	38215.237	37.02	<0.0001
Seedling(Family)	935	1032.163	2.49	<0.0001
Year	2	1722.464	4.16	0.0159
Y*F interaction	6	2146.523	5.19	<0.0001
Error	874	413.840		
COL*area*				
Family	3	126091.000	116.86	<0.0001
Seedling(Family)	927	1078.995	7.26	<0.0001
Year	2	3241.881	21.81	<0.0001
Y*F interaction	6	953.627	6.42	<0.0001
Error	883	148.614		
STRIPE*				
Year	2	8541.831	0.44	0.6608
Family	3	58621.045	3.05	0.1138
Y*F interaction	6	19225.210		
Error=Seedling(Y*F)	1814	488.592		
TOP*bright**				
Year	2	7172.458	4.95	0.0538
Family	3	14946.853	10.31	0.0088
Y*F interaction	6	1449.557		
Error=Seedling(Y*F)	1811	530.3153		
BACK*bright**				
Year	2	47923.326	13.81	0.0057
Family	3	11421.804	3.29	0.0999
Y*F interaction	6	3470.400		
Error=Seedling(Y*F)	1814	496.585		
OVER*light*				
Family	3	58051.040	90.79	<0.0001
Seedling(Family)	931	639.419	3.77	<0.0001
Year	2	1854.705	10.92	<0.0001
Y*F interaction	6	1319.363	7.77	<0.0001
Error	882	169.824		

* Y*F interaction was used as error term in ANOVA for marked attributes

Table 4 Analysis of variance (ANOVA) for trained panel analysis of quality attributes in four apple breeding families. Data were recorded on seedling trees during three years (2008, 2009 and 2010). Attributes included sour taste (SOUR*tp*), sweet taste (SWEET*tp*), apple flavour (FLAV*tp*), crispness (CRISP*tp*), hardness (TEXT*tp*) and juiciness (JUICY*tp*)

Attribute and source of variation	*df*	*MS*	*F*	*P*
SOUR*tp*				
Family	3	5355.955	29.96	<0.0001
Seedling(Family)	195	178.794		
Year	2	282.767	2.93	0.0566
Y*F interaction	6	353.649	3.66	0.0020
Error=Seedling(Y*F)	145	96.498		
SWEET*tp**				
Year	2	1101.824	3.77	0.0871
Family	3	1721.150	5.89	0.0321
Y*F interaction	6	292.447		
Error=Seedling(Y*F)	340	36.944		
FLAV*tp*				
Family	3	299.699	8.82	<0.0001
Seedling(Family)	195	33.962		
Year	2	730.161	46.94	<0.0001
Y*F interaction	6	59.668	3.84	0.0014
Error=Seedling(Y*F)	145	15.557		
CRISP*tp*				
Family	3	2958.066	19.77	<0.0001
Seedling(Family)	195	149.632		
Year	2	243.099	3.68	0.0276
Y*F interaction	6	277.511	4.20	0.0006
Error=Seedling(Y*F)	145	66.043		
TEXT*tp*				
Family	3	2168.906	16.77	<0.0001
Seedling(Family)	195	129.337		
Year	2	38.155	0.76	0.4695
Y*F interaction	6	183.628	3.66	0.0021
Error=Seedling(Y*F)	145	50.204		
JUICY*tp*				
Family	3	784.344	10.49	<0.0001
Seedling(Family)	195	74.750		
Year	2	1002.150	30.36	<0.0001
Y*F interaction	6	189.028	5.73	<0.0001
Error=Seedling(Y*F)	145	33.009		

* Y*F interaction was used as error term in ANOVA for marked attributes

Table 5 Variance components and intraclass correlation coefficients for instrumentally measured attributes in four apple breeding families. Attributes included weight of the fruit (WEIGHT), diameter (DIAM), titratable acidity (TA), total soluble solids (TSS), TSS/TA and instrumental texture (TEXT). Colour measurements included lightness (TOPL), chroma (TOPC), hue angle (TOPH) of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively, and the lightness (BACKL), chroma (BACKC) and hue angle (BACKH) of the background colour

	Source of variation					Intraclass correlation	
Attribute	**Family (F)**	**Seedling(Family)**	**Year (Y)**	**Y*F**	**Error**	**t1**	**t2**
WEIGHT (g)	39.67	337.74	74.65	91.18	401.68	0.04	0.46
%	4.20	35.74	7.90	9.65	42.51		
DIAM (mm)	0.00	18.53	3.20	3.69	21.31	0.00	0.47
%	0.00	39.65	6.85	7.89	45.62		
TSS (ºBrix)	0.91	0.53	6.93	5.45	1.99	0.06	0.21
%	5.77	3.35	43.81	34.46	12.60		
TA (% malic acid)	0.02	0.02	0.00	0.00	0.02	0.32	0.55
%	31.51	35.23	3.32	0.66	29.28		
TSS/TA	146.61	282.16	32.53	18.53	156.85	0.23	0.64
%	23.03	44.32	5.11	2.91	24.64		
TEXT (N)	0.00	0.95	2.83	4.78	2.20	0.00	0.30
%	0.00	8.85	26.27	44.40	20.49		
TOPL	109.25	83.02	0.13	3.03	23.54	0.50	0.78
%	49.89	37.91	0.06	1.38	10.75		
TOPC	30.09	13.51	0.00	0.71	18.92	0.48	0.42
%	47.59	21.36	0.00	1.13	29.92		
TOPH	240.93	241.04	0.00	4.04	64.83	0.44	0.79
%	43.74	43.76	0.00	0.73	11.77		
BACKL	35.21	40.85	14.21	8.23	64.64	0.22	0.39
%	21.58	25.04	8.71	5.05	39.62		
BACKC	5.51	11.83	0.56	0.43	18.21	0.15	0.39
%	15.07	32.37	1.52	1.18	49.85		
BACKH	118.00	181.14	60.79	28.60	215.25	0.20	0.46
%	19.54	30.00	10.07	4.74	35.65		

t1 Intraclass correlation coefficient for between-family variance

t2 Intraclass correlation coefficient for within-family variance

Table 6 Variance components and intraclass correlation coefficients for sensory attributes assessed by the individual researcher in four apple breeding families. Attributes included coloured area (COL*area*), stripeness (STRIPE), visual brightness of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively (TOP*bright*), brightness of the background colour (BACK*bright*), lightness of the overall colour (OVER*light*), russetting (RUS), lenticel conspicuousness (LENT), toughness of the fruit peel (PEEL*ind*), sour taste (SOUR*ind*), sweet taste (SWEET*ind*), apple flavour (FLAV*ind*), juiciness (JUICY*ind*) and perceived texture (TEXT*ind*)

	Source of variation					Intraclass correlation	
Attribute	**Family (F)**	**Seedling(Family)**	**Year (Y)**	**Y*F**	**Error**	**t1**	**t2**
COL*area*	276.39	498.56	6.02	6.05	150.02	0.29	0.77
%	29.50	53.21	0.64	0.65	16.01		
STRIPE	85.17	149.41	0.00	119.16	342.62	0.12	0.30
%	12.23	21.46	0.00	17.11	49.20		
TOP*bright*	27.54	241.02	8.39	5.78	293.04	0.05	0.45
%	4.78	41.86	1.46	1.00	50.90		
OVER*light*	115.63	249.80	0.09	9.67	172.90	0.21	0.59
%	21.10	45.58	0.02	1.76	31.55		
BACK*bright*	13.39	112.16	64.02	20.62	385.24	0.02	0.23
%	2.25	18.84	10.75	3.46	64.70		
RUS	74.15	204.51	47.32	48.16	252.78	0.12	0.45
%	11.83	32.62	7.55	7.68	40.32		
LENT	81.25	312.97	0.00	15.02	423.70	0.10	0.42
%	9.75	37.57	0.00	1.80	50.87		
PEEL*ind*	0.00	117.78	34.74	38.12	557.54	0.00	0.17
%	0.00	15.74	4.64	5.09	74.52		
SOUR*ind*	93.81	99.23	20.17	20.62	245.86	0.20	0.29
%	19.56	20.69	4.21	4.30	51.25		
SWEET*ind*	24.01	21.09	51.50	27.15	166.32	0.08	0.11
%	8.28	7.27	17.76	9.36	57.34		
FLAV*ind*	0.00	11.87	376.94	29.67	208.76	0.00	0.05
%	0.00	1.89	60.10	4.73	33.28		
JUICY*ind*	24.39	87.38	0.00	20.67	415.88	0.04	0.17
%	4.45	15.94	0.00	3.77	75.85		
TEXT*ind*	49.86	79.34	3.45	10.78	452.43	0.08	0.15
%	8.37	13.32	0.58	1.81	75.93		

t1 Intraclass correlation coefficient for between-family variance

t2 Intraclass correlation coefficient for within-family variance

Table 7 Descriptive statistics of instrumentally measured attributes for each of four apple breeding families, i.e. families 1, 2, 3 and 4 (F1-F4). Attributes included weight of the fruit (WEIGHT), diameter (DIAM), titratable acidity (TA), total soluble solids (TSS), TSS/TA and instrumental texture (TEXT). Colour measurements included lightness (TOPL), chroma (TOPC), hue angle (TOPH) of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively, and the lightness (BACKL), chroma (BACKC) and hue angle (BACKH) of the background colour. Descriptive statistics included standard deviation (SD) and standard error (SE). Means were separated by LSD (5%) and different alphabetical letters indicate significant differences

Family	Descriptor	WEIGHT* (g)	DIAM* (mm)	TA (% malic acid)	TSS* (ºBrix)	TSS/TA	TEXT* (N)	TOPL	TOPC	TOPH	BACKL*	BACKC	BACKH
F1	Minimum	14.00	36.00	0.09	4.57	7.63	35.30	26.00	22.67	10.70	30.67	26.00	19.00
	Maximum	241.00	81.00	1.12	23.10	115.38	185.20	63.00	56.70	68.70	84.00	60.00	108.70
	Progeny mean	110.62[a]	61.50[a]	0.43[c]	13.71[a]	40.51[b]	101.10[a]	39.92[b]	41.38[b]	24.87[c]	65.45[a]	40.50[b]	69.22[b]
	Parental mean	123.00	63.90	0.39	14.10	40.51	60.10	40.67	42.38	28.24	66.95	44.69	77.07
	Variance (n)	1163.21	51.19	0.04	17.91	569.08	13.04	40.20	24.90	52.89	108.45	28.50	450.19
	SD	34.11	7.15	0.21	4.23	23.86	3.61	6.34	4.99	7.27	10.41	5.34	21.22
	SE	1.65	0.35	0.01	0.21	1.26	0.18	0.30	0.24	0.35	0.50	0.26	1.02
F2	Minimum	37.00	40.00	0.15	3.75	4.87	27.30	21.70	10.50	1.07	30.00	27.33	15.00
	Maximum	173.00	90.00	1.39	21.10	49.39	174.40	53.70	47.50	51.70	78.70	53.30	110.00
	Progeny mean	94.92[a]	61.63[a]	0.75[a]	13.20[a]	19.48[d]	93.50[a]	33.23[c]	32.29[c]	19.07[d]	57.38[b]	38.92[c]	62.47[c]
	Parental mean	102.41	63.38	0.46	14.51	39.28	50.00	34.40	33.14	23.14	63.10	42.02	79.01
	Variance (n)	543.49	35.43	0.05	20.67	69.76	15.14	20.28	37.30	37.20	106.10	21.81	627.28
	SD	23.31	5.95	0.21	4.55	8.35	3.89	4.50	6.11	6.10	10.30	4.67	25.05
	SE	1.11	0.28	0.01	0.22	0.43	0.19	0.21	0.29	0.29	0.49	0.22	1.19
F3	Minimum	27.00	37.67	0.08	10.40	12.18	25.10	30.50	27.67	17.33	28.06	29.67	31.00
	Maximum	188.00	79.00	1.33	22.20	158.33	127.40	80.50	67.00	95.70	85.70	66.50	107.00
	Progeny mean	103.11[a]	61.08[a]	0.44[c]	16.95[a]	50.86[a]	81.50[a]	55.33[a]	44.52[a]	51.35[a]	71.21[a]	44.46[a]	83.60[a]
	Parental mean	134.23	67.14	0.38	15.37	42.26	68.80	57.70	46.68	61.74	67.16	43.00	85.68
	Variance (n)	858.19	51.35	0.05	3.05	965.60	3.03	135.96	31.48	449.41	88.83	41.22	251.49
	SD	29.29	7.17	0.22	1.75	31.07	1.74	11.66	5.61	21.20	9.42	6.42	15.86
	SE	1.39	0.34	0.01	0.08	1.57	0.08	0.55	0.27	1.01	0.45	0.31	0.75

F4	Minimum	31.00	40.67	0.10	12.00	9.87	35.1	25.33	26.00	10.33	22.04	27.00	27.00
	Maximum	197.00	79.00	1.19	20.70	142.00	130.3	81.50	60.00	97.67	85.70	57.50	110.33
	Progeny mean	109.93[a]	62.79[a]	0.54[b]	15.60[a]	33.21[c]	80.56[a]	53.86[a]	43.75[a]	45.88[b]	70.58[a]	41.17[b]	83.93[a]
	Parental mean	141.03	69.11	0.40	13.81	37.58	63.40	56.28	38.25	48.40	72.68	41.87	100.84
	Variance (n)	842.85	39.54	0.03	1.91	226.42	3.85	200.01	34.71	589.31	170.67	30.39	437.05
	SD	29.03	6.29	0.18	1.38	15.05	1.96	14.14	5.89	24.28	13.06	5.51	20.91
	SE	1.27	0.27	0.01	0.06	0.70	0.09	0.63	0.26	1.08	0.58	0.25	0.93

* Y*F interaction was used as error term in analysis of variance (ANOVA) for marked attributes

Table 8 Descriptive statistics of sensory attributes assessed by the individual researcher for each of four apple breeding families, i.e. families 1, 2, 3 and 4 (F1-F4). Attributes included coloured area (COL*area*, higher values=higher coloured area), stripeness (STRIPE, higher values=higher incidence of stripes), visual brightness of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively (TOP*bright,* higher values=higher brightness), lightness of the overall colour (OVER*light*, higher values=lower lightness), brightness of the background colour (BACK*bright*, higher values=higher brightness), russetting (RUS, higher values=lower incidence), lenticel conspicuousness (LENT, higher values=lower incidence), toughness of the fruit peel (PEEL*ind*, higher values=tougher peel), sour taste (SOUR*ind*¸ higher values=sourer taste), sweet taste (SWEET*ind*, higher values=sweeter taste), apple flavour (FLAV*ind*, higher values=higher apple flavour), juiciness (JUICY*ind*, higher values=higher juiciness) and perceived texture (TEXT*ind*, higher values=crisper texture). Descriptive statistics included standard deviation (SD) and standard error (SE). Means were separated by LSD (5%) and different alphabetical letters indicate significant differences

Family	**Descriptor**	**COL *area***	**STRIPE***	**TOP *bright****	**OVER *light***	**BACK *bright****	**RUS**	**LENT**	**PEEL *ind****	**SOUR *ind****	**SWEET *ind****	**FLAV *ind****	**JUICY *ind****	**TEXT *ind****
F1	Minimum	38.00	23.00	8.00	2.00	4.00	6.00	4.00	5.00	2.00	18.00	0.00	4.00	2.00
	Maximum	100.00	100.00	97.00	72.00	96.00	100.00	98.00	97.00	83.00	88.00	95.00	98.00	97.00
	Progeny mean	86.65^{a}	85.79^{ab}	61.59^{a}	26.98^{b}	56.64^{a}	70.78^{b}	51.32^{c}	53.14^{a}	30.13^{c}	55.37^{ab}	54.96^{a}	63.59^{ab}	67.52^{a}
	Parental mean	82.40	87.05	58.91	29.09	52.77	58.74	51.22	69.64	25.09	52.48	61.76	65.34	64.20
	Variance (n)	150.74	175.21	442.63	198.72	556.65	584.30	653.72	673.79	351.25	240.66	518.89	474.55	508.77
	SD	12.28	13.24	21.04	14.10	23.59	24.17	25.57	25.96	18.74	15.51	22.78	21.78	22.56
	SE	0.59	0.64	1.02	0.68	1.14	1.17	1.24	1.25	0.91	0.75	1.10	1.06	1.10
F2	Minimum	57.00	32.00	2.00	1.00	4.00	9.00	9.00	5.00	6.00	10.00	8.00	2.00	2.00
	Maximum	100.00	100.00	94.00	67.00	95.00	100.00	100.00	96.00	92.00	76.00	92.00	95.00	95.00
	Progeny mean	90.24^{a}	89.77^{a}	52.06^{bc}	18.72^{c}	50.64^{ab}	77.72^{a}	72.70^{a}	54.98^{a}	53.73^{a}	45.12^{b}	56.86^{a}	55.04^{b}	56.80^{b}
	Parental mean	83.37	85.10	47.49	21.00	49.33	80.12	80.53	65.47	36.76	50.68	64.75	47.33	39.49
	Variance (n)	77.39	96.85	446.71	116.68	557.25	336.53	516.44	664.38	327.92	208.65	400.92	601.21	663.77
	SD	8.80	9.84	21.14	10.80	23.61	18.34	22.73	25.78	18.11	14.44	20.02	24.52	25.76
	SE	0.42	0.46	1.00	0.51	1.12	0.87	1.08	1.23	0.86	0.69	0.96	1.17	1.23

F3	Minimum	0.00	0.00	0.00	8.00	5.00	0.00	5.00	9.00	2.00	12.00	4.00	2.00	3.00
	Maximum	100.00	100.00	88.00	100.00	90.00	95.00	99.00	96.00	82.00	88.00	94.00	98.00	97.00
	Progeny mean	60.22[b]	66.51[b]	48.42[c]	40.69[a]	45.05[b]	54.29[c]	54.85[c]	59.77[a]	35.93[bc]	56.28[a]	55.28[a]	66.40[a]	70.02[a]
	Parental mean	56.19	55.97	57.64	39.18	56.08	78.50	63.83	70.10	31.35	66.16	72.62	76.05	75.92
	Variance (n)	1188.95	801.95	520.77	590.20	501.59	760.37	784.92	712.79	402.20	275.74	594.05	536.36	540.83
	SD	34.48	28.32	22.82	24.29	22.40	27.57	28.02	26.70	20.05	16.61	24.37	23.16	23.26
	SE	1.66	1.36	1.09	1.16	1.07	1.32	1.33	1.28	0.96	0.79	1.16	1.10	1.11
F4	Minimum	0.00	0.00	7.00	95.00	6.00	7.00	5.00	0.00	2.00	13.00	5.00	3.00	0.00
	Maximum	100.00	100.00	95.00	5.00	95.00	100.00	100.00	96.00	79.00	87.00	94.00	99.00	98.00
	Progeny mean	59.32[b]	70.43[ab]	58.18[ab]	42.11[a]	55.57[a]	77.37[a]	61.92[b]	51.78[a]	43.30[b]	54.30[ab]	56.20[a]	65.16[ab]	72.82[a]
	Parental mean	44.99	63.74	65.76	39.24	67.53	85.49	54.79	67.23	44.46	59.60	71.91	66.96	67.15
	Variance (n)	1044.25	1090.38	723.50	719.86	601.60	407.67	956.34	822.60	371.71	243.31	552.19	462.34	460.57
	SD	32.31	33.02	26.90	26.83	24.53	20.19	30.92	28.68	19.28	15.60	23.50	21.50	21.46
	SE	1.44	1.47	1.20	1.20	1.10	0.90	1.38	1.28	0.86	0.70	1.04	0.96	0.96

* Y*F was used as error term in analysis of variance (ANOVA) for marked attributes

Table 9 Descriptive statistics of sensory attributes assessed by the trained panel for each of four apple breeding families, i.e. families 1, 2, 3 and 4 (F1-F4). Attributes included sour taste (SOUR*tp*), sweet taste (SWEET*tp*), apple flavour (FLAV*tp*), crispness (CRISP*tp*), hardness (TEXT*tp*) and juiciness (JUICY*tp*). Descriptive statistics included standard deviation (SD) and standard error (SE). Means were separated by LSD (5%) and different alphabetical letters indicate significant differences

Family	Descriptor	SOUR*tp*	SWEET*tp**	FLAV*tp*	CRISP*tp*	TEXT*tp*	JUICY*tp*
F1	Minimum	13.00	33.50	33.88	13.50	11.63	17.63
	Maximum	76.38	68.25	58.25	63.70	58.88	62.00
	Progeny mean	41.93[c]	53.70[a]	45.59[b]	44.92[b]	41.30[b]	45.63[b]
	Parental mean	43.18	52.00	47.12	45.43	41.03	40.82
	Variance (n)	183.10	45.43	26.25	102.31	87.70	69.82
	SD	13.53	6.74	5.12	10.12	9.36	8.36
	SE	1.49	0.74	0.56	1.11	1.03	0.92
F2	Minimum	26.90	34.60	30.38	17.20	14.00	23.63
	Maximum	78.13	57.00	53.13	58.56	59.31	57.00
	Progeny mean	59.61[a]	45.32[b]	45.26[b]	37.71[c]	34.81[c]	42.42[c]
	Parental mean	46.79	50.67	46.16	36.83	34.06	33.52
	Variance (n)	92.66	19.99	20.59	114.22	105.25	65.13
	SD	9.63	4.47	4.54	10.69	10.26	8.07
	SE	1.10	0.51	0.52	1.22	1.17	0.92
F3	Minimum	13.90	26.50	30.10	16.60	15.30	32.00
	Maximum	74.75	74.13	60.38	71.50	65.30	64.13
	Progeny mean	44.11[c]	55.50[a]	47.98[a]	51.16[a]	46.35[a]	49.40[a]
	Parental mean	46.29	55.64	50.18	47.53	42.76	42.92
	Variance (n)	194.61	78.78	42.08	119.86	89.39	57.08
	SD	13.95	8.88	6.49	10.95	9.45	7.56
	SE	1.46	0.93	0.68	1.15	0.99	0.79
F4	Minimum	24.80	35.00	37.44	14.30	18.60	31.40
	Maximum	71.19	71.63	60.75	70.00	63.88	62.13
	Progeny mean	50.99[b]	51.63[ab]	49.12[a]	48.88[a]	44.48[ab]	48.05[ab]
	Parental mean	40.82	51.21	47.22	49.36	44.24	44.57
	Variance (n)	112.74	43.63	30.46	125.35	100.24	58.24
	SD	10.62	6.61	5.52	11.20	10.01	7.63
	SE	1.12	0.70	0.58	1.18	1.06	0.80

* Y*F interaction was used as error term in analysis of variance (ANOVA) for marked attributes

Table 10 Descriptive statistics of sensory attributes assessed by the individual researcher for parental genotypes in four apple breeding families, i.e. 'Anna' (AN), 'Scarlet Gala' (SG), 2B-19-22 (2B), 'Prima' (PR), 'Treco Red' (TR), 'Golden Delicious' (GD), 8F-8-6 (8F) and 'Cripps' Pink' (CP). Attributes included coloured area (COL*area*, higher values=higher coloured area), stripeness (STRIPE, higher incidence of stripes), visual brightness of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively (TOP*bright*, higher values=higher brightness), lightness of the overall colour (OVER*light*, higher values=lower lightness), brightness of the background colour (BACK*bright*, higher values=higher brightness), russetting (RUS, higher values=lower incidence), lenticel conspicuousness (LENT, higher values=lower incidence), toughness of the fruit peel (PEEL*ind*, higher values=tougher peel), sour taste (SOUR*ind*, higher values=sourer taste), sweet taste (SWEET*ind*, higher values=sweeter taste), apple flavour (FLAV*ind*, higher values=higher apple flavour), juiciness (JUICY*ind*, higher values=higher juiciness) and perceived texture (TEXT*ind*, higher values=crisper texture). Descriptive statistics included standard deviation (SD) and standard error (SE). Means were separated by LSD (5%) and different alphabetical letters indicate significant differences

Parent	Descriptor	COL *area*	STRIPE*	TOP *bright**	OVER *light*	BACK *bright**	RUS	LENT	PEEL *ind**	SOUR *ind**	SWEET *ind**	FLAV *ind**	JUICY *ind**	TEXT *ind**
AN	Minimum	62.00	56.00	11.00	11.00	8.00	4.00	16.00	63.00	8.00	17.00	17.00	25.00	7.00
	Maximum	100.00	100.00	80.00	64.00	80.00	95.00	92.00	95.00	66.00	75.00	82.00	92.00	89.00
	Mean	85.19	87.68	40.12	29.65	35.92	48.38	41.54	82.38	25.56	46.65	66.43	47.31	42.35
	Variance (n)	173.68	93.73	401.39	246.56	298.79	1033.81	316.74	74.16	230.51	234.96	316.16	257.50	485.28
	SD	13.18	9.68	20.03	15.70	17.29	32.15	17.80	8.61	15.18	15.33	17.78	16.05	22.03
	SE	2.58	1.94	3.93	3.08	3.39	6.56	3.49	1.76	3.04	3.20	3.88	3.15	4.32
SG	Minimum	38.00	62.00	38.00	11.00	15.00	21.00	19.00	14.00	7.00	22.00	12.00	45.00	57.00
	Maximum	100.00	98.00	91.00	71.00	88.00	93.00	92.00	90.00	67.00	76.00	80.00	95.00	96.00
	Mean	79.60	86.43	77.70	28.52	69.62	69.10	60.90	56.90	24.62	58.32	57.10	83.38	86.05
	Variance (n)	218.15	73.16	210.22	250.66	561.15	477.25	749.29	623.99	184.15	321.78	564.49	140.65	70.75
	SD	14.77	8.55	14.50	15.83	23.69	21.85	27.37	24.98	13.57	17.94	23.76	11.86	8.41
	SE	3.30	1.87	3.24	3.45	5.17	4.88	5.97	5.59	2.96	4.12	5.18	2.59	1.84
2B	Minimum	69.00	65.00	19.00	9.00	23.00	71.00	57.00	19.00	8.00	20.00	17.00	13.00	8.00
	Maximum	100.00	98.00	85.00	49.00	87.00	95.00	97.00	94.00	63.00	74.00	91.00	68.00	50.00
	Mean	88.97	86.00	41.26	21.47	51.94	86.70	84.73	60.37	29.71	50.64	64.00	37.47	23.65
	Variance (n)	65.56	61.69	324.20	74.00	437.09	34.66	83.79	642.53	176.97	227.80	444.39	207.10	134.72
	SD	8.10	7.85	18.01	8.60	20.91	5.89	9.15	25.35	13.30	15.09	21.08	14.39	11.61
	SE	1.37	1.37	3.04	1.52	3.59	1.02	1.67	4.28	2.25	2.63	3.73	2.54	1.99

PR	Minimum	57.00	69.00	25.00	10.00	6.00	38.00	37.00	36.00	21.00	19.00	25.00	23.00	8.00
	Maximum	94.00	94.00	82.00	35.00	87.00	94.00	96.00	91.00	73.00	74.00	89.00	84.00	90.00
	Mean	77.77	84.19	53.73	20.52	46.73	73.55	76.32	70.57	43.81	50.71	65.50	57.19	55.33
	Variance (n)	161.80	66.66	295.45	58.86	699.73	237.21	163.85	235.86	215.66	183.91	290.17	378.46	455.83
	SD	12.72	8.16	17.19	7.67	26.45	15.40	12.80	15.36	14.69	13.56	17.03	19.45	21.35
	SE	2.71	1.78	3.66	1.67	5.64	3.44	2.73	3.35	3.20	2.96	3.63	4.25	4.66
TR	Minimum	64.00	34.00	36.00	13.00	22.00	48.00	49.00	23.00	10.00	28.00	40.00	47.00	57.00
	Maximum	100.00	98.00	86.00	33.00	92.00	95.00	98.00	93.00	66.00	83.00	91.00	97.00	102.00
	Mean	95.05	79.50	71.74	20.72	61.74	80.08	80.63	71.74	29.89	64.03	72.82	84.67	84.13
	Variance (n)	62.97	185.72	155.04	35.94	492.20	105.64	155.27	485.20	297.72	206.40	237.40	146.28	90.01
	SD	7.94	13.63	12.45	6.00	22.19	10.28	12.46	22.03	17.25	14.37	15.41	12.09	9.49
	SE	1.29	2.21	1.99	0.96	3.60	1.67	2.02	3.53	2.80	2.33	2.50	1.94	1.52
GD	Minimum	0.00	0.00	7.00	22.00	7.00	37.00	15.00	21.00	6.00	28.00	25.00	21.00	33.00
	Maximum	82.00	97.00	82.00	96.00	78.00	93.00	98.00	95.00	69.00	90.00	92.00	94.00	89.00
	Mean	17.32	32.44	43.53	57.63	50.42	73.66	47.03	68.46	32.80	68.30	72.42	67.43	67.71
	Variance (n)	520.16	1476.25	618.77	852.65	524.98	216.43	513.38	566.03	316.99	196.55	299.17	319.92	246.91
	SD	22.81	38.42	24.88	29.20	22.91	14.71	22.66	23.79	17.80	14.02	17.30	17.89	15.71
	SE	3.91	6.79	4.40	5.33	4.12	2.60	3.83	3.91	3.01	2.30	2.81	2.94	2.55
8F	Minimum	0.00	0.00	11.00	18.00	20.00	37.00	12.00	27.00	8.00	33.00	32.00	15.00	14.00
	Maximum	86.00	100.00	90.00	96.00	88.00	98.00	98.00	93.00	67.00	70.00	92.00	83.00	93.00
	Mean	34.51	60.44	44.03	59.05	57.08	81.08	70.56	73.53	35.25	53.27	68.34	47.05	44.80
	Variance (n)	511.10	1385.30	687.16	560.73	398.67	190.51	811.28	284.96	316.59	82.65	236.06	362.33	480.69
	SD	22.61	37.22	26.21	23.68	19.97	13.80	28.48	16.88	17.79	9.09	15.36	19.03	21.92
	SE	3.62	5.96	4.25	3.79	3.24	2.24	4.75	2.74	2.97	1.49	2.60	3.13	3.71
CP	Minimum	26.00	0.00	81.00	8.00	54.00	77.00	18.00	12.00	39.00	50.00	47.00	77.00	80.00
	Maximum	91.00	98.00	93.00	32.00	93.00	98.00	90.00	92.00	71.00	78.00	90.00	94.00	97.00
	Mean	55.47	67.05	87.49	19.42	77.97	89.89	39.03	60.94	53.68	65.92	75.47	86.87	89.50
	Variance (n)	295.68	1608.70	12.31	22.30	150.32	27.77	354.94	739.46	62.71	64.45	132.31	22.82	21.28
	SD	17.20	40.11	3.51	4.72	12.26	5.27	18.84	27.19	7.92	8.03	11.50	4.78	4.61
	SE	2.87	6.51	0.58	0.77	2.07	0.85	3.23	4.88	1.36	1.30	1.87	0.77	0.75

Table 11 Descriptive statistics of instrumentally measured attributes for parental genotypes in four apple breeding families, i.e. 'Anna' (AN), 'Scarlet Gala' (SG), 2B-19-22 (2B), 'Prima' (PR), 'Treco Red' (TR), 'Golden Delicious' (GD), 8F-8-6 (8F) and 'Cripps' Pink' (CP). Attributes included weight of the fruit (WEIGHT), diameter (DIAM), titratable acidity (TA), total soluble solids (TSS), TSS/TA and instrumental texture (TEXT). Colour measurements included lightness (TOPL), chroma (TOPC), hue angle (TOPH) of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively; and the lightness (BACKL), chroma (BACKC) and hue angle (BACKH) of the background colour. Descriptive statistics included standard deviation (SD) and standard error (SE). Means were separated by LSD (5%) and different alphabetical letters indicate significant differences

Parent	Descriptor	WEIGHT (g)	DIAM (mm)	TA (% malic acid)	TSS (ºBrix)	TSS/TA	TEXT (N)	TOPL	TOPC	TOPH	BACKL	BACKC	BACKH
AN	Minimum	92.00	54.00	0.23	11.40	17.32	27.80	20.00	33.00	18.00	54.00	42.00	17.00
	Maximum	219.00	76.00	0.71	17.90	49.57	74.50	49.00	47.00	46.00	76.00	56.00	105.00
	Mean	139.12^{ab}	65.32^{c}	0.50^{b}	14.21^{cd}	28.78^{d}	46.60^{d}	39.05^{e}	39.71^{b}	28.62^{de}	65.33^{cd}	47.86^{a}	79.81^{c}
	Variance (n)	1070.11	30.26	0.02	3.14	63.08	1.08	37.25	19.21	48.45	42.83	18.33	470.26
	SD	32.71	5.50	0.13	1.77	7.94	1.04	6.10	4.38	6.96	6.54	4.28	21.69
	SE	6.42	1.10	0.03	0.38	1.99	0.20	1.33	0.96	1.52	1.43	0.93	4.73
SG	Minimum	71.00	55.00	0.21	11.50	17.69	63.10	36.00	41.00	22.00	51.00	31.00	17.00
	Maximum	139.00	67.33	0.65	15.00	65.91	93.80	62.00	52.00	41.00	80.00	52.00	100.00
	Mean	106.89^{d}	62.48^{d}	0.29^{e}	14.00^{cd}	52.30^{a}	73.70^{b}	42.29^{d}	45.05^{a}	27.86^{de}	68.57^{bc}	41.52^{de}	74.33^{cd}
	Variance (n)	290.23	10.23	0.01	0.70	169.77	0.91	35.11	6.05	25.63	90.66	29.46	524.93
	SD	17.04	3.20	0.11	0.83	13.03	0.95	5.93	2.46	5.06	9.52	5.43	22.91
	SE	3.72	0.70	0.03	0.21	3.36	0.21	1.29	0.54	1.10	2.08	1.18	5.00
2B	Minimum	62.00	54.00	0.21	11.40	24.34	27.90	26.00	18.00	11.00	42.00	33.00	22.00
	Maximum	118.00	68.00	0.53	19.20	74.29	59.50	44.00	42.00	41.00	77.00	52.00	104.00
	Mean	80.54^{e}	59.43^{e}	0.33^{de}	14.49^{bc}	48.40^{ab}	38.22^{e}	35.20^{f}	32.67^{d}	21.80^{f}	59.97^{e}	39.13^{f}	68.18^{d}
	Variance (n)	205.00	11.69	0.01	2.74	157.74	0.56	19.34	26.23	55.54	97.03	20.12	546.00
	SD	14.32	3.42	0.08	1.66	12.56	0.75	4.40	5.12	7.45	9.85	4.49	23.37
	SE	2.71	0.63	0.02	0.34	2.88	0.14	0.80	0.94	1.36	1.83	0.82	4.42

PR	Minimum	78.67	58.00	0.25	11.90	13.66	40.20	21.00	24.00	11.00	42.00	31.00	30.00
	Maximum	208.00	81.00	1.01	19.60	53.13	96.80	53.00	41.00	59.00	74.00	90.00	106.00
	Mean	121.81^{c}	67.07^{bc}	0.58^{a}	14.79^{bc}	30.61^{d}	61.4^{c}	33.35^{f}	33.43^{d}	23.96^{ef}	65.30^{cd}	45.91^{bc}	87.18^{b}
	Variance (n)	949.85	28.74	0.05	3.40	149.97	2.44	40.78	16.98	102.41	70.13	120.18	398.16
	SD	30.82	5.36	0.22	1.84	12.25	1.56	6.39	4.12	10.12	8.37	10.96	19.95
	SE	6.43	1.12	0.05	0.40	2.89	0.33	1.33	0.86	2.11	1.75	2.34	4.25
TR	Minimum	81.00	47.00	0.25	11.80	21.76	60.20	39.00	41.00	25.00	36.00	31.00	46.00
	Maximum	194.00	74.00	0.68	18.60	66.43	91.50	48.00	50.00	43.00	75.00	46.00	92.00
	Mean	129.26^{bc}	66.03^{bc}	0.39^{c}	15.18^{ab}	40.72^{c}	74.50^{b}	43.84^{d}	46.30^{a}	30.81^{d}	62.78^{de}	39.46^{ef}	66.03^{d}
	Variance (n)	413.34	22.86	0.01	2.23	80.68	0.52	7.53	3.99	17.05	110.90	19.26	149.19
	SD	20.33	4.78	0.09	1.49	8.98	0.72	2.74	2.00	4.13	10.53	4.39	12.21
	SE	3.39	0.80	0.02	0.25	1.54	0.12	0.45	0.33	0.68	1.73	0.72	2.01
GD	Minimum	71.00	59.00	0.27	13.00	30.44	47.80	47.00	37.00	64.00	45.00	41.00	100.00
	Maximum	197.00	77.00	0.48	17.90	63.33	83.80	81.00	93.00	109.00	78.00	53.00	110.00
	Mean	139.20^{ab}	68.25^{b}	0.37^{cd}	15.57^{a}	43.81^{bc}	63.10^{c}	71.56^{a}	47.06^{a}	92.67^{a}	71.53^{ab}	46.53^{ab}	105.32^{a}
	Variance (n)	808.99	26.49	0.00	1.49	64.95	0.72	38.20	80.28	123.14	47.00	6.56	7.44
	STD	28.44	5.15	0.06	1.22	8.06	0.85	6.18	8.96	11.10	6.86	2.56	2.73
	SE	4.81	0.87	0.01	0.20	1.38	0.14	1.03	1.49	1.85	1.14	0.44	0.47
8F	Minimum	110.00	62.33	0.23	12.10	30.41	33.00	34.00	28.00	20.00	45.00	32.00	54.00
	Maximum	225.00	80.00	0.49	16.60	63.75	90.50	82.00	47.00	99.00	83.00	49.00	111.00
	Mean	146.78^{a}	70.54^{a}	0.31^{e}	13.62^{d}	45.85^{b}	47.40^{d}	63.13^{b}	36.31^{c}	59.55^{b}	74.13^{a}	40.10^{ef}	98.33^{ab}
	Variance (n)	615.68	12.52	0.00	1.41	66.12	1.72	103.34	18.85	381.48	146.43	21.73	132.53
	SD	24.81	3.54	0.06	1.19	8.13	1.31	10.17	4.34	19.53	12.10	4.66	11.51
	SE	3.88	0.56	0.01	0.18	1.37	0.22	1.61	0.70	3.09	1.94	0.74	1.82
CP	Minimum	56.00	57.00	0.28	13.20	19.29	64.60	40.00	34.00	24.00	41.00	37.00	86.00
	Maximum	176.00	75.33	0.70	15.80	49.64	93.10	62.00	46.00	56.00	81.00	51.00	109.00
	Mean	135.28^{abc}	67.68^{b}	0.50^{b}	14.00^{cd}	29.31^{d}	79.30^{a}	49.44^{c}	40.19^{b}	37.25^{c}	71.22^{ab}	43.64^{cd}	103.37^{a}
	Variance (n)	601.68	17.50	0.01	0.33	35.12	0.31	23.74	7.82	75.68	105.15	12.47	23.12
	SD	24.53	4.18	0.09	0.58	5.93	0.56	4.87	2.80	8.70	10.25	3.53	4.81
	SE	3.93	0.67	0.01	0.09	0.95	0.09	0.81	0.47	1.45	1.71	0.59	0.81

Table 12 Mean values for instrumentally measured attributes for each of four apple breeding families, i.e. families 1, 2, 3 and 4 (F1-F4) for data recorded on seedling trees during three years (2008, 2009 and 2010) and means per year across all families. Attributes included weight of the fruit (WEIGHT), diameter (DIAM), titratable acidity (TA), total soluble solids (TSS), TSS/TA and instrumental texture (TEXT). Colour measurements included lightness (TOPL), chroma (TOPC), hue angle (TOPH) of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively; and the lightness (BACKL), chroma (BACKC) and hue angle (BACKH) of the background colour. Means were separated by LSD (5%) and different alphabetical letters indicate significant differences

Family	Year	F1	F2	F3	F4	Year effects
WEIGHT* (g)	2008	110.76^{c}	88.43^{g}	119.96^{b}	126.11^{a}	109.53^{ab}
	2009	127.00^{a}	106.98^{cd}	103.67^{d}	117.68^{b}	114.18^{a}
	2010	96.68^{e}	90.78^{fg}	94.16^{ef}	97.89^{e}	95.14^{b}
DIAM* (mm)	2008	61.91^{d}	60.41^{e}	64.89^{b}	66.76^{a}	63.10^{ab}
	2009	64.47^{bc}	64.28^{c}	60.84^{e}	63.76^{c}	63.41^{a}
	2010	58.54^{f}	60.49^{e}	59.27^{f}	60.50^{e}	59.79^{b}
TA (% malic acid)	2008	0.40^{g}	0.70^{b}	0.46^{f}	0.54^{d}	0.53^{b}
	2009	0.48^{ef}	0.84^{a}	0.49^{ef}	0.58^{c}	0.60^{a}
	2010	0.41^{g}	0.71^{b}	0.41^{g}	0.51^{ed}	0.51^{c}
TSS* (ºBrix)	2008	8.76^{h}	7.38^{i}	15.96^{e}	14.59^{g}	11.11^{b}
	2009	17.48^{b}	16.89^{c}	18.09^{a}	16.37^{d}	17.17^{a}
	2010	15.53^{f}	15.67^{ef}	16.82^{c}	15.59^{f}	15.95^{a}
TSS/TA	2008	27.15^{f}	11.64^{h}	43.63^{c}	30.34^{e}	26.40^{c}
	2009	45.51^{bc}	21.48^{g}	47.23^{b}	30.19^{ef}	35.50^{b}
	2010	48.04^{b}	23.72^{g}	55.21^{a}	35.70^{d}	41.05^{a}
TEXT* (N)	2008	141.81^{a}	141.61^{a}	81.34^{cd}	76.64^{ef}	116.62^{a}
	2009	81.24^{cd}	73.99^{f}	78.50^{de}	74.68^{f}	76.93^{a}
	2010	76.24^{ef}	63.80^{g}	83.20^{bc}	85.65^{b}	78.69^{a}
TOPL	2008	42.43^{d}	33.88^{g}	53.61^{b}	52.62^{c}	43.76^{c}
	2009	37.56^{f}	31.23^{h}	54.74^{b}	54.20^{b}	45.11^{b}
	2010	39.36^{e}	34.28^{g}	56.48^{a}	54.05^{b}	47.92^{a}
TOPC	2008	42.08^{c}	32.64^{e}	43.91^{b}	43.67^{b}	39.75^{b}
	2009	39.93^{d}	30.87^{f}	45.60^{a}	43.69^{b}	40.23^{b}
	2010	41.90^{c}	33.33^{e}	44.13^{b}	43.82^{b}	41.44^{a}
TOPH	2008	26.34^{d}	20.22^{f}	48.40^{b}	47.03^{b}	32.42^{c}
	2009	23.87^{e}	16.77^{g}	51.30^{a}	47.49^{b}	35.70^{b}
	2010	24.21^{e}	19.86^{f}	52.79^{a}	44.34^{c}	37.86^{a}
BACKL*	2008	71.27^{c}	60.23^{gh}	70.48^{c}	72.26^{bc}	67.79^{a}
	2009	61.73^{fg}	52.88^{i}	66.91^{d}	63.90^{e}	61.48^{b}
	2010	62.72^{ef}	58.47^{gh}	73.97^{ab}	74.77^{a}	68.93^{a}

BACKC	2008	39.51[de]	38.94[ef]	43.52[b]	42.40[c]	40.64[b]
	2009	41.74[c]	39.56[de]	45.99[a]	41.96[c]	42.24[a]
	2010	40.46[d]	38.42[f]	43.98[b]	40.19[d]	40.96[b]
BACKH	2008	81.92[cde]	72.84[f]	86.07[b]	90.05[a]	81.27[a]
	2009	60.18[h]	48.33[i]	79.61[e]	80.88[de]	68.18[c]
	2010	64.19[g]	64.21[g]	84.66[bc]	84.05[bcd]	76.37[b]

* Y*F was used as error term in analysis of variance (ANOVA) for marked attributes

Table 13 Mean values for sensory attributes assessed by the individual researcher for each of four apple breeding families, i.e. families 1, 2, 3 and 4 (F1-F4) for data recorded on seedling trees during three years (2008, 2009 and 2010) and means per year across all families. Attributes included coloured area (COL*area*, higher values=higher coloured area), stripeness (STRIPE, higher values=higher incidence of stripes), visual brightness of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively (TOP*bright*, higher values=higher brightness), brightness of the background colour (BACK*bright*, higher values=higher brightness), lightness of the overall colour (OVER*light*, higher values=lower lightness), russetting (RUS, higher values=lower incidence), lenticel conspicuousness (LENT, higher values=lower incidence), toughness of the fruit peel (PEEL*ind*, higher values=tougher peel), sour taste (SOUR*ind*, higher values=sourer taste), sweet taste (SWEET*ind*, higher values=sweeter taste), apple flavour (FLAV*ind*, higher values=higher apple flavour), juiciness (JUICY*ind*, higher values=higher juiciness) and perceived texture (TEXT*ind*, higher values=crisper texture). Means were separated by LSD (5%) and different alphabetical letters indicate significant differences

Attribute	Year	F1	F2	F3	F4	Year effects
COL*area*	2008	81.69^{b}	88.69^{a}	57.89^{ef}	55.20^{f}	73.11^{b}
	2009	89.34^{a}	91.50^{a}	64.94^{c}	57.71^{ef}	75.74^{a}
	2010	88.99^{a}	90.58^{a}	59.04^{e}	62.04^{d}	72.67^{b}
STRIPE*	2008	77.75^{d}	85.57^{c}	76.02^{d}	85.99^{c}	81.34^{a}
	2009	91.46^{ab}	93.62^{a}	59.39^{f}	49.67^{g}	73.41^{a}
	2010	88.57^{bc}	90.51^{ab}	65.06^{e}	76.08^{d}	78.67^{a}
TOP*bright**	2008	61.38^{b}	51.36^{d}	50.16^{de}	61.77^{ab}	56.11^{ab}
	2009	65.73^{a}	59.80^{bc}	51.75^{d}	57.34^{c}	58.79^{a}
	2010	58.69^{bc}	46.43^{ef}	45.92^{f}	57.16^{c}	52.17^{b}
BACK*bright**	2008	63.84^{a}	47.14^{de}	54.63^{b}	62.30^{a}	56.67^{a}
	2009	61.72^{a}	63.55^{a}	52.60^{bc}	60.94^{a}	60.04^{a}
	2010	46.13^{de}	43.57^{e}	36.10^{f}	49.48^{cd}	43.94^{b}
OVER*light*	2008	31.96^{d}	20.46^{fg}	36.90^{c}	40.89^{ab}	31.51^{b}
	2009	22.64^{ef}	17.11^{h}	38.64^{bc}	42.38^{a}	30.08^{b}
	2010	25.65^{e}	18.68^{gh}	43.75^{a}	42.48^{a}	34.44^{a}
RUS	2008	65.09^{f}	72.93^{d}	64.16^{f}	82.83^{b}	70.81^{b}
	2009	80.26^{bc}	83.86^{ab}	70.26^{de}	86.46^{a}	80.86^{a}
	2010	68.86^{e}	77.42^{c}	40.93^{g}	69.73^{de}	63.31^{c}
LENT	2008	59.79^{cde}	74.19^{a}	52.50^{f}	61.01^{cd}	62.62^{a}
	2009	46.88^{g}	75.17^{a}	56.48^{def}	61.16^{cd}	60.52^{ab}
	2010	46.45^{g}	68.54^{b}	55.43^{ef}	62.76^{c}	58.75^{b}
PEEL*ind**	2008	45.22^{e}	42.61^{e}	52.96^{d}	57.73^{bcd}	48.71^{b}
	2009	60.88^{b}	60.09^{bc}	69.13^{a}	60.79^{b}	62.40^{a}
	2010	55.03^{cd}	62.06^{b}	58.32^{bcd}	43.97^{e}	53.88^{ab}
SOUR*ind**	2008	32.03^{f}	53.73^{ab}	44.85^{c}	55.37^{a}	45.84^{a}
	2009	27.65^{gh}	51.53^{b}	25.75^{h}	38.44^{de}	36.64^{b}
	2010	30.14^{fg}	54.65^{ab}	36.55^{e}	40.97^{d}	40.41^{ab}

SWEET*ind**	2008	48.95^{e}	42.15^{f}	58.97^{c}	62.22^{b}	51.88^{b}
	2009	62.74^{b}	55.22^{d}	69.54^{a}	62.50^{b}	62.11^{a}
	2010	55.41^{d}	39.76^{f}	48.24^{e}	46.08^{e}	47.20^{b}
FLAV*ind**	2008	56.37^{c}	59.09^{c}	73.60^{b}	73.30^{b}	64.33^{b}
	2009	74.13^{ab}	73.29^{b}	77.08^{a}	77.44^{a}	75.49^{a}
	2010	38.52^{de}	40.81^{d}	35.00^{f}	36.39^{ef}	37.34^{c}
JUICY*ind**	2008	64.78^{cd}	58.61^{ef}	71.06^{ab}	60.66^{de}	63.52^{a}
	2009	59.26^{ef}	55.37^{fg}	73.15^{a}	71.68^{a}	64.69^{a}
	2010	66.41^{bc}	51.70^{g}	60.83^{de}	63.21^{cde}	60.81^{a}
TEXT*ind**	2008	67.76^{cde}	59.78^{f}	76.23^{a}	70.53^{bcd}	67.89^{a}
	2009	65.78^{de}	58.46^{f}	74.53^{ab}	77.61^{a}	69.04^{a}
	2010	68.97^{cde}	52.98^{g}	64.75^{e}	71.00^{bc}	65.15^{a}

* Y*F was used as error term for marked attributes

Table 14 Mean values for sensory attributes assessed by the trained panel for each of four apple breeding families, i.e. families 1, 2, 3 and 4 (F1-F4) for data recorded on seedling trees during three years (2008, 2009 and 2010) and means per year across all families. Attributes included sour taste (SOUR*tp*), sweet taste (SWEET*tp*), apple flavour (FLAV*tp*), crispness (CRISP*tp*), hardness (TEXT*tp*) and juiciness (JUICY*tp*). Means were separated by LSD (5%) and different alphabetical letters indicate significant differences

Attribute	Family	F1	F2	F3	F4	Overall
SOUR*tp*	2008	41.57^{g}	61.45^{a}	35.50^{h}	46.70^{def}	45.73^{b}
	2009	42.53^{efg}	58.45^{ab}	49.03^{d}	54.97^{bc}	51.28^{a}
	2010	41.81^{fg}	56.48^{ab}	47.10^{de}	50.27^{cd}	48.87^{a}
SWEET*tp**	2008	55.42^{bc}	45.51^{ef}	53.19^{cd}	46.58^{ef}	50.16^{a}
	2009	54.26^{c}	47.22^{e}	61.48^{a}	57.45^{b}	55.07^{a}
	2010	51.30^{d}	44.30^{f}	51.47^{d}	50.84^{d}	49.60^{a}
FLAV*tp*	2008	44.52^{def}	44.50^{def}	46.50^{bcd}	47.29^{bc}	45.71^{b}
	2009	48.51^{b}	47.74^{bc}	53.05^{a}	54.02^{a}	50.89^{a}
	2010	43.44^{f}	43.07^{f}	44.14^{ef}	46.08^{cde}	44.26^{c}
CRISP*tp*	2008	48.30^{cde}	35.39^{h}	53.06^{ab}	50.09^{bcd}	47.09^{a}
	2009	45.15^{ef}	37.52^{gh}	54.51^{a}	50.37^{abc}	46.83^{a}
	2010	41.60^{fg}	39.93^{g}	45.93^{de}	46.45^{cde}	43.66^{b}
TEXT*tp*	2008	42.07^{cdef}	31.80^{g}	47.94^{a}	45.14^{abc}	42.09^{a}
	2009	40.76^{ef}	33.80^{g}	47.50^{ab}	43.90^{bcde}	41.43^{a}
	2010	41.19^{def}	38.56^{f}	43.66^{cde}	44.46^{abcd}	42.11^{a}
JUICY*tp*	2008	49.37^{bc}	43.32^{d}	51.65^{ab}	49.52^{b}	48.63^{a}
	2009	46.51^{c}	42.79^{d}	53.37^{a}	52.30^{ab}	48.70^{a}
	2010	41.32^{d}	41.25^{d}	43.18^{d}	42.80^{d}	42.18^{b}

* Y*F was used as error term for marked attributes

Table 15 Variance components and intraclass correlation coefficients for individual, instrumental and trained panel assessment of a subsample of 32 seedlings per family. Instrumentally measured attributes included titratable acidity (TA), total soluble solids (TSS), TSS/TA and texture (TEXT). Sensory attributes assessed by the individual researcher included sour taste (SOUR*ind*), sweet taste (SWEET*ind*), apple flavour (FLAV*ind*) and perceived texture (TEXT*ind*). Sensory attributes assessed by the trained panel included sour taste (SOUR*tp*), sweet taste (SWEET*tp*), apple flavour (FLAV*tp*), hardness (TEXT*tp*), crispness (CRISP*tp*), juiciness (JUICY*tp*) and mealiness (MEALY*tp*)

	Source of variation					**Intraclass correlation**	
Attribute	**Family (F)**	**Seedling (S)**	**Year (Y)**	**Y*F**	**ERROR**	**t1**	**t2**
TA[32] (% malic acid)	0.02	0.02	0.00	0.00	0.02	0.31	0.47
%	30.63	28.88	6.26	1.97	32.26		
SOUR*ind*[32]	93.92	53.14	23.95	9.27	277.75	0.21	0.16
%	20.51	11.60	5.23	2.02	60.64		
SOUR*tp*	58.72	45.21	1.74	12.42	92.58	0.28	0.33
%	27.87	21.46	0.83	5.89	43.95		
TSS[32] (ºBrix)	1.32	0.59	6.69	4.80	1.94	0.09	0.23
%	8.63	3.86	43.61	31.27	12.63		
SWEET*ind*[32]	4.47	16.09	24.68	49.02	162.56	0.02	0.09
%	1.74	6.27	9.61	19.08	63.30		
SWEET*tp*	17.01	8.86	7.02	8.54	28.02	0.24	0.24
%	24.50	12.75	10.11	12.29	40.34		
TSS/TA[32]	124.91	233.33	15.39	3.24	125.97	0.25	0.65
%	24.84	46.40	3.06	0.65	25.05		
FLAV*ind*[32]	0.00	5.56	390.04	36.62	199.65	0.00	0.03
%	0.00	0.88	61.73	5.80	31.60		
FLAV*tp*	3.00	6.03	11.00	1.08	15.59	0.08	0.28
%	8.18	16.42	29.98	2.94	42.47		
TEXT[32] (N)	0.00	1.02	2.94	4.12	1.95	0.00	0.34
%	0.00	10.18	29.34	41.08	19.40		
TEXT*ind*[32]	7.03	77.65	2.04	16.66	360.19	0.02	0.18
%	1.52	16.75	0.44	3.59	77.70		
JUICY*ind*[32]	0.00	43.46	0.00	15.90	381.67	0.00	0.10
%	0.00	9.85	0.00	3.61	86.54		
TEXT*tp*	22.89	44.01	0.00	3.52	52.23	0.19	0.46
%	18.66	35.88	0.00	2.87	42.58		
CRISP*tp*	30.17	44.70	0.28	8.43	67.80	0.20	0.40
%	19.93	29.53	0.19	5.57	44.79		
JUICY*tp*	6.31	19.11	10.66	5.86	33.34	0.08	0.36
%	8.39	25.38	14.16	7.78	44.29		
MEALY*tp*	15.89	23.43	0.73	6.09	44.23	0.18	0.35
%	17.58	25.93	0.81	6.74	48.94		

T1 Intraclass correlation coefficient for between-family variance

T2 Intraclass correlation coefficient for within-family variance

[32] Analyses conducted on a subsample of 32 seedlings per family

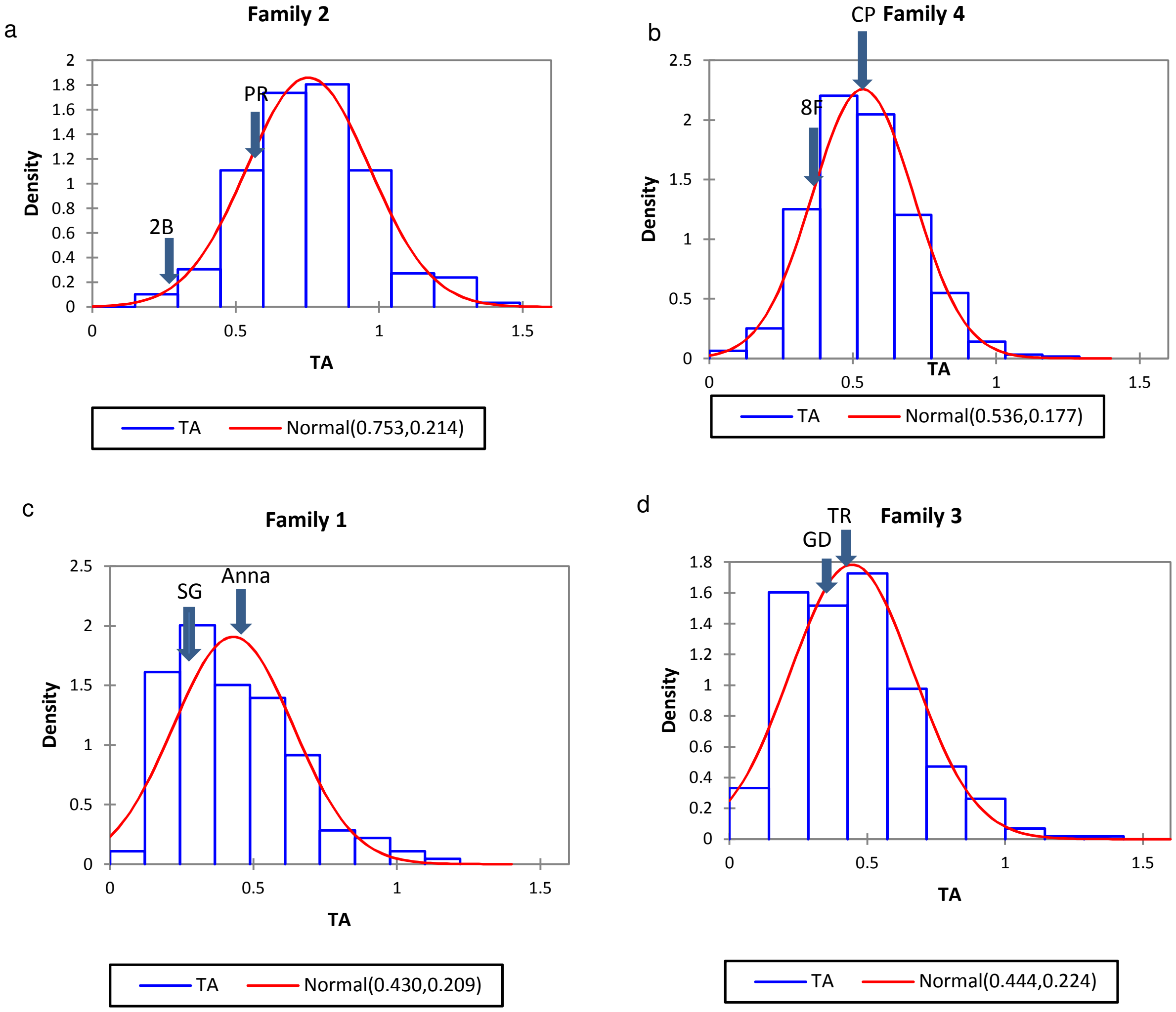

Figure 1 Seedling distribution frequencies of titratable acidity (TA) for families 2 (a), 4 (b), 1 (c) and 3 (d). Mean parental values are indicated with arrows and include 2B-19-22 (2B), 'Prima' (PR), 8F-8-6 (8F), 'Cripps' Pink' (CP), 'Scarlet Gala' (SG), 'Anna' (AN), 'Golden Delicious' (GD) and 'Treco Red' (TR).

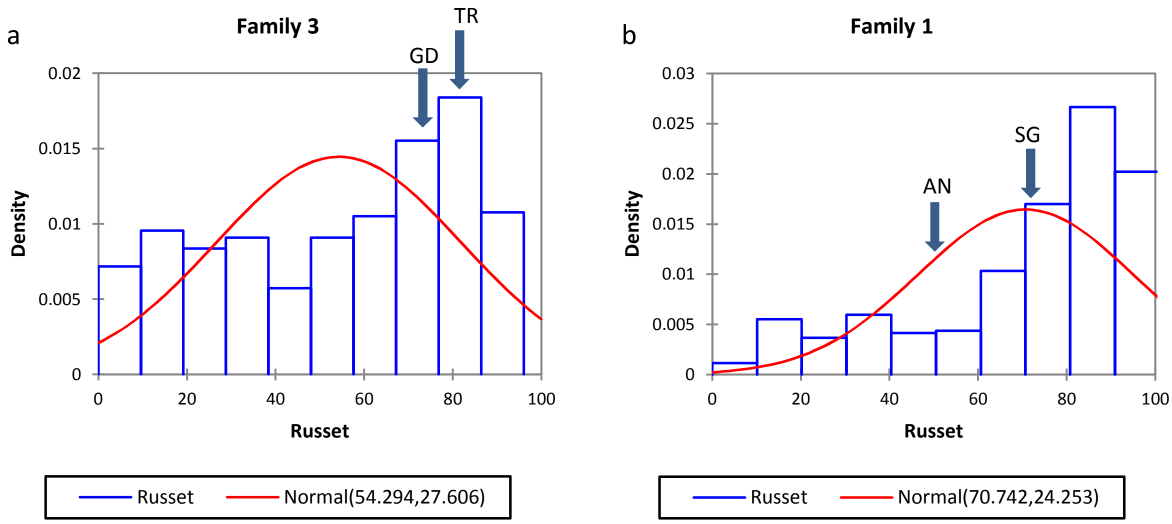

Figure 2 Seedling distribution frequency of russet for family 3 (a) and family 1 (b). Mean parental values are indicated with arrows and include 'Golden Delicious' (GD), 'Treco Red' (TR), 'Anna' (AN) and 'Scarlet Gala' (SG). Higher russet values indicate lower incidence of russet.

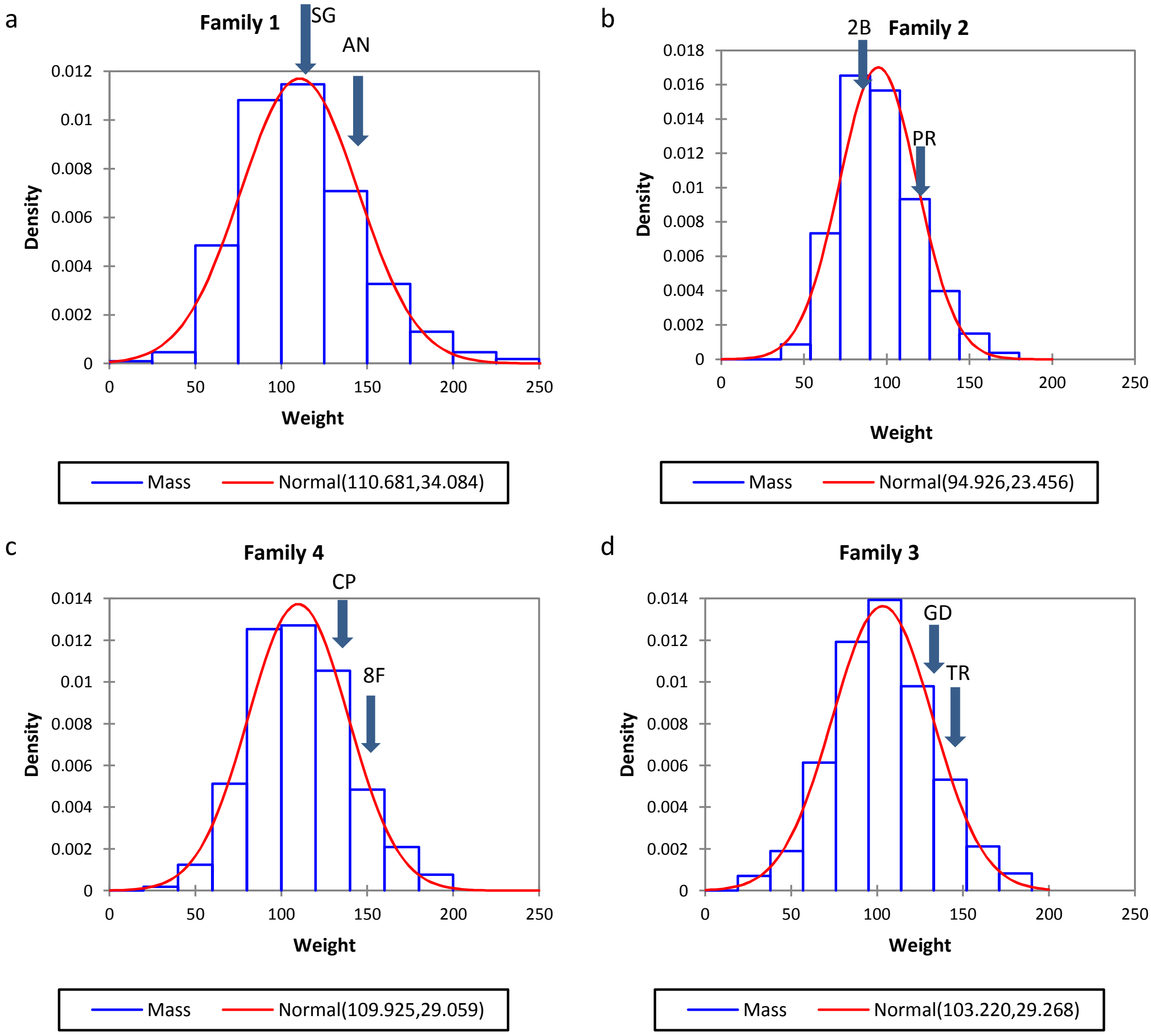

Figure 3 Seedling distribution frequencies of weight for families 1 (a), 2 (b), 4 (c) and 3 (d). Mean parental values are indicated with arrows and include 'Scarlet Gala' (SG), 'Anna' (AN), 2B-19-22 (2B), 'Prima' (PR), 'Cripps' Pink' (CP), 8F-8-6 (8F), 'Golden Delicious' (GD) and 'Treco Red' (TR).

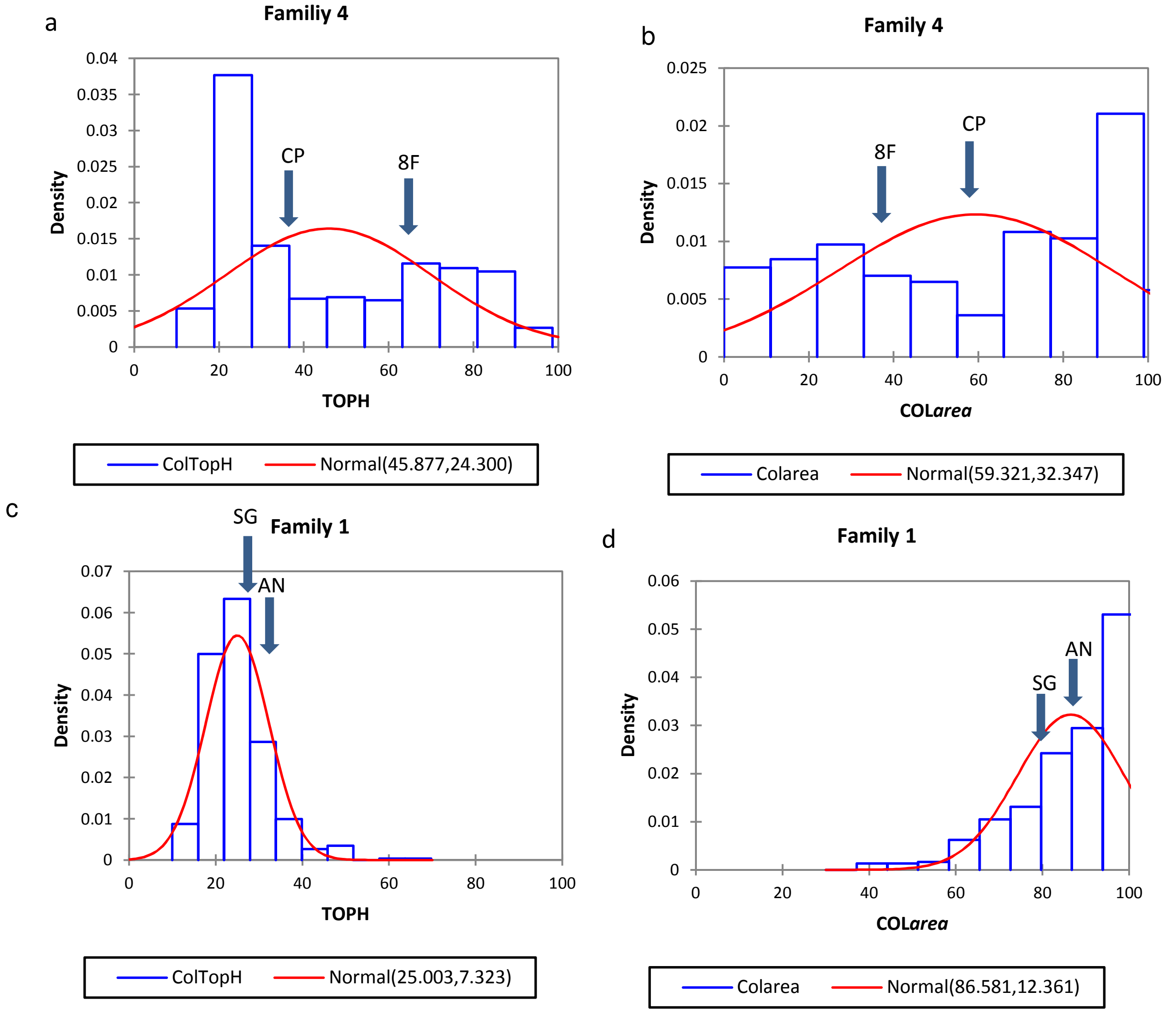

Figure 4 Seedling distribution frequencies of hue angle of overcolour (TOPH) and of percentage red coverage on the fruit peel (Col*area*) for family 4 (a,b) and family 1 (c,d). Mean parental values are indicated with arrows and include 'Anna' (AN), 'Scarlet Gala' (SG), 8F-8-6 (8F) and 'Cripps' Pink' (CP).

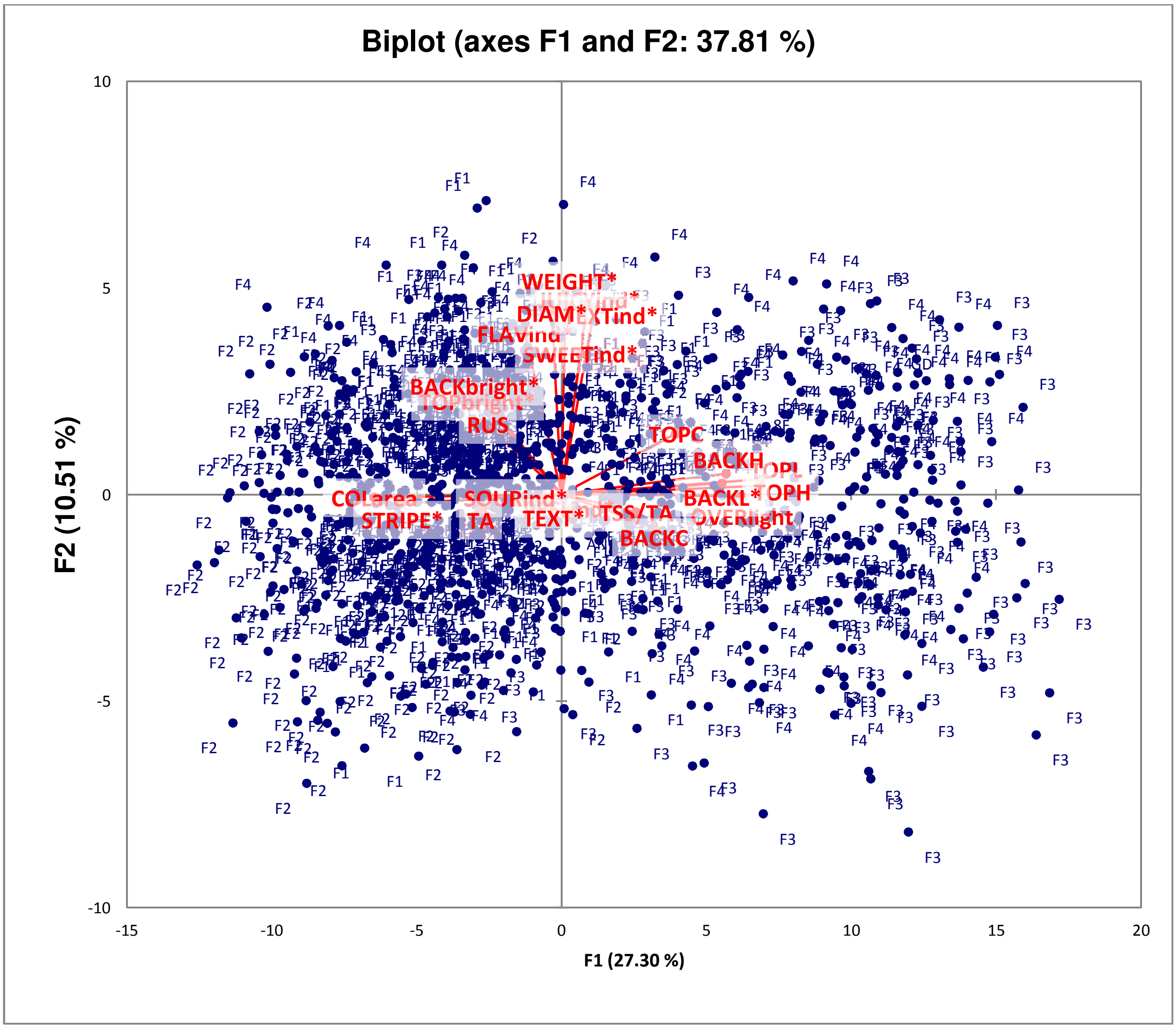

Figure 5 Principal component analysis bi-plot of instrumentally and sensorially measured attributes for each of four apple breeding families and their parental genotypes, i.e. families 1, 2, 3 and 4 (F1, F2, F3 & F4); 'Anna' (AN), 'Scarlet Gala' (SG), 2B-19-22 (2B), 'Prima' (PR), 'Treco Red' (TR), 'Golden Delicious' (GD), 8F-8-6 (8F) and 'Cripps' Pink' (CP). Sensorially measured attributes included coloured area (COL*area*, higher values=higher coloured area), stripeness (STRIPE, higher values=higher incidence of stripes), visual brightness of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively (TOP*bright*, higher values=higher brightness), lightness of the overall colour (OVER*light*, higher values=lower lightness), brightness of the background colour (BACK*bright*, higher values=higher brightness), russetting (RUS, higher values=lower incidence), sour taste (SOUR*ind*), sweet taste (SWEET*ind*, higher values=sweeter taste), apple flavour (FLAV*ind*, higher values=higher apple flavour), juiciness (JUICY*ind*, higher values=higher juiciness), and perceived texture (TEXT*ind*, higher values=crisper texture). Instrumental attributes included titratable acidity (TA), total soluble solids/TA (TSS/TA), instrumental texture (TEXT) and colour measurements included lightness (TOPL), chroma (TOPC), hue angle (TOPH) of the blushed, reddest, most yellow or greenest sides for blushed, full red, yellow and green apples, respectively; and the lightness (BAKCL), chroma (BACKC) and hue angle (BAKCH) of the background colour.

CHAPTER 8
General discussion and conclusions

The goal of the local Agricultural Research Council (ARC) apple breeding programme is to develop new, unique cultivars with greater appeal among local and international consumers (Labuschagnè, 2012). Preferences of European apple consumers have been investigated widely (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998; Carbonell *et al.*, 2008), but limited information is available on the intrinsic attributes (factors relating to apples such as appearance, flavour and texture) and extrinsic attributes (factors relating to consumers' socio-demographic characteristics and information about the product) that drive the preference of consumers in the local market. This study was partly undertaken to establish the drivers of apple eating quality and appearance liking for consumers from different socio-demographic backgrounds in the Western Cape Province of South Africa, viz. black, coloured and white consumers from different age groups. We aimed to determine the validity of the general perception in the apple industry that black and coloured consumers like sweet apples and dislike sour apples (Fick, 2011). However, apple preferences among consumers from the same ethnic group are not expected to be homogenous (Daillant-Spinnler *et al.*, 1996; Carbonell *et al.*, 2008). Clustering of consumer segments with similar preferences for apple eating quality and appearance was therefore conducted to determine the relative differences between the sensory attributes that drive the apple preferences of consumers in each cluster, the cluster size and its socio-demographic composition. Considering the importance of apple appearance as a pre-selection criterion (Shankar *et al.*, 2010), our investigations were also concerned with the extent and impact of appearance and flavour/texture associations on consumers' apple preferences. In order to reduce the time and costs involved in the commercialisation of cultivars that fail to satisfy consumer demands, it is essential to optimise the fruit quality parameters used to screen and select new cultivars. In this study, we also conducted quantitative genetic analysis and studied the genotypic variation in four apple breeding families to determine the relative ease of breeding and selection for fruit quality attributes, especially attributes that drive consumer preference. We used the breeding material to determine the validity of using single assessors and instrumental measurements to quantify fruit quality attributes, as is currently used (Oraguzie *et al.*, 2009), or whether advanced forms of descriptive sensory analysis (DSA) can be used to optimise the evaluation and selection process.

Intrinsic and extrinsic drivers of consumers' apple preferences

Results from our study conducted on breeding families showed that sensory attributes relating to firmness (crispness, juiciness, hardness and crunchiness), sweetness and apple flavour were important drivers of liking for a large proportion of a generic consumer group that was not selected to be representative of Western Cape consumers. The importance of sweetness and firmness in driving the preference of European apple consumers is firmly established in literature (Daillant-Spinnler *et al*., 1996, Jaeger *et al*., 1998). However, fruit quality attributes in apple cultivars vary concomitantly due to complexities related to genetic and environmental factors, which can impede breeding and selection of a specific cultivar with high levels of sweet taste, firmness and apple flavour. Interrelated fruit quality attributes were also evident in the commercial cultivars investigated in our study, i.e., sour fruit generally also associated with crispness, juiciness and crunchiness, while sweeter fruit associated with low levels of sour taste and in some cases also with mealiness. Our study confirmed that individual consumers have divergent apple preferences and that firmness, sweetness and apple flavour are not equally important to all consumers. Segmentation of consumers with similar apple preferences into clusters will enable breeders and commercial entities to determine the proportion of consumers who actually like sour taste and have a higher tolerance towards softer apples. Consumers in our study could be segmented into three clusters based on the relative importance they placed on firmness, sweetness and apple flavour to conform to the particular set of sensory attributes nested in each cultivar. A large proportion of the total consumer group (44%) did not value firmness as a very important quality attribute as their preference was primarily driven by flavour attributes. Consumers in this eating quality cluster (E3) disliked sourness more than consumers in the other clusters and were prepared to accept low levels of mealiness in highly sweet fruit. Consumers in eating quality cluster 1 (E1), who constituted 34% of the total consumer group, responded primarily and positively to sensory attributes relating to firmness and therefore disliked mealiness. These consumers also tolerated sour taste that generally associated with firmness. They liked sweet fruit of cultivars such as Topred, Starking and Royal Gala, but gave lower liking scores for these fruit compared to consumers in E2 and E3. Apple flavour was the most important driver of liking for consumers in eating quality cluster 2 (E2) (22%). E2 also liked sour taste, which generally associated with high levels of apple flavour, more than E1 and E3 consumers. Although the preference of E2 associated with sour taste, they also liked sweet fruit. Consideration of only the residual preference data can therefore be misleading. Residual preference scores computed from double mean centred data can be used to determine the relative importance of apple attributes for each cluster. However, it should be noted that these relative preferences are only indicative of the preference of one cluster in comparison to other clusters and that they emphasise preference differences. Hence, the absolute preference scores should not be overlooked, as this provides important information regarding the most preferred apple attributes for consumers in each of these clusters.

Clustering of consumers based on their responses to sour taste, or whether their preference was primarily driven by texture or flavour, was in accordance with segmentation results reported in literature (Daillant-Spinnler *et al.*, 1996; Jaeger *et al.*, 1998; Carbonell *et al.*, 2008). The size of the sour liking segment in our study and that of Carbonell *et al.* (2008) (29%) was similar, but a considerably smaller proportion of consumers in the study of Carbonell *et al.* (2008) disliked sour taste (22%). The largest proportion of consumers (49%) in Carbonell *et al.* (2008) was situated between the sour liking and sour aversive clusters. In accordance with equal sized sour liking and sour aversive clusters reported by Daillant-Spinnler *et al.* (1996) and Symoneaux *et al.* (2012), the proportion of consumers in our study who liked or tolerated sour taste was approximately equal to the proportion that disliked it.

Commercial success of new cultivars could be improved if fruit are directed at the consumer group who is more likely to prefer and purchase the cultivars that exhibit their preferred sensory attributes. Commercial entities should thus not only be acquainted with the intrinsic attributes that drive consumer liking, but also with the extrinsic attributes and consumer characteristics that greatly impact on cultivar success. Black, coloured and white consumers often reside in largely homogenous neighbourhoods, and knowledge of the preference differences between these ethnic groups should be a guideline to the localities where higher concentrations of consumers would have a high preference for fruit that characterise specific sensory attributes. Although our results confirmed that black and coloured consumers generally like sweet apples and dislike sour apples, the socio-demographic composition of consumers in the sour liking (E2) and sour tolerant (E1) clusters showed that this was not true for all coloured and black consumers. In fact, coloured and black consumers who also like sour cultivars constitute an important 41% of the total consumer group in the Western Cape. However, considering the large proportion of coloured and black consumers in E3, who far exceed the white consumer group in the Western Cape, more consumers may have an aversion to sour taste. Firmness that generally associated with sour taste was a more important driver to white and younger consumers compared to older, coloured and black consumers. However, sweet apples should also be targeted at white consumers. Consumers in sweet liking E3 were mostly in the older age group, who could mainly be responsible for fruit purchasing of households and thereby contribute greatly to the annual fruit expenditure that is higher for white consumers compared to coloured and black consumers (STATSSA, 2006). Coloured consumers, who constitute approximately half of the consumer population in the Western Cape, preferred a variety of apple eating quality and appearance attributes. Diverse apple cultivars should thus be made available to the particular retailers favoured by these consumers.

The importance of apple appearance is firmly established in literature (Cliff *et al.*, 1999, 2002). Consumers in the eating quality clusters in our study generally liked the appearance of the cultivars that traditionally associated with the set of sensory attributes that they preferred, i.e., consumers who preferred sour and firm apples, generally also preferred the appearance of full green coloured fruit (this combination being typical of ‘Granny Smith’), while consumers who preferred sweet apples that were also softer, generally also preferred the appearance of full red or striped red fruit (this combination being typical of ‘Royal Gala’ or ‘Topred’). Expectations created by apple appearance greatly impacted on consumers' eating quality experience. Consumers generally associate red colour with sweetness and green colour with immaturity and sour taste (Steyn, 2012, and references therein). A mismatch between expected and actual eating quality experiences led to disconfirmation and a lower preference score e.g., when a red 'Fuji' photograph was presented with a green 'Granny Smith' photograph. The importance of brand image was illustrated when consumers liked 'Pink Lady®' more when it was presented with its corresponding photograph compared to presentation with the 'Starking' photograph that they possibly associated with poor eating quality. Consumer preference for apple eating quality and appearance should thus not only be tested in isolation, but consumers' eating quality should be tested while also considering the appearance of the fruit. In the case where disconfirmation might result from differences between expected and actual eating quality attributes, consumers should be informed about the sensory profile of the apples. Consumers can be educated via taste tests through in-store demonstrations or clear labelling on apple packaging. Attributes such as "sweet", "juicy", "sour" and "high apple flavour" should be clearly indicated. In our study it was shown that consumers are not always familiar with their preferred apple cultivars, but they were generally aware of the quality attributes that they liked. A three-cluster solution based on consumers' preferences for apple appearance in our study showed that consumers in appearance cluster 1 (A1) had a higher preference for green peel colour and pink bi-colour (45% of the total consumer group), consumers in appearance cluster 2 (A2) liked green/yellow and red striped peel colours (38%), and consumers in appearance cluster 3 (A3) liked red peel colour (17%).

Optimisation of parameters that drive consumer preference

Results from our study showed that an individual assessor cannot accurately select fruit according to the preferences of a large consumer group. This practice is currently commonly used in fruit breeding programmes to identify selections with good commercial potential. Parameters of apple quality should therefore be quantified as objectively as possible and in relation to consumer preference in order to optimise the parameters used to predict drivers of liking. Divergent preferences among consumers in different clusters require the use of different parameters to predict their preference. Sensory attributes as quantified by a trained sensory panel were generally better predictors of consumer liking compared to attributes quantified by an individual assessor or by instruments. However, due to the time and costs involved in advanced forms of descriptive sensory analysis (DSA), individual and instrumental assessment of fruit quality attributes are still the mainstay of evaluation of selections from breeding families (Brookfield *et al.*, 2011). A compromise between the accuracy of trained panel analysis and lower costs of rapid individual and instrumental analysis would be a viable solution to routine screening of selections in the early phases of breeding.

Despite practical limitations in the current study that reduced the accuracy with which we could report on the strength of sensory-instrumental correlations, results from the literature supported our suggestion that instrumental measurements could not always accurately quantify the sensory attributes that they characterised (Harker *et al.*, 2002; Brookfield *et al.*, 2011). TSS (total soluble solids) concentration has shown to be a poor predictor of sweet taste, but is often used as proxy for sweetness (Harker *et al.*, 2002; Oraguzie *et al.*, 2009). The poor instrumental-sensory relationship for TSS and sweet taste probably could be ascribed to the integration of the perception of sensory sensations caused by sweet and sour tastes, i.e. linkage perception. The negative phenotypic correlation between sweet and sour tastes showed that trained panellists perceived sour taste as the lack of sweetness, and *vice versa*. Instrumentally measured TSS/titratable acidity (TA) showed stronger correlations with sweet taste compared to TSS and should thus be used to quantify sweet taste. TSS\TA is an important predictor of the preference for E1, who liked sweet taste less compared to the other clusters. Here breeders should select against high TSS/TA levels that resulted from intermediate TSS and low TA, considering that consumers in E1 accepted fruit with high levels of TA. TA was a good predictor of sour taste and a better predictor of consumer responses than sour taste. Higher levels of TA should thus be used to select fruit that would also be liked by consumers in E2, but should be used to select against the preference of E3 consumers. Apple flavour, which is the complex product of flavour volatiles, sweet and sour tastes, showed poor correlations with instruments that only measured TSS, TA and TSS/TA and did not account for flavour volatiles. The importance of apple flavour in driving the preference of E2 requires accurate sensory quantification for efficient selection for this cluster. Mealiness, which may develop during periods of commercial storage (Mehinagic *et al.*, 2004), was a strong negative driver of liking for consumers in E1, but could not be predicted by puncture measurements. Apple fruit should be subjected to storage periods of approximate eight weeks (Brookfield *et al.*, 2011) before DSA commence to ensure that softer fruit are not discarded based on over maturity and to prevent selection of genotypes that develop mealiness during periods of commercial storage.

Panellists trained in DSA (approximately 8) should be encouraged to use the entire range of each attribute spanned by the measuring scales to exhibit the variability within all the apples used in similar studies. Product specific unipolar scales should be used that measure attribute intensity within the specific product category, rather than bi-polar scales that measure different attributes on the same scale or subjective attributes ranging from “bad” to “good”. For example, “firmness” should be rating from “extremely low” to “extremely high” (firmest sample in the studied material) and not from “mealy” to “crispy”, as is often used in evaluations of breeding programmes. Wider genotypic variation could subsequently be reported that could better quantify attribute intensity, and the problem of intermediate mean scores for attributes such as “apple flavour” could be eliminated. Strong phenotypic correlations between crispness, crunchiness and hardness indicated that similar sensory perceptions were measured by these attributes. Hardness can be used as proxy for crispness and crunchiness, considering that a higher rate of genetic gain was suggested by broad-sense heritability estimates for hardness. Recent research by Palmer *et al.* (2010) established dry matter concentration (DMC) measurement as a good predictor of apple quality and consumer preference. In retrospect, DMC should have been included as an additional quality parameter in the analysis of a breeding programme in our study, but was not tested in the first two years before these results were published and was therefore also omitted in the last season.

Visual assessment of colour attributes by the individual assessor was a better predictor of consumer preference for appearance compared to instrumental colour measurements. This could be attributed to instrumental measurement of a localised area, while colour contrast could have an effect on colour perception when the individual assessor and consumer panel viewed both the blushed and background colour.

Breeding and selection for drivers of consumer liking

Selection for favourable attributes would be viable if a high rate of genetic gain is predicted by high heritability estimates and if favourable attributes are not phenotypically correlated with negative attributes. However, results showed that most attributes investigated are under polygenic control and inherited quantitatively. In this study it was found that breeding and selection for sweetness, high levels of apple flavour or firmness can be hampered by low heritability levels. TA and total TSS/TA were intermediately heritable and showed a wide genetic range among the families. High broad-sense heritabilities among families for attributes relating to colour predicted high genetic gain in a breeding programme for lightness, colourfulness, the percentage of coloured area on the fruit peel and the proportion of red or green colour in the peel. Expression and inheritance of anthocyanin pigmentation that determine the red colour of apple peel is influenced by groups of structural genes that follow a heritability behaviour similar to a single gene that is dominant for red (Honda *et al.*, 2002). It should therefore be relatively easy to breed and select genotypes for a particular peel colour. Genetic factors determining and influencing ranges between dark red and pink and between bright red and dull red is however more difficult to identify and describe (Honda *et al.*, 2002).

Broad-sense heritability estimates calculated for attributes quantified by the individual assessor were mostly lower compared to instrumentally measured attributes. Different evaluation protocols that were applied for instrumental, individual and trained panel analysis complicated the comparison of these data sets. The inherent genotypic variation was larger for the full set of genotypes analysed by the individual breeder compared to the subset analysed by the trained panel. Repeatability estimates calculated for trained panel analysis were mostly higher than broad-sense heritability estimates computed for the individual assessor. Care had to be taken in the interpretation of these results and the focus should rather be on the effect and standardisation of evaluation protocols and heritability estimates. Since repeated measures on the same fruit were conducted by the trained panel, the error component for trained panel assessment accounted for within-fruit variation, while the error component for individual assessment of a composite three-fruit sample accounted for different fruit from the same tree. Variance contributed by an individual assessor is expected to inflate the error component and thereby reduce the heritability component. However, the mentioned differences in evaluation protocols complicated the quantification of the variance contributed by assessor. Results therefore emphasised the importance of a universally agreed method for calculation of heritability estimates and fruit evaluation protocols in general.

A summarised proposal for optimising the ARC apple breeding programme

Results from DSA and consumer preference testing conducted in our study can be successfully used to optimise fruit quality parameters in all four phases of fruit evaluation in the ARC apple breeding programme. These phases include: 1) Selection of superior genotypes (seedlings) from diverse breeding families; 2) Testing of clonally propagated trees of the first phase selections to evaluate fruit quality attributes and identify promising selections by comparing them with commercial cultivars; 3) Proper evaluation of semi-commercial selections under varying climatic conditions and 4) Release of commercial cultivars to the industry (Labuschagné, 2012).

First and second phases

Seedlings that show obvious defects and poor fruit quality (for example, visually unattractive fruit, very small fruit, very mealy texture or unacceptably low levels of apple flavour) are eliminated by individual breeders during the first phase in most breeding programmes (Labuschagnè, 2012). Instrumental analysis and DSA by small groups (2-4) of expert assessors should be conducted on all superior selections in the first phase. Breeders and breeding institutions should be acquainted with the divergent preferences of consumers in the target market from the early phases of breeding. Expansion into new markets where limited information is available on consumer preferences may require consumer preference studies. Multivariate preference plots illustrating the drivers of consumer liking generated in our study should be used to direct breeding aims for the ARC apple breeding programme. Parental genotypes with high potential should be identified by comparing these preference plots with multivariate plots illustrating the eating quality and appearance profiles generated by instrumental and expert assessment data.

Preference maps can thus be used to identify selections early in the breeding process that satisfy the demands of consumers in the different clusters. Novel selections from breeding families with unique eating qualities can also be identified by selection of genotypes that are situated on the preference space that is not occupied by other genotypes. Selections can be screened for the different consumer clusters identified in our study. Based on our results, consumers in all three clusters generally liked sweet fruit, although consumers in E3 liked sweetness more than consumers in the other clusters. Selections that are developed for E3 should be analysed by TSS/TA and TA. High levels of TSS/TA and low levels of TA in apple fruit could contribute to cultivar success in this cluster. Although these consumers' preference associated with slight levels of mealiness, the upper threshold at which these consumers would reject fruit remains to be established. Sensory attributes relating to firmness should be used to screen genotypes directed at E1. However, the upper limit of firmness at which these consumers would prefer apples, should still be determined. Physical measurements that correlate better with sensory hardness than the puncture test should be investigated. Apple flavour, which was the most important driver of liking for E2, did not strongly correlate with instrumental measurements. A prediction model could be developed whereby a combination of instrumental measurements (TSS, TA and DMC) could be analysed to predict high levels of apple flavour that would be favoured by E2.

Third and fourth phases

It is recommended that formal sensory analysis and consumer preference testing are performed in the third evaluation phase to verify the intrinsic qualities and commercial potential of the genotypes before their release to the industry. Results from our study showed that South African consumers' preferences for apple eating quality were generally in agreement with clusters of European consumers who either liked or disliked sour taste (Daillant-Spinnler et al., 1996). Hence, apples that are preferred by local consumers or consumer clusters, should also be acceptable to European consumers. The local panel provided a good estimate of the preference patterns of European consumers and could be used to screen breeding selections for the European market, which is an important export market for South African apples (DFPT, 2011). However, divergent preferences of international markets should be taken into consideration and the expertise of commercial entities applied during this phase. For example, consumers in the Eastern markets generally prefer full red, sweet apples, while consumers in some Eastern European countries generally prefer softer apples (Labuschagnè, 2012). Taking this into consideration, commercial entities will base their decisions on the suitability of new cultivars for specific markets on their experience of selling apples in these markets and the sensory data generated for the new cultivars.

Panellists should be highly trained, especially in complex attributes such as apple flavour and sweet taste with which we experienced difficulties to quantify in this study. Consumer preference for apple eating quality and appearance should be tested by presenting consumers with sliced taste samples and whole fruit, respectively. However, these samples should be presented simultaneously to also test for preference of the total product. The selected consumer group should represent consumers from different ethnic groups, age groups and socio-demographic backgrounds of the intended target market. In this phase, the particular sensory profile of promising selections should be projected unto the preference space to see where it would fit in the market and which consumer segment would be most likely to buy it (Daillant-Spinnler *et al.*, 1996). Cultivar development actions such as marketing, branding, packaging and information displayed on the packaging should be investigated in conjunction with commercial entities, which should be part of the process of cultivar development. Semi-commercial trials should be performed in conjunction with commercial entities who will supply fruit to the targeted markets.

Limitations and future studies

Due to working with single seedling trees from breeding families, the current study imposed certain limitations, some of which could be circumvented in future studies. The biggest challenge and limitation of the study conducted on the breeding selections pertained to the temporal storage differences between individual, instrumental, trained panel and consumer preference analysis. These storage differences were a direct consequence of the large number of fruit that had to be evaluated for the quantification of the genotypic variability in the breeding families (Chapter 7). Fatigue of the individual assessor who had to analyse 3 fruit of approximately 600 genotypes each season, probably added to the large variance components contributed by error for individually analysed attributes. In the case where smaller numbers of fruit are evaluated for consumer preference testing (Chapter 6), fruit should be kept in the cold store until commencement of all analyses. Early bearing families were harvested too early in 2008, probably due to difficulties in determining optimum maturity of full red progenies, which the individual assessor was not familiar with in the first harvest season. Fruit from different seedling trees did not mature simultaneously. Consequently, some genotypes were stored for up to eight weeks before consumer preference testing and DSA commenced, while genotypes that were harvested closer to these assessment dates were subjected to shorter periods of cold storage. Temporal storage differences between instrumental measurements, individual assessment, DSA and consumer preference testing, impeded the accuracy with which we could comment on the ability of instruments and the individual assessor to predict the attributes quantified by the trained panel and also the instrumental and individually assessed attributes that drive consumer preference. However, considering that DSA and consumer preference analysis were conducted shortly after each other, we could conclude with certainty that several eating quality attributes (as analysed by the trained panel) are important and good drivers of liking for consumer preference of eating quality. Results suggested that the time elapsed between instrumental, individual and trained panel analysis in 2008 and 2009 and for the early bearing families in 2010 did not greatly affect instrumental-sensory relationships for all attributes, although this effect was more pronounced for attributes relating to texture. However, the fact that fruit were cold stored between individual, instrumental and trained panel analyses are still considered as a shortcoming for the accurate comparison of sensory and instrumental measurements. The small amount of fruit available from seedling trees that were used in the study on breeding selections often necessitated utilisation of very small fruit and made it unfeasible to conduct DSA and instrumental measurements on the same fruit. Irregular bearing of seedling trees complicated the use of the exact same trees for all three harvest years for consumer preference testing and DSA. Alternative seedling trees from the same family had to be harvested in the case where insufficient fruit were available from the seedling trees that were initially selected in 2008. In future studies, assessment of fruit quality attributes could be optimised in the first phase to successfully identify all potential genotypes. This could be done by repeated measurements by a trained panel on each fruit in a composite sample of a sub-sample of selections. This approach could lead to reduced within-fruit and between-fruit variation and variance contributed by the assessor, which would reduce the error components in estimates of genetic parameters, e.g. a lower error component could increase the accuracy with which heritability estimates could be calculated in family studies and could optimise identification of favourable parental genotypes to develop new breeding families.

Limitations and challenges in the study conducted on commercial cultivars pertained to sensory attributes that varied concomitantly between cultivars and to unrepresentative age distribution in the consumer groups that participated in the study. The specific fruit that were used in this study did not span a wide range of sensory attribute combinations, which complicated the identification of isolated sensory attributes that drove consumer preferences (as is possible with processed foods where attribute intensity can be manipulated). None of the fruit were considerably mealy and the highest score on a 100-point intensity scale for mealiness was only 5. Although it is widely reported in literature (Jaeger *et al.*, 1998) that consumers dislike mealiness, we cannot accurately conclude on the response to mealiness among Western Cape consumers. In order to determine consumers' responses to mealiness and firmness *per se*, different levels of these attributes should be obtained. Fruit could be subjected to different storage periods to acquire different levels of mealiness, but care should be taken to ensure that the sweetness or TA of these fruit is consistent and does not contribute to preference differences. A wider range of sensory profiles can be obtained by storage of sour fruit, while sweet and crisp fruit should also have been selected. The sensory profiles of selected fruit can be further diversified in future studies by the utilisation of breeding selections that show a wide range of sensory attribute combinations on a PCA plot, although apples from seedling trees may be more variable in sensory attributes compared to commercially produced fruit. The young consumers who partook in this study were mostly students at the University of Stellenbosch and thus not representative of the total consumer group in the Western Cape that is younger than 25. White consumers were mostly represented by students from the younger age groups, which possibly caused biased towards the higher preference of sour fruit among the white consumer group. The preferences of younger consumers might also change in the future to adapt to the sensory profiles of new apple cultivars while the preference differences between the three ethnic groups may decline as black and coloured consumers become more familiar with newer cultivars.

Therefore it might be necessary to conduct a follow-up study in a few years to validate the consumer preferences reported and to revise the relative sizes of the preference clusters. Clustering of consumers from different groups in South Africa could be expanded by using new multi-block statistical methodologies to determine the relation between several large blocks of data (Næs, 2011). In experimental consumer studies, three pieces of information should be linked, i.e. 1) information about the samples being tested; 2) consumer liking of the same samples and 3) additional information about the consumers (socio-demographics, attitudes and habits). How to combine these three pieces of information statistically is crucial in all types of product development.

Our study was limited to consumers in the Stellenbosch area in the Western Cape. Establishing preferences of consumers in other parts of the country may prove rewarding. A similar study in Gauteng province should follow on the current study, considering that Gauteng is the most densely populated province in South Africa (STATSSA, 2006). Considering the increased importance of other African countries as importers of South African apples (DFPT, 2011) and the geographic proximity of South Africa compared to other competitors (O'Rourke, 2011), further research is required to gain knowledge into the sensory attributes preferred by consumers in other African countries and also the extrinsic factors that would determine their purchase decisions.

This study build on research previously conducted in collaboration between the Departments of Food Science and Horticultural Science that incorporated sensory analysis conducted by a trained panel and consumer preference testing into the evaluation of breeding selections and development of new cultivars in South Africa. This study was novel in the quantification of genetic variation for sensory attributes analysed by a trained panel in South Africa. Our study was the first to examine the preference differences for any food product among black, coloured and white consumers. Novel research was conducted on the application of cluster analysis on residual preference data in determining drivers of liking for different consumer groups in South Africa relative to each other. The principles of breeding programme evaluation described above, are not only limited to apple breeding families and could successfully be applied to breeding programmes of other fruit crops.

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APPENDIX 1

Table 1 ANOVA (Analysis of variance) table with main and interaction effects for judge, cultivar and peel for research conducted in 2009, as mentioned in Chapter 3. 'Peel' refers to the effect of peel, i.e. preference for peeled versus unpeeled samples

Factor	DF	Pr>F
Judge	212	<0.0001
Cultivar	8	<0.0001
Peel	1	<0.0001
Cultivar*Peel	8	0.0683

APPENDIX 2

JUDGE NO: ________

ACCEPTABILITY OF COMMERCIAL APPLES

NAME OF JUDGE: ____________________________________ *CONTACT NUMBER (Mobile or Landline):*

PLEASE CIRCLE WHICHEVER IS APPLICABLE

GENDER: Male / Female	**WHAT IS YOUR CURRENT EMPLOYMENT:** Student / Assistent / Administrative / Professional
AGE: 18-25 / 26-35 / 36-50 / 51-65 / 65+	**HOW MANY PEOPLE IN YOUR HOUSEHOLD (INCLUDING YOURSELF)?** 1 / 2 / 3 / >3
RACIAL ORIENTATION: Black / Coloured / White / Other	**HOW MANY CHILDREN IN YOUR HOUSEHOLD?** 0 / 1 / 2 / 3+
MARITAL STATUS: MARRIED / SINGLE	**WHO IS PRIMARILY RESPONSIBLE FOR PURCHACING FRUIT FOR YOUR HOUSEHOLD?** Yourself / Spouse / Parents / Other
INCOME GROUP: Please give an indication of your MONTHLY **OR** YEARLY income Monthly: < 5 000 / 5,001 – 30,000 / > 30,000 Yearly: < 60,000 / 60,000 – 360,000 / >360,000	**WHERE DO YOU USUALLY PURCHASE APPLES?** Woolworths / Pick'nPay / Shoprite / Checkers / Fruit&Veg / Hawker / Other
EDUCATION: Grade 11 (Standard 9) or below / Grade 12 (Matric) / Diploma/degree	**WHEN IN SEASON, HOW OFTEN DO YOU CONSUME APPLES?** Daily / Approx 2-3 times a week / 2x per month / Approx 4 times a year / NEVER

APPENDIX 3

ACCEPTABILITY OF TASTE

1. THE SAMPLES SHOULD BE TASTED IN THE ORDER PRESENTED. RANK THE SAMPLES ON THE SCALE & CIRCLE THE NUMBER NEXT TO THE PREFERRED DEGREE OF LIKING
2. TAKE A GENEROUS BITE FROM EACH SAMPLE & RINSE YOUR MOUTH WITH WATER BETWEEN SAMPLES.

CODE		CODE		CODE	
9	Like extremely	9	Like extremely	9	Like extremely
8	Like very much	8	Like very much	8	Like very much
7	Like moderately	7	Like moderately	7	Like moderately
6	Like slightly	6	Like slightly	6	Like slightly
5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike
4	Dislike slightly	4	Dislike slightly	4	Dislike slightly
3	Dislike moderately	3	Dislike moderately	3	Dislike moderately
2	Dislike very much	2	Dislike very much	2	Dislike very much
1	Dislike extremely	1	Dislike extremely	1	Dislike extremely

CODE		CODE		CODE	
9	Like extremely	9	Like extremely	9	Like extremely
8	Like very much	8	Like very much	8	Like very much
7	Like moderately	7	Like moderately	7	Like moderately
6	Like slightly	6	Like slightly	6	Like slightly
5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike
4	Dislike slightly	4	Dislike slightly	4	Dislike slightly
3	Dislike moderately	3	Dislike moderately	3	Dislike moderately
2	Dislike very much	2	Dislike very much	2	Dislike very much
1	Dislike extremely	1	Dislike extremely	1	Dislike extremely

CODE		CODE		CODE	
9	Like extremely	9	Like extremely	9	Like extremely
8	Like very much	8	Like very much	8	Like very much
7	Like moderately	7	Like moderately	7	Like moderately
6	Like slightly	6	Like slightly	6	Like slightly
5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike
4	Dislike slightly	4	Dislike slightly	4	Dislike slightly
3	Dislike moderately	3	Dislike moderately	3	Dislike moderately
2	Dislike very much	2	Dislike very much	2	Dislike very much
1	Dislike extremely	1	Dislike extremely	1	Dislike extremely

APPENDIX 4

GENERAL QUESTIONS

Indicate your *degree of liking* of the following APPLE TASTE attributes 1____2____3____4____*5*____6____7____8____9 Dislike Extremely — Not sure — Like Extremely	
Sour Apple Taste	1____2____3____4____5____6____7____8____9
Sweet Apple Taste	1____2____3____4____5____6____7____8____9
Prominent Apple Flavour	1____2____3____4____5____6____7____8____9
Juiciness	1____2____3____4____5____6____7____8____9
Mealiness	1____2____3____4____5____6____7____8____9

Indicate your *degree of liking* of the following APPLE PEEL APPEARANCE 1____2____3____4____*5*____6____7____8____9 Dislike Extremely — Not sure — Like Extremely	
Red full-coloured	1____2____3____4____5____6____7____8____9
Yellow full-coloured	1____2____3____4____5____6____7____8____9
Green full-coloured	1____2____3____4____5____6____7____8____9
Red striped	1____2____3____4____5____6____7____8____9
Red bi-coloured (**more** than 50% coloured)	1____2____3____4____5____6____7____8____9
Red blushed (**less** than 50% coloured)	1____2____3____4____5____6____7____8____9
Pink bi-coloured (**more** than 50% coloured)	1____2____3____4____5____6____7____8____9

How important **are the following aspects when** ***purchasing / consuming*** **APPLES?** 1____2____3____4____*5*____6____7____8____9 Not important — Not sure — Extremely important	
Purchasing price of APPLES	1____2____3____4____5____6____7____8____9
Colour of the APPLE	1____2____3____4____5____6____7____8____9
Size of the APPLE	1____2____3____4____5____6____7____8____9
I am extremely loyal to **specific apple cultivars**	1____2____3____4____5____6____7____8____9
Cultivar name must be **indicated** on the packaging	1____2____3____4____5____6____7____8____9
APPLES should be grown **organically**	1____2____3____4____5____6____7____8____9
I am always **familiar** with the apple cultivars I purchase	1____2____3____4____5____6____7____8____9

Indicate your degree of liking of the following APPLE CULTIVARS 1____2____3____4____*5*____6____7____8____9		
Royal Gala	*I am not familiar with this cultivar*	1____2____3____4____5____6____7____8____9
Granny Smith	*I am not familiar with this cultivar*	1____2____3____4____5____6____7____8____9
Pink Lady	*I am not familiar with this cultivar*	1____2____3____4____5____6____7____8____9
Starking	*I am not familiar with this cultivar*	1____2____3____4____5____6____7____8____9
African Carmine	*I am not familiar with this cultivar*	1____2____3____4____5____6____7____8____9

Pink blushed (**less** than 50% coloured)	**1____2____3____4____5____6____7____8____9**

Thank you for your assistance!!

Please collect a gift as you leave the room!

Topred	*I am not familiar with this cultivar*	**1____2____3____4____5____6____7____8____9**
Golden Delicious	*I am not familiar with this cultivar*	**1____2____3____4____5____6____7____8____9**
Fuji	*I am not familiar with this cultivar*	**1____2____3____4____5____6____7____8____9**
Sundowner	*I am not familiar with this cultivar*	**1____2____3____4____5____6____7____8____9**

APPENDIX 5


African Carmine
Topred
Starking
Royal Gala
Sundowner
Fuji
Pink Lady
Golden Delicious
Granny Smith