THE EFFECT OF CANOPY POSITION ON THE FRUIT QUALITY AND CONSUMER PREFERENCE OF APPLES

By

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DECLARATION

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SUMMARY

We aimed to determine how canopy microclimate influences fruit quality and consumer preference in apples. Our postulate was that consumer preference would be higher for the taste, but not necessarily for the appearance of outer canopy fruit.

Outer canopy fruit, exposed to higher irradiance and temperatures, accumulated more phenolics and ascorbic acid, and had higher antioxidant capacities in their peel compared to inner canopy fruit. Phenolic levels and antioxidant capacity were also higher in the flesh of outer canopy fruit while ascorbic acid was higher in the flesh of outer canopy 'Granny Smith'. From a marketing perspective, outer canopy fruit can be seen as possessing greater potential health benefits.

Outer canopy fruit were higher in dry matter content (DMC), sugars and TSS, but lower in TA in the first season of the study. The sweeter and less sour taste of outer canopy fruit was preferred in all three cultivars over two years of study. Sunburnt fruit were higher in DMC, TSS:TA ratio, lower in TA and were perceived to be the sweetest, least sour and lowest in apple flavour and textural attributes. The effect of canopy position on apple flavour and textural attributes was inconsistent.

The redder outer canopy 'Starking' fruit were preferred by consumers because this cultivar is marketed with full red colour. The appearance of blushed, outer canopy 'Granny Smith' and 'Golden Delicious', and sunburnt 'Golden Delicious' were not preferred by consumers. Consumers are not familiar with such fruit. Blushed 'Granny Smith' is downgraded and sometimes sold at a lower price while sunburnt apples are processed or dumped depending on sunburn severity.

The consistency of these results was investigated in one season for 'Golden Delicious' from five locations. The consumer taste preference differential for inner and outer canopy fruit diminished as canopy size decreased. This indicates that there generally would be no benefit in harvesting and marketing outer and inner canopy 'Golden Delicious' separately.

We investigated the effect of familiarity on consumer preference by utilising an "experienced" consumer group of farm labourers from Ceres who are familiar with all fruit on a tree compared to an "inexperienced" consumer group of Stellenbosch consumers who are only exposed to fruit on the commercial market and eat apples less frequently. Both groups preferred the taste and appearance of outer canopy 'Starking'. The taste of sunburnt fruit was preferred by a substantial segment of both consumer groups, but the appearance was preferred

by only some Ceres consumers. A small segment of Ceres consumers preferred the taste and appearance of the blushed outer canopy 'Granny Smith' and 'Golden Delicious' while some Stellenbosch consumers preferred the taste of outer canopy 'Golden Delicious', but not 'Granny Smith'. Therefore, Ceres consumers who are more familiar with the taste attributes of sunburnt and blushed fruit of green cultivars have a higher preference for the appearance of these fruit. Based on our results, fruit marketers may be able to develop niche markets for outer canopy and sunburnt 'Golden Delicious' fruit.

OPSOMMING

Ons het ondersoek hoe vrugkwaliteit en verbruikersvoorkeur in appels deur die blarekoepel mikroklimaat beïnvloed word. Ons vermoede was dat verbruikersvoorkeur hoër sou wees vir die smaak, maar nie noodwendig vir die voorkoms van vrugte aan die buitekant van die boom (buitevrugte) nie.

Buitevrugte was blootgestel aan hoër ligstraling en temperature en hul skil het meer fenole en askorbiensuur geakkumuleer asook ŉ hoër antioksidantkapasiteit gehad vergeleke met binnevrugte. Fenole en die antioksidantkapasiteit was ook hoër in die vleis van buitevrugte terwyl askorbiensuur hoër was in die vleis van 'Granny Smith' buitevrugte. Vanuit ŉ bemarkingsperspektief kan buitevrugte gesien word as vrugte met hoër potensiële gesondheidsvoordele.

Buitevrugte was hoër in droë materiaal inhoud (DMC), suikers en TSS, maar laer in TA, laasgenoemde slegs in die eerste seisoen van die studie. Verbruikers het die soeter en minder suur smaak van buitevrugte verkies in beide jare van die studie. Vrugte met sonbrand was hoër in DMC, TSS:TA verhouding, laer in TA en was die soetste, minste suur en laagste in appelgeur en tekstuureienskappe. Die effek van blaredakposisie op appelgeur en tekstuureienskappe was variërend.

Verbruikers het die rooier buitevrugte van 'Starking' verkies. Ons reken dit is omdat hierdie kultivar as 'n volrooiappel bemark word. Verbruikers het minder van die voorkoms van rooiblos 'Granny Smith' en 'Golden Delicious' asook van 'Golden Delicious' met sonbrand gehou. Verbruikers is nie vertroud met sulke vrugte nie. Rooiblos 'Granny Smith' appels word afgradeer en word soms teen laer pryse verkoop terwyl sonbrand appels geprosesseer of uitgeskot word afhangend van die graad van sonbrand.

Die konsekwentheid van ons resultate is ondersoek met 'Golden Delicious' van vyf lokaliteite. Die smaakvoorkeur differensiaal tussen binne- en buitevrugte het afgeneem met ŉ afname in boomgrootte. Oor die algemeen sou daar dus geen voordeel wees om 'Golden Delicious' binne- en buitevrugte apart te oes en te bemark nie.

Ons het die effek van vertroudheid op verbruikervoorkeur ondersoek deur gebruik te maak van ŉ "ervare" verbruikergroep bestaande uit plaasarbeiders in Ceres en ŉ "onervare" verbruikersgroep van Stellenbosch. Die Ceres verbruikers is vertroud met al die appels op die boom vergeleke met die Stellenbosch verbruikers wat net blootstelling het aan vrugte op die kommersiële mark en ook minder gereeld appels eet. Beide verbruikersgroepe het die

voorkoms en smaak van ‘Starking’ buitevrugte verkies. ’n Substansiële segment van beide verbruikersgroepe het die smaak van sonbrand vrugte verkies, maar die voorkoms van hierdie vrugte is slegs deur sommige Ceres verbruikers verkies. ’n Klein segment Ceres verbruikers het die smaak en voorkoms van ‘Granny Smith’ en ‘Golden Delicious’ buitevrugte verkies terwyl sommige Stellenbosch verbruikers die smaak van ‘Golden Delicious’, maar nie ‘Granny Smith’ buitevrugte verkies het nie. Ceres verbruikers is meer vertroud met die smaakeienskappe van sonbrand en blosvrugte van groen kultivars en het gevolglik ’n hoër voorkeur vir die voorkoms van hierdie vrugte. Gebaseer op ons resultate kan bemarkers moontlik ’n nismark vir gebloste en sonbrand ‘Golden Delicious’ vrugte ontwikkel.

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DEDICATION

To growing in love and wisdom

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GENERAL INTRODUCTION

Research on consumer preferences for apple taste and appearance has mostly focused on cultivars (Daillant-Spinnler et al., 1996; Iglesias et al., 2008; Jaeger, 2000). However, the effect of the variation in apple fruit quality within a cultivar on consumer preference has received little research attention (Casals et al., 2005; Jaeger et al., 1998). Apple appearance and eating quality can vary considerably between trees in an orchard and even within the tree (Johnson and Ridout, 2000). Such variation is prevalent because the fruit are exposed to different environments within the orchard and within the canopy. In this research, we focus on fruit quality differences brought about by microclimatic differences within the apple tree canopy and how this influences consumer preference.

Fruit quality is of paramount importance as it forms the basis of consumer satisfaction in fresh produce (Jaeger et al., 2002). The first assessment of fruit by the consumer is of a visual nature. Therefore, peel colour is an important quality attribute in determining consumer acceptance of apples (Saure, 1990; Iglesias et al., 2008). The development of red blush and sunburn is associated with high light environments in the outer canopy (Saure, 1990; Schrader et al., 2003). Red blush in 'Granny Smith' apples results in degradation of the fruit (Hirst et al., 1990) on a purely aesthetic basis. Similarly, the fate of sunburnt fruit is primarily based on appearance. However, upon tasting, internal quality characteristics such as flavour, sweetness, sourness and texture attributes are also determinants of consumer preference in apples (Jaeger et al., 1998).

The main objective of this study was to determine how microclimatic variation brought about by canopy position affects the chemical and nutritional composition as well as the appearance and taste of apple fruit. We also endeavoured to determine whether the downgrading of outer canopy fruit of green cultivars with a red blush or sunburn is justified. This we did by evaluating consumer preference for the taste and appearance of outer and inner canopy fruit. These results enabled us to gain an appreciation of the role of red peel colour as a reliable indicator of fruit quality. Apart from fruit quality, consumer preference and food choice are also greatly influenced by other factors such as familiarity, social interactions or media to name a few (Pollard et al., 2002). Therefore, we also determined how familiarity influences consumer preference of fruit from different canopy positions by assessing the consumer preference of two consumer groups with different exposure and experience with apples.

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LITERATURE REVIEW: FRUIT QUALITY AND CONSUMER PREFERANCE

Introduction

The quality of a fruit is a cornerstone in building consumer satisfaction. Jaeger et al. (2002) defines quality as all those characteristics of a fruit that lead a consumer to be satisfied with the product. Fruit quality is based on several dimensions, many of which may not be readily evaluated by the consumer prior to purchase. Consumers therefore tend to use indirect indicators of quality to make judgement of the perceived quality from an array of product-related attributes (Kays, 1998). These quality attribute indicators play an important role in consumer preference and choices made when purchasing fruit. Sloof et al. (1996) classified fruit quality attributes into three categories , viz. search attributes including factors such as colour, appearance and price, experience attributes including taste, texture and flavour, and credence attributes viz. health benefits and microbiological safety issues. Consumer preference and food choice studies tend to be complex because apart from the main factors being investigated (eg. fruit quality or sensory appeal), other factors such as familiarity, habit, social interactions, media, advertising, cost, availability, time constraints and personal ideology also play a role (Pollard et al., 2002). Therefore, fruit quality should be considered as a non-absolute variable subject to change.

1. Consumer preference: a focus on apples

Fruit colour and appearance: Red, blue, yellow and orange colours play an important role in making fruit more conspicuous to their consumers (Willson and Whelan, 1990). Chlorophylls, carotenoids, betalains and anthocyanins are the four pigments that contribute to the colours of fruits and the colours perceived are due to absorption by pigments of different wavelengths from the visible spectrum of light (Steyn, 2009). Chlorophylls are responsible for the green colour of fruits. Yellow, orange and some red colours as in tomatoes, peppers and grapefruit are derived from carotenoids (Steyn, 2009). Betalains are a rare red coloured pigment, found in a few plant species, for example, cacti and prickly pears (Stafford, 1994). Phenolic oxidation and polymerization products gave rise to brown fruit colours (Macheix et al., 1990). Anthocyanins provide the blue, purple, black and most of the red colours in fruit (Macheix et al., 1990). In apple peel, a blend of chlorophylls and carotenoids as well as anthocyanins, depending on cultivar, is responsible for the appearance of the fruit (Lancaster et al., 1994).

The appearance of fresh fruit is an important criterion in making purchasing decisions (Kays, 1991). Product appearance is characterized by colour, size, shape, form, condition and absence of defects and upon first visual assessment of appearance of fruit by consumers, colour is the critical factor used to determine the quality of fruit (Kays, 1998). Standards have been set for edible eating quality of apples in many countries all over the world. These legal standards are often classified into grades and they set numerical limits for all quality parameters including colour (Oraguzie et al., 2008). The quality recommendations can be specific to cultivars as is the case for apples. The development of yellow, orange or red blush is not acceptable for the green apple 'Granny Smith' and such fruit are downgraded (Hirst, 1990).

Fruit colour and the consumer: Visual cues may influence taste preferences of various foods (Delwiche, 2012). Colour interferes with the judgment of flavour intensity and identification of foods and in so doing, dramatically influence their pleasantness and acceptability (Spence et al., 2010; Zampini et al., 2007). For example, brighter coloured yoghurts were perceived to be sweeter (Calvo et al., 2001) and a cherry flavoured beverage coloured green was mistakenly identified as a lime or lemon flavoured beverage (DuBose et al., 1980). Johnson and Clydesdale (1982) discovered that, when they coloured odourless solutions red, consumers more easily detected the presence of sucrose while increasing the red colour intensity of odourless and cherry flavoured solutions significantly increased sweetness perception. However, the effect of colour on taste is not always consistent. For example, strawberry odour and not red colouring were found to increase sweetness perception of aqueous solutions (Frank et al., 1989).

One of the most significant changes during fruit ripening is an increase in sugar concentration (Wills et al., 2007). The well-known natural colour transitions from the green colour of most unripe fruit to the yellow and red colours in many ripe and sweeter tasting fruits, may explain why consumers associate red colouration with sweetness and green colour with sourness (Maga, 1974). The reliability of fruit colour as an indicator of quality was investigated for 'Brook' cherries. Consumer acceptance was related to cherry skin colour. Full light red cherries had the lowest consumer acceptance while the sweeter full bright red and full dark red cherries had 82% and 91% consumer acceptance, respectively (Crisosto et al., 2002).

In apples, consumers know from experience that even within a variety, redder apples often taste better than greener apples because of their higher sugar content and greater flavour

(Saure, 1990). Bicolour apple cultivars gained popularity over traditional cultivars since their introduction on the market (Seaton, 1996). The success of red and bicoloured apples in the marketplace is determined by their visual appearance and the association by consumers of red and bicoloured apples with better taste and flavour (Iglesias et al., 2008).

Daillant-Spinnler et al. (1996) presented consumers with peeled and unpeeled samples of twelve red and green apple cultivars. When tasted unpeeled, the red cultivars were generally associated with sweet descriptors and the green cultivars were generally associated with acidic, sour or grassy descriptors. However, when peeled, one red cultivar was described as sour tasting while one green cultivar was described as sweet. The discrepancies in the results between peeled and unpeeled apples may have been due to the cues given to the panellists by the colour of the peel, which probably influenced expectations of other sensory characteristics. Schechter (2010) found that consumers may perceive apple quality as well as sweet and tart tastes based on visual cues and that visual cues may mislead consumer perception of taste based on learned associations. However, when children were presented with a choice of red and green apples, a greater percentage chose green apples (Thybo et al., 2004). Those who reported that they like red apples had high preference for the taste of the red apples, and those who reported liking for green apples had a high preference for the taste of green apples.

Taste and flavour: Flavour is defined as "a complex combination of the olfactory, gustatory and trigeminal sensations perceived during tasting" (ISO, 1992). The sour taste in apples is due to the absolute amount of acid in the flesh and the amount of acid relative to the other flavour components. Malic acid accounts for about 90% of the acid content in apples while citric acid, succinic acid and traces of several other acids make up the rest (Hulme and Rhodes, 1971). Sugars are responsible for the sweet taste and the contribution of sugars to total soluble solids (the extractable juice in fruit cells comprising sugars, salts and amino acids) varies between 56% and 72% (Fourie et al., 1991).

Texture: Texture relates to the mechanical properties of the flesh, mouth-feel and juiciness and has been defined as the sensory manifestation of the structure of the food and the manner in which this structure reacts to applied forces, the specific senses being involved being vision, kinaesthesia and hearing (Szczesniak, 1990). The sensory attributes that define apple fruit texture include firmness, crispness, mealiness and juiciness. Mann et al. (2005) defined these four attributes as follows: firmness is the force required to bite into fruit, crispness is the amount and pitch of sound generated when the fruit is first bitten with the front teeth, mealiness is the degree to which flesh breaks down to a fine lumpy mass and juiciness is the amount of juice released from the fruit in the first three chews, when chewing with the back teeth. Other descriptors that have been used are hardness, which is the resistance when biting, and crunchiness, which is defined as the ease of disintegration in the mouth.

Fruits generally soften during ripening in a progressive way and the initial firmness at harvest controls the rate of softening (Jackson, 2003). Softening can result from a number of factors including loss of tugor (Hatfield and Knee, 1988), the degradation of starch and cell wall degradation (Tucker, 1993). The breakdown of the middle lamella between cell walls leads to cell separation until a dry or mealy texture is developed. Therefore, when the consumer bites into the fruit, his teeth just pass between cells without breaking them (Knee, 1993) thereby failing to release juice and neither achieving the crisp nor hard textural qualities.

Juiciness is perceived as greater the more juice is released on chewing and the greater the force at which it is released (Jackson, 2003). If the middle lamella is stronger than the cell walls, the cells fracture on biting and juice is released. If it is weaker, the fracture is between cells, juice is not released and the fruit is perceived as non-juicy or mealy (Tu et al., 1996). Consumers enjoy fruit for the benefit of this attribute as not many foods can match fruit when it comes to juiciness.

Taste, flavour, texture and the consumer: Consumer preference for apples seems to be derived from the interaction between taste, texture and flavour (Harker, 2001). When consumers taste a bad apple, they respond by changing cultivars, purchasing fewer apples, switching to other fruit, stop buying for a while, switching to higher priced apples or switching brands in this respective order (Batt and Sadler, 1998). A consumer study on apples revealed that there are consumers whose preference is driven more by texture and juiciness, while the other consumers regarded flavour as the key component, even at the expense of texture (Daillant-Spinner et al., 1996).

Flavour, including sugars and acids, is an important trait that guides consumer preference for apples (Daillant-Spinnler et al., 1996; Jaeger et al., 1998). The ratio of soluble solids to acids (Harker, 2001; Jackson, 2003) and the dry matter concentration (Palmer et al., 2010) are reliable indicators of eating quality in apples. The published recommendation of minimum soluble solids for apples is between 12% and 16% (Harker, 2001). Malic acid can range from 0.35% to 0.95% and soluble solid to acid ratio can range from 12 to 36 (Corrigan et al., 1997). These ranges reflect the wide scope of consumer preference based on these parameters of taste. Consumers were found to fall into two categories of preference when it comes to apple taste, i.e., those that prefer sweet, high acid or tart apples and those that prefer sweet, low acid or sweet apples (Dailliant-Spinner et al., 1996). Flavour attributes such as an off-flavour, soapiness and pear-like flavour impact negatively on consumer preference for apples (Dailliant-Spinner et al., 1996).

Consumer preference for texture shows that consumers expect fruit to provide the sensation of juiciness no matter what fruit it is (Harker et al, 2002). Mealiness influences consumer preferences for apples negatively (Jaeger et al., 1998). For 'Golden Delicious', consumer acceptability is increased with firmer fruit, particularly if the firm fruit have higher soluble solids (Oraguzie et al., 2008). However, soft apples with high soluble solids seemed to be rejected by consumers. Furthermore, apples that have crisp, juicy textures and maintain these characteristics during postharvest life are highly favoured by consumers. In a consumer study on 'Gala' apples, four groups of consumers with different sensory preferences were found: 26% preferred a crisp, firm, acidic apple, 24% preferred a very ripe, soft texture with high levels of soluble solids, 45% preferred firm apples with not very high levels of soluble solids while 5% preferred a very sweet, firm apple (Casals et al., 2005).

Other factors affecting consumer preference: A lot of factors come into play where consumer's preferences are concerned and it is important to explore as many avenues as possible. In a consumer survey for apples, 42% of the consumers responded to food safety issues, 9% of the consumers primarily responded to price, 13% responded to the levels of blemishes on the fruit surface while the rest had balanced concerns for all these factors (Baker, 1999). Consumers tend to retain a preference for those apple cultivars that they were served as children (Harker, 2001). In Canada, consumers were found to prefer the appearance of cultivars grown in their region (Cliff et al., 1999). Exposure of toddlers to pictures of fruits resulted in their increased willingness to taste familiar and unfamiliar fruits and vegetables (Houston-Price et al., 2009). Cross-cultural studies reveal how dietary experience influences consumer preferences for various foods. For example, Prescott (1998) found that Japanese consumers had greater preference for sour and umami tastes than Australian consumers. However, there was no difference in consumer taste perception or ability to finely discriminate taste differences. Hence, divergent taste preferences within foods are mostly due to different exposure to these tastes (Harris and Booth, 1987). No cross-cultural differences were observed in the preferences for three apple cultivars between Danish and British consumers (Jaeger et al., 1998). This was attributed to the similar degree of familiarity of both consumer groups with the cultivars. Preferences based on experience may also relate to personality type. “Neophobic” consumers fear unfamiliar foods as illustrated in a kiwifruit study where one group of consumers rejected a new, unfamiliar yellow fleshed cultivar (Jaeger et al., 2002).

The apple - a source of beneficial nutrients: Apples are a source of nutrients and energy. In a survey, more than 85% of consumers revealed that apart from taste and textural attributes, they eat apples because they are good for health and promote long life (Jaeger and MacFie, 2001). The apple consists of approximately 86% moisture, 14.5% carbohydrates and 0.3% proteins and they are a source of various minerals, vitamins, fibre, lipids and organic acids (Stuttgart, 1991). They are deemed as healthy fruit as they are rich in phytochemicals with strong antioxidant capacities (Boyer and Liu, 2004). Antioxidants play a significant role in preventing free radical-induced oxidative damage to cells, which is thought to be the basis for many diseases in humans (Dragsted et al., 1993).

Polyphenolics as group are the main antioxidants in apple fruit (Lee et al., 2003), and they are more concentrated in the peel than in the flesh (Wolfe et al., 2003). Apple peel may contain 1.5 to 9.2 times greater total antioxidant capacity and 1.2 to 3.3 greater phenolic concentration compared with apple flesh (Drogoudi et al., 2008). Red apples owe their colour to anthocyanins, which also form part of the polyphenol group (Saure, 1990). ‘Starkrimson’, which recorded a higher anthocyanin concentration, also had significantly higher antioxidant capacities than ‘Golden Delicious’ and ‘Granny Smith’ (Drogoudi et al., 2008). Phenolic compounds are an important dietary component as they reduce the risk of cancers, cardiovascular diseases, asthma and diabetes (Boyer and Liu, 2004; Kang et al., 2004).

Although apples contain ascorbic acid, it is in relatively lower quantities compared to other fruits (Leong and Shui, 2002). The contribution of ascorbic acid to the antioxidant capacity can be as low as 0.4% (Eberhardt et al., 2000).

2. Canopy position and fruit quality

Canopy microclimate

The dry matter accumulation and composition of apples varies depending on the light levels they are exposed to within the canopy (Scurlock et al., 1985). This may have a significant bearing on various aspects of apple fruit quality.

Canopy microclimate (light, temperature, wind speed, humidity) depends on the amount and distribution of leaf area in space and its interaction with the above ground climate (Smart, 1985). The two main factors that vary highly in the canopy are light and temperature. Temperature relates to light exposure due to radiant heating. Canopy microclimate varies from the inside to the outside and from the top to the bottom of the canopy (Sansavini and Corelli-Grappadelli, 1992; Morales et al., 2000). The effective penetration depth of light into unrestricted apple canopies is approximately 1 m and the main canopy receives a minimum of 35% full sun (Jackson, 1970). 'Granny Smith' fruit in the inner canopy can receive as little as 2% (33 $\mu mol \cdot m^{-2} \cdot s^{-1}$) of full sunlight compared to 54% (962 $\mu mol \cdot m^{-2} \cdot s^{-1}$) in the outer canopy (Fouché et al., 2010). Peel temperatures of outer canopy fruit on the northern side of the rows were found to exceed air temperatures by approximately 5 ºC on average while fruit from the inner canopy did not differ from the ambient temperature (Fouché et al., 2010). Furthermore, light quality also differs throughout plant canopies and this is dependent on distribution of gaps in the canopy as well as the light scattering processes in the canopy (Grant, 1997).

Productivity

In well managed orchards, the yield of marketable apples increases linearly with light (Monteith, 1977). Fruit quality is dependent on intercepted light as well as light distribution within the canopy (Palmer, 1989; Robinson et al., 1983; Sansavini and Correlli-Grappadelli, 1992). Light is an important factor in obtaining good quality fruit and light conditions in the orchards are optimised by using various technologies such as proper row orientation, suitable planting, training and pruning systems and using dwarf rootstocks (Jackson, 1980; Lakso, 1994; Wagenmakers, 1991). Shading of leaves and fruits has adverse effects on productivity (Bepete and Lakso, 1998). Shading to 35% of available light, 5 weeks after full bloom, strongly reduced export of labelled assimilates to apple fruit (Corelli-Grappadelli et al., 1994). However, shading as fruit reaches maturity reduced the incidence of peel disorders such as sunburn (Gindaba and Wand, 2005).

Adverse canopy microclimate

PAR (photosynthetic active radiation) is the driving energy for photosynthesis, and the rate of leaf photosynthesis increases linearly until a saturation point of 50% full sunlight (600-1200 $\mu mol\ m^{-2}\ s^{-1}$) above which light is excess for the proper functioning of the leaf. Under these very high light levels, excessive photons may be intercepted by leaves resulting in photorespiration and photoinhibition (Asada, 1999) affecting the net carbon gain and damaging the photosynthetic apparatus. In addition, the combination of high light, including high UV-radiation, which is harmful to plants (Janssen et al., 1998), and high temperatures in the outer canopy causes a significant amount of stress to plants as well as the formation of harmful reactive oxygen species (Foyer et al., 1994). These are dangerous to plant cells as they cause damage to phospholipid membranes, proteins and nucleic acids and therefore are detrimental to the plant (Alscher et al., 1997). Fruit are susceptible to peel disorders such as sunburn when exposed to high light and high temperature (≥46 ºC) conditions (Schrader et al., 2003). The apple fruit have mechanisms to mitigate the detrimental effects brought about by these environments. The ascorbate glutathion cycle (Demmig-Adams and Adams III, 1992) and the xanthophyll cycle (Gilmore, 1997) play important photoprotective roles by reducing oxidative stress caused by excess excitation energy and excessive reactive oxygen species in a high light environment. Sun exposed apple peel from the outer canopy acclimatize to high irradiance by elevating enzyme activity in the xanthophyll cycle and the ascorbate glutathione pathway to meet the need for dissipating excess absorbed light and scavenging reactive oxygen species (Ma and Cheng, 2003). A class of phenols known as flavonoids, including anthocyanins, flavones and flavonols, accumulate mainly in the epidermal layers of plants and are reported to protect cells from excessive UV-B radiation by absorbing light in the UV- B region while allowing passage to photosynthetically active wavelengths (Solovchenko and Merzlyak, 2003). One primary function of the anthocyanins, other than giving red colouration to fruit, is photoprotection (Steyn et al., 2009). They fulfil this function by protecting chlorophyll against photoinhibition and photobleaching by acting as a selective screen against excessive blue-green light (Smillie and Hetherington, 1999). Anthocyanins may also abate oxidative damage by reactive oxygen species (Hatier and Gould, 2009). Phenolics are important in plant protection as they strongly screen UV radiation (Krauss et al., 1997). Phenolics in the cuticle of apple peels in both shaded and sun exposed apples are able to filter UV-A and UV-B radiation before they reach the epidermal and hypodermal cells (Solovchenko and Merzlyak, 2003).

Canopy position and fruit quality

At the time of commercial harvest, the visual quality of apples in terms of size and colour, as well as eating quality in terms of sugar and acid concentration and fruit texture can vary considerably both between trees in an orchard and within the tree (Johnson and Ridout, 2000).

Fruit appearance: Canopy position influences the appearance of apples due to irradiance levels affecting pigment concentrations in the peel. Light is an important factor for the synthesis of chlorophyll at the beginning of fruit development (Gorski and Creasy, 1977). As fruit mature, high irradiances lead to the degradation of chlorophyll to reveal carotenoids (Felicetti and Schrader, 2008). Low light environments during the early fruit development stages are responsible for pale green fruit (Fouché et al., 2010; Hirst et al., 1990). Carotenoid concentrations increase as light intensity (Ma and Cheng, 2004) and temperatures increase (Chen et al., 2008). No differences in chlorophyll and carotenoid concentrations were found between inner and outer canopy 'Fuji' apples (Jakopic et al., 2009) while Ma and Cheng (2003) report outer canopy fruit to be lower in chlorophyll and higher in carotenoid concentrations. High light intensity increased carotenoid concentration in 'Fuji' and 'Delicious' but not in 'Granny Smith' apples (Felicetti and Schrader, 2009).

Higher light conditions and cool temperatures promote anthocyanin synthesis in apple peel (Saure, 1990; Steyn et al., 2005). Apple peel from the sun-exposed outer canopy is higher in anthocyanin concentrations than inner canopy fruit (Awad et al., 2001; Jakopic et al., 2009). Peach fruit from the canopy exterior had more red colouration and a lighter ground colour than those from the interior (Lewallen and Marini, 2003).

Apples from the outer canopy are also susceptible to various intensities of browning colouration commonly known as sunburn when exposed to high light and high temperature conditions. Sunburn browning occurs when temperatures reach a range of 46 ºC to 49 ºC in the presence of light (Schrader et al., 2003). Sunburn necrosis is the result of thermal death of the epidermal and subepidermal cells caused by extreme heat (52 ºC). Photo-oxidative bleaching can occur at temperatures below 30 ºC when shaded peel is suddenly exposed to light.

Sugars and acids: Higher absorbance of PAR by the leaves results in enhanced synthesis of photo-assimilates (Johnson and Lakso, 1986). Sorbitol and sucrose are the main photosynthetic products and translocation sugars in apples (Zhou et al., 2006). In the fruit, sorbitol is converted fructose via sorbitol dehydrogenase while sucrose is metabolised to glucose and fructose by invertases and sucrose synthase (Zhou et al., 2006). As mentioned earlier, sugars are responsible for the sweet taste and the contribution of sugars to total soluble solids varies between 56% and 72% (Fourie et al., 1991). Soluble solids concentration is influenced by the amount of irradiation received during the growing season and this has been reported in a number of fruit. Shading reduced soluble solids in peaches (Lewallen and Marini, 2003), cherries (Flore and Layne, 1999), grapes (Kliewer and Smart 1989) and apples (Solomakhin and Blanke, 2010; Nilsson and Gustavsson, 2007). The level of light exposure positively correlated with the total soluble solids in apples (Robinson et al., 1983; Tustin et al., 1988) and peaches (Feng-li et al., 2008), while the total acids in apples were negatively correlated to sunlight exposure (Robinson et al., 1983). Fruit that develop sunburn have higher higher TSS (Makeredza, 2011; Schrader et al., 2009), dry matter concentration (Racsko et al., 2005) and firmness (Racsko et al., 2005; Makeredza, 2011) than fruit without the disorder. The relationship between flesh firmness and canopy position in peach was inconsistent (Lewallen and Marini, 2003). In earlier studies on apples, Seeley et al. (1980) concluded that light conditions did not influence firmness. Robinson et al. (1983) found an inverse relationship between irradiance and firmness in apples and concluded that light indirectly influenced firmness due to its effect on maturity and fruit size.

Mineral composition: The microclimatic differences brought about by canopy position may influence the accumulation of mineral nutrients in the fruit. Water and minerals transport in the plant occurs via the xylem stream and transpiration is the main driving force of the xylem stream (Jarvis, 1985). Fruit transpiration is therefore an important factor for xylem born minerals, while other nutrients and carbohydrates for fruit growth depend on the phloem stream (Morandi et al., 2010). High light and temperature, which promote fruit transpiration, are positive drivers for mineral nutrient transport into fruit (Morandi et al., 2010). Shaded kiwifruit fruit accumulated less calcium than fruit exposed to light and this was attributed to the higher xylem inflows of the latter fruit (Montanaro et al., 2006). The flavedo outer canopy mandarin fruit had higher concentrations of calcium and magnesium and inner canopy fruit had higher concentrations of potassium (Cronje et al., 2011). A slight trend towards decreased nutrient concentration per unit dry weight with increased crown height was observed in apple fruit (Haynes and Goh, 1980).

Antioxidant capacity, phenolic compounds and ascorbic acid: Phenolic compounds are secondary metabolites derived from phenylalanine, a product of the shikimic acid pathway (Taiz and Zeiger, 2002). The activity of phenylalanine ammonium lyase, an enzyme that catalyses an important regulatory step in the formation of phenols, is influenced by light (Takos et al., 2006). Apple peel from the upper portions of the canopy had greater phenolic concentrations in three of four cultivars (Drogoudi and Pantelidis, 2011). Flavonoids were significantly higher in fruit from the top of the tree (Awad et al., 2001). Hagen et al. (2007)

found no difference in phenolic concentration in the apple flesh between sun exposed and shaded apples. However, two of four apple cultivars had increased concentrations of total phenolics in the flesh from apples from the upper parts of the canopy compared to the inner canopy fruit (Drogoudi and Pantelidis, 2011). As discussed earlier, phenolic compounds are the main antioxidants in apple fruit (Lee et al., 2003). Drogoudi and Pantelidis (2011) recorded greater concentration of antioxidant in the apple flesh of fruit harvested from the upper and middle portions of the canopy in two of four apple cultivars. The antioxidant capacity of sun-exposed peel was higher than that of shaded peel (Ma and Cheng, 2004).

With regards to ascorbic acid, sun-exposed peel had significantly higher concentrations than shaded apple peels (Ma and Cheng, 2004). The exposure of shaded peel to full sunlight led to an up regulation of the ascorbate glutathione cycle, which is an important pathway for the recycling of ascorbic acid (Ishikawa et al. 2006). However, light does not affect the ascorbic acid concentration and recycling in apple flesh (Li et al., 2008). This may be because in 'Gala' apple, the peel was found to be capable of de novo ascorbic acid biosynthesis via the L- galactose and D-galacturonic pathways, whereas flesh and seeds are only able to synthesize ascorbic acid via the L-galactose pathway (Li et al., 2008).

CONCLUSION

The position of an apple fruit in the canopy determines its external and internal quality due to microclimatic variation within the canopy and the effect thereof on biochemical pathways. Fruit from the outer canopy accumulate more carbohydrates and are higher in soluble solids and dry matter concentration. Hence, these fruit generally are sweeter and this may affect consumer preference for their taste. Outer canopy fruit experience much higher irradiance and temperatures than shaded, inner canopy fruit. They are therefore prone to develop irradiance-induced defects such as sunburn, which results in the downgrading of the fruit. Outer canopy fruit employ various mitigatory measures such as the upregulation of anthocyanin, carotenoid, ascorbic acid and phenolic synthesis in the peel, to curb the damage from reactive oxygen species to photosynthetic machinery and plant cells. The effect of canopy position on peel pigmentation may affect appearance positively or negatively, depending on the cultivar. Differences in the content of health beneficial compounds such as phenolics may also affect consumer preference for the fruit.

There is a need to study the effect of canopy position on consumer preference of the fruit, both in terms of appearance and taste. Blushed outer canopy fruit of green cultivars are downgraded for processing or are marketed to consumers at a much lower price. Sunburnt fruit are generally downgraded, processed or dumped based on the severity of sunburn. However, consumers may actually prefer the taste of these fruit. With some effort, marketers could create a market for these fruits thereby increasing the profitability of these cultivars.

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EFFECT OF CANOPY POSITION ON FRUIT PHYSICAL PARAMETERS AND CHEMICAL COMPOSITION

Abstract

We investigated the relationship between canopy position and various fruit quality parameters in three apple cultivars, viz. Golden Delicious, Granny Smith and Starking. Outer canopy fruit are exposed to higher irradiance and are heated to higher temperatures than inner canopy fruit. We hypothesized that the different environments of outer and inner canopy apples cause various biochemical and physiochemical differences in the flesh and peel that ultimately translates into fruit quality differences. The size of inner and outer canopy fruit was the same. In all three cultivars, outer canopy fruit flesh was higher in TSS, reducing sugars and total carbohydrates, and lower in titratable acidity. Outer canopy 'Golden Delicious' and 'Granny Smith' fruit peel contained some anthocyanin, which accounts for the red blush of these fruit. Outer canopy fruit peel of these cultivars also had lower chlorophyll concentrations. Outer canopy 'Starking' peel was higher in carotenoids and anthocyanins than inner canopy fruit. The antioxidant capacity of both flesh and peel in all three cultivars were higher in outer canopy fruit. Ascorbic acid was higher in the flesh of outer canopy 'Granny Smith' and higher in the peel of outer canopy fruit in all three cultivars. Total phenolics were analysed using the Folin Ciocalteu (FC) and direct absorbance method (UV). The UV method underestimated the concentration of phenolics, whilst the FC method revealed that outer canopy flesh and peel contained higher concentrations of phenolics than inner canopy fruit. Generally, ascorbic acid, total phenolics and antioxidant capacity were higher in the peel than in the flesh. Inner canopy flesh accumulated higher concentrations of N, P, K, Mg, Cu, B and Mn while inner canopy peel accumulated higher concentrations of Ca, B and Mg. Fruit were comparable in size and percentage dry matter concentration as covariant analyses did not remove differences between inner and outer canopy fruit, except for Mg in the flesh. Hence, differences in mineral concentration cannot be ascribed to dilution.

INTRODUCTION

At 69 million metric tonnes, apples are the second most produced tree fruit crop in the world after bananas (FAOstat, 2011). Despite competition from exotic and tropical fruits, world apple production has grown by about two per cent per year during the last decade (World Apple Review, 2011). From 1991 to 2010, apple consumption has decreased by 10.5% in the EU (World Apple Review, 2011), the main export destination for South African apples.

The chemical composition of apples can be a good indicator of their quality and consumer acceptability. The concentration of various sugars and acids are important as the taste of the fruit is an important factor in the consumption of apples (Harker, 2001). Pigment composition determines the appearance of the fruit, which from an aesthetic and from a quality signalling perspective has an important function in consumer acceptability (Steyn, 2012). Apart from gustatory reasons, consumers indicate that they eat apples because they are healthy and promote long life (Jaeger and MacFie, 2001). Apples are a rich source of phenolic compounds (Boyer and Liu, 2004). Phenolic compounds contribute to flavour and are an important dietary component due to their antitumor and chemopreventive properties (Kang et al., 2004; Santos-Buelga and Scalbert). Phenolics as group constitute the largest fraction of the total antioxidant capacity of apple fruit (Lee et al., 2003). Total phenolics correlated strongly with total antioxidant activity in the flesh (0.91) and peel (0.98) of seven apple cultivars (Drogoudi et al., 2008). Antioxidants play an important role in preventing free radicals from causing oxidative damage, which is linked to many diseases in humans (Dragsted et al., 1993; Lila, 2004). Apples contain relatively low levels of ascorbic acid compared to other fruits (Leong and Shui, 2002). However, consumers associate ascorbic acid with health benefits (Jaeger and MacFie, 2001) and in that regard, it is an important component of any fruit. Ascorbic acid is one of the most widely used vitamin supplements with a recommended 100 mg per day intake for adults (Naidu, 2003).

Apple fruit are exposed to different microclimates at different positions in the canopy. The main factor that varies highly in the canopy is light. Inner canopy ‘Granny Smith’ fruit from trees with a height of 3 m and canopy width of 2.5 m received on average only 2% (33 $\mu mol \cdot m^{-2} \cdot s^{-1}$) of full sun compared to 54% (962 $\mu mol \cdot m^{-2} \cdot s^{-1}$) in the outer canopy (Fouché et al., 2010). Radiant heating increased the peel temperature of outer canopy fruit on the northern side of east west rows by an average of 5 ºC compared to ambient air temperature.

These microclimatic differences may affect the composition of fruit since many biochemical pathways are light and temperature responsive.

Light exposure affects apple peel colour. Light is an important factor in the synthesis of chlorophyll during fruit development (Gorski and Creasy, 1977). Fruit exposed to higher levels of light accumulated greater amounts of chlorophyll more rapidly (Reay et al., 1998). Hence, shading results in pale green fruit (Fouché et al., 2010; Hirst et al., 1990). At the same time, high irradiation in association with high peel temperatures can also cause chlorophyll degradation, thereby exposing carotenoids and resulting in more yellow peel colour while excessive light exposure may cause sunburn necrosis, browning or bleaching (Felicetti and Schrader, 2008). A combination of low temperatures and high irradiance favours anthocyanin synthesis in apples (Saure, 1990, Steyn et al., 2005). Carotenoids of the photoprotective xanthophyll cycle are upregulated by high irradiance (Ma and Cheng, 2004) and high temperatures (Chen et al., 2008). High irradiance increased carotenoid concentrations in 'Fuji' and 'Delicious', but not in 'Granny Smith' apples (Felicetti and Schrader, 2008).

Carbon metabolism in plants is dependent on light in the photosynthetic active radiation range (400 nm – 700 nm). The amount of dry matter produced by a fruit crop is linearly related to the amount of intercepted light (Monteith, 1977). Fruit in canopy positions that receive more sunlight are expected to receive more photoassimilates from nearby leaves and consequently to have higher concentrations of sugars and other soluble solids (Robinson et al., 1983). Outer canopy apple fruit accumulated significantly higher concentrations of dry matter, soluble solids and the sugars sucrose, glucose and fructose and lower concentrations of acids than inner canopy fruit (Nilsson and Gustavsson, 2007). Consumers prefer the taste of apples with a higher dry matter concentration (Palmer et al., 2010; Paper 2, Paper 3).

The activity and expression of key enzymes and genes in the phenolic pathway in apple peel are reportedly light dependent (Takos et al., 2006). Hagen et al. (2007) found that sun-exposed apples had higher concentrations of total phenols in their peel while post-harvest irradiation of apples increased phenolic concentrations in the peel, but not in the flesh. The distribution and regulation of ascorbic acid levels differs in the different apple tissues (Li et al., 2008). Light is an important factor in the biosynthesis of ascorbic acid in apple peel, but not so much in the flesh (Ma and Cheng, 2004). Higher concentrations of ascorbic acid were found in the peel of sun-exposed compared to shaded 'Aroma' apples (Hagen et al., 2007).

Canopy position may also influence the accumulation of mineral nutrients in the fruit. Mineral nutrients are transported in the xylem, and transpiration is the main driving force of the xylem stream (White and Broadley, 2003). Therefore, fruit transpiration may be an important factor for accumulation of xylem born minerals (Morandi et al., 2010). Sun-exposed kiwifruit, which experienced higher transpiration rates, were found to accumulate more calcium than shaded fruit (Montanaro et al., 2006). Many physiological disorders and poor storability of fruit are associated with low levels of Ca (Dris and Niskanen, 1997; Sams et., 1997).

In this study we seek to determine how canopy position affects the chemical composition of apples. We were particularly interested in chemical components that affect the appearance, taste and nutritional value - or perceptions thereof - of the fruit.

MATERIALS AND METHODS

Plant material and experimental design

Three commercial apple cultivars were used for this study, viz. Granny Smith, which is dark green at harvest maturity, Golden Delicious, which is yellow-green at harvest maturity, and Starking, which vary from red-striped to green depending on canopy position. Fruit were sourced from Vastrap Farm, in the Witzenberg Valley, Ceres (latitude: 33º 23’S, longitude: 19º 19’E), Western Cape, South Africa. Fruit were harvested at commercial maturity, ‘Golden Delicious’ and ‘Starking’ on 1 March 2010 and ‘Granny Smith’ on 8 April 2010.

The ‘Granny Smith’ trees on seedling rootstock were planted in 1974 in an N-S row direction at a spacing of 6.71 m x 3.35 m. The ‘Golden Delicious’ orchard, also on seedling rootstock, was planted in 1960 at the same spacing and row orientation. ‘Starking’ on seedling rootstock was planted in 1974 at a spacing of 5 m x 3 m and similar row orientation as mentioned above. These older open vase orchards were selected so as to maximise the contrast between inner and outer canopy fruit. For ‘Granny Smith’ and ‘Golden Delicious’, only fruit with a red blush, mainly found at the top, outer positions of the tree canopy, were harvested as the outer canopy fruit.

Fruit harvested from three consecutive trees represented a replicate and fifteen inner and outer canopy fruit were harvested for each replicate. There were ten replicates in total per canopy position. Of the fifteen fruit harvested for each replicate, four were allocated for the consumer panel (reported on in Paper 2), five were allocated for the trained panel (reported on in Paper 2), and five fruit were set aside for the physiochemical analysis, which consisted of non-destructive and destructive measurements (reported on in this paper). The cultivars were not statistically compared with each other.

Maturity analysis by assessing the percentage of starch breakdown was carried out immediately after harvest as described below. One fruit from each replicate was randomly selected and assessed in order to determine whether outer and inner canopy fruit differed in maturity. Since the intention was to use outer and inner canopy fruit of comparable maturity, a further harvest would have been scheduled if the fruit differed in maturity. Fruit was stored at -0.5 ºC before physiochemical measurements on the 12 May 2010.

Light and temperature measurements

Light received by fruit in the inner and outer canopy in the 'Starking' orchard was measured every two hours from 0900 HR to 1700 HR on 1 March 2010. Shaded fruit from the inner canopy and fruit fully exposed to sunlight on the north side of the tree row were selected for inner and outer canopy measurements, respectively. Measurements were carried out using a quantum sensor attached to a light meter (LI-250, LI-COR, Lincoln, NEB, USA) that was held above the fruit with the sensor orientated toward the sun. Peel temperatures of inside and outside canopy fruit were also measured on the fruit surface perpendicular to the current position of the sun at the same time intervals as the light measurements using a high performance infrared thermometer (Rayner MX4, Raytek Corporation, Santa-Cruz, USA). Measurements were taken on ten trees in the same orchards from which fruit were harvested for the experiment.

Physical measurements

Fruit size: Each fruit was weighed on an electronic balance and fruit diameter was determined using a digital Mitutoyo calliper (Mitutoyo, Japan).

Fruit colour: The hue angle of each apple was measured using a colorimeter (Konica CR-400, Minolta Co. Ltd., Tokyo, Japan). On each fruit, hue angle was recorded at the reddest and least red (or greenest) position. Colour charts (Unifruco Research Services Ltd, Bellville, South Africa) specific for each cultivar (Granny Smith chart set A33, Starking chart set A34, Golden Delicious chart set A28) were used to score the colour of each apple. Ground colour

(Unifruco Research Services Ltd, Bellville, South Africa) and blush intensity (Granny Smith blush chart set A33) of each apple was assessed by chart.

Maturity indices and internal quality parameters: The percentage starch breakdown of the apples was determined by placing one half of the apple in an iodine solution and evaluating the starch breakdown using a starch conversion chart for pome fruit (Unifruco Reseach Services, Bellville, South Africa). Flesh firmness was measured using a penetrometer (Fruit Texture Analyser, GUSS Manufacturing (Pyt) Ltd., Strand, South Africa) fitted with an 11 mm diameter probe. Two readings were taken on opposite paired sides of the fruit approximately half way between the calyx and the stem. Slices of apple were placed in a juice extractor and the juice was used to determine the total soluble solids (TSS) concentration and the titratable acidity (TA). TSS was measured using a calibrated hand refractometer (TSS 0-32%, Model N1, Atago, Tokyo, Japan). TA was measured using an automated titrator (Tritino 719S and Sample Changer 674, Metrohm Ltd., Herisau, Switzerland) by titrating 5 g of juice from each apple sample with 0.1 M NaOH to a pH of 8.2. The TA is expressed as percentage malic acid. Percentage dry matter concentration (DMC) was determined by weighing a fresh sample of fruit and oven drying the fruit over a period of 72 hours at 45 ºC. Fruit were weighed immediately and returned into the oven for a further 24 hours and re-weighed to ensure all the moisture had evaporated. DMC was calculated as dry weight as a percentage of fresh weight.

After physical measurements were taken, fruit were peeled, making every effort not to include the apple flesh. The peel sample and a flesh sample were immediately frozen in liquid nitrogen, milled to a fine powder and stored in tubes at -80 ^{0}C for a month until the chemical analysis.

Pigment analysis

Chlorophylls and carotenoids were extracted from 0.5 g fresh peel sample in 3 ml of cold, 100% acetone as the extraction solvent. The samples were stirred on a magnetic stirrer at 4 ºC for 24 hours and then centrifuged for fifteen minutes at 10000 rpm at 4 ºC. The supernatant was decanted and 2 ml of cold, 100% acetone were added to the pellet. The sample was then centrifuged a second time for fifteen minutes at 10000 rpm. The supernatant was decanted and added to the first supernatant. This final supernatant was filtered using a 0.45 μm filter (Millex-HV, Millipore, Corporation, Milford, MA, USA) into a glass cuvette and placed in a spectrophotometer (Cary 50 Bio, Varian, Australia (PTY) Ltd, Melborne, Australia) measuring absorbance at 470, 645 and 670 nm. The extinction coefficients of Licthentaler (1987) were used to calculate the chlorophyll and carotenoid concentrations in $\mu g \cdot g^{-1}$ FW (fresh weight) peel.

Anthocyanins were extracted from 0.2 g of fresh frozen peel samples in 5 ml methanol and 3 M HCl (95:5 v/v) as the extraction solvent. The samples were stirred using a magnetic stirrer for 1 hour at 4 ºC. They were then centrifuged at 10000 rpm for 10 minutes at 4 ºC. The supernatant was decanted and placed at 4 ºC. 5 ml of acidified methanol was added to the remaining pellet that was then vortexed and centrifuged for another ten minutes at 10000 rpm at 4 ºC. The second supernatant was added to the first and mixed well using the vortex. The solution was filtered using a 0.45 µm filter (Millex-HV, Millipore, Corporation, Milford, MA, USA) into plastic cuvettes and analyzed by spectrophotometer (Cary 50 Bio, Varian, Australia (PTY) Ltd, Melborne, Australia). Absorbance was measured at 530 nm and 635 nm. Samples highly concentrated with anthocyanins were further diluted with the extraction solvent at a ratio of 1:1. The following equation was used to remove chlorophyll absorbance peaks: absorption at 530 nm – 0.24 x absorption at 653 nm (Mancinelli et al., 1975). The concentration of anthocyanin calculated from the standard curve of cyanidin-3-galactoside (Carl Roth, Karlsruhe, Germany) were expressed $\mu g\ g^{-1}$ FW peel.

Carbohydrates and reducing sugars

Sugars were analysed on HPLC (Agilent 1100 series, Hewlett Packard, USA) with a photo diode array detector (DAD) and refractive index detector (RID) series. The sugars were separated using a 300 x 7.8 transgenomic ion 300 column (Phenomenex, USA). 1 g fresh apple samples were weighed out and 1.5 ml extraction solvent of 2 g L^{-1} mannitol solution was added to the sample. These were placed in an ultrasonic bath for 13 min and centrifuged (Eppendorf 5417 R, Merck, Hamburg, Germany) for 10000 rpm at 4 ºC for 15 min. 300 µl of the supernatant was decanted and 1.2 ml of acetronitrile were added to the pellet and allowed to stand for 15 min before centrifuging again for 10000 rpm at 4 ºC. The supernatant was carefully decanted. A further 250 µl of acetronitrile was added to the pellet and this too was decanted and added to the first supernatant. These samples were then placed in the Thermosavant (SC210A, SpeedVac, Holbrook, NY) for approximately 30 min at 70 ºC. The dried samples were reconstituted with 1 ml of water and vortexed. This was followed by filtering of the samples using a 0.45 µm filter (Millex-HV, Millipore, Corporation, Milford, MA, USA) into HPLC vials for analysis. Sucrose, glucose, fructose and sorbitol were identified and quantified by comparing their retention times and peak heights to 2 g L^{-1} mannitol which also served as the internal standard.

Ascorbic acid

Ascorbic acid was analysed on a HPLC (Agilent 1100 series, Hewlett Packard, USA) using a C18 pre-column with 4.6 x 12.5 mm, 5 micron and a main column 250x 4.6 mm (Capcell Pak, 5µ C18 MG, Phenomenex, USA). A computer program (Chemstation LC 3D, Rev.B.01.03, Agilent, USA) was used for identification and quantification of ascorbic acid peaks against reference standards. 3 g of apple flesh and 1 g of apple peel were weighed and 6 ml and 3 ml extraction buffer (100 mM EDTA) added to each sample, respectively. The samples were vortexed and stored at 4 ºC for an hour before being centrifuged (Eppendorf 5417R, Merck, Hamburg, Germany) at 20000 rpm for fifteen minutes at 4 ºC. 600 µl of the supernatant was decanted and to 40 µl of this supernatant; 20 µl of reduction solution - dithiothreitol (DTT) and Trizma base (1:1 v/v) were added. The sample was vortexed and allowed to stand for 20 min. Finally, 20 µl of a stop solution (8.5% ortho phosphoric acid) was added to the solution and vortexed well before analysis on the HPLC. The ascorbic acid peak was identified by retention time and spectral comparison to a prepared ascorbic acid standard (Sigma-Aldrich, Steinheim, United Kingdom), which was used to calibrate and determine the concentration of ascorbic acid.

Determination of total phenolic concentration

Total phenolics were quantified using two methods of analysis, viz. a simple, direct, spectral absorbance analysis and a colorimetrical method. For the colorimetrical method, phenolics were quantified using a slightly modified Folin Ciocalteu method (Slinkard and Singleton, 1977) measuring absorbance at 750 nm (FC method). Direct spectral absorbance analysis entailed measuring absorbance of a dilution of the extract at 280 nm using the ultra violet light spectrum (UV method).

Standards were prepared using a 500 mg L^{-1} solution of gallic acid and these were used to calibrate the spectrophotometer and to quantify the phenolics in the samples. Phenolics were extracted from 1 g of fresh frozen peel and flesh sample using a total of 10 ml of 80% ethanol as the extraction solvent. In the UV method, the apple flesh extract was diluted at a ratio of 1:2 with the extraction solvent. The peel extract was diluted at ratio of 1:49. The diluted extracts were analyzed in quartz cuvettes for analysis on the spectrophotometer (Cary 50 Bio, Varian, Australia (PTY) Ltd, Melborne, Australia). The phenolics were measured at 280 nm and quantified using a gallic acid (Sigma-Fluka, Steinheim, United Kingdom) standard curve.

In the FC method, 450 µl of 1:6 Folin-Ciocalteu reagent was added to 50 µl of apple flesh extract and a further 500 µl sodium bicarbonate was added after a 5 min waiting step. This was followed by a 90 min waiting step. Peel samples were diluted using a dilution of 1:9 with the extraction solvent. The absorbance was measured at 750 nm on the spectrophotometer (Cary 50 Bio, Varian, Australia (PTY) Ltd, Melborne, Australia). The phenolics were measured at 750 nm and were quantified using a gallic acid standard curve.

Determination of total antioxidant capacity

Total antioxidant capacity was determined using a slightly modified method of Vinotur and Rodov (2006) where the activity of hydrophilic and lipophilic antioxidants was evaluated as scavenging capacity towards the ion radical of 2,2'- azino-bis-(3-ethylbenzthiazoline-6-sulphonic acid) (ABTS) and expressed as Trolox (6-hydrooxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) equivalent antioxidant capacity (TEAC). For the apple flesh sample, 1 g fresh weight of apple flesh was used for extraction of the antioxidants, while for apple peel, 0.5 g fresh weight was used. Acidified ethanol (0.1% H_2SO_4 in 99% ethanol) reagent was prepared and placed in a water bath at 45 °C. 1.77 mM AAPH (2.2'- azobis (2-amidinopropane) dihydrochloride) and 0.15 mM ABTS solutions were added into acidified ethanol and placed in a water bath for 75 min. This $ABTS^+$ radical stock solution was added to the extracts before spectrophotometric analysis. Extraction of antioxidants was carried out by first extracting hydrophilic antioxidants with 6 ml acetone and 2 ml of 0.05 mM acetate buffer solutions. Samples were washed three times in these solvents to ensure that all hydrophilic antioxidants had been extracted. This was followed by an extraction of lipophilic antioxidants with 6 ml hexane. 10 µl of lipophilic and hydrophilic extracts were pipetted into plastic curvettes followed by 0.990 ml of the pre-prepared $ABTS^+$ radical. The sample was incubated for 15 min (during which decolourisation of the $ABTS^+$ by the antioxidants was observed) before analysis against 10 mM Trolox standards on the spectrophotometer (Cary 50 Bio, Varian, Australia (PTY) Ltd, Melborne, Australia) at 734 nm.

Minerals analysis

Mineral analysis of apple flesh and peel for 'Granny Smith' were conducted by a private laboratory (Environmental Laboratory, Central Analytical Facility, Stellenbosch University, South Africa). Samples were analysed for concentration of nitrogen (N), carbon (C), magnesium (Mg), calcium (Ca), boron (B), potassium (K), phosphorous (P), sodium (Na), iron (Fe), manganese (Mn) and zinc (Zn) based on the methodology of Beyers (1962).

Statistical analysis

The data were analysed by Analysis of Variance (ANOVA) using SAS General Linear Models (SAS Version 9.1; SAS Institute, 2006, Cary, NC27513, USA).

RESULTS

Light and temperature

Light and temperature measurements were taken on (3 March 2010) to illustrate the different microclimatic conditions that inner and outer canopy fruit may experience. Average light readings for outer canopy fruit were almost thirty times higher than for fruit in the inner most portion of the canopy (Fig. 1). The average peel temperature of outer canopy fruit was approximately 10 ºC higher than inner canopy fruit and 9 ºC higher than the average ambient air temperature (Fig. 2).

Physical parameters

Average fruit size of the fruit sampled from different canopy positions did not differ significantly for all three cultivars (Table 1).

The TSS of outer canopy fruit was nearly 2º BRIX higher in all three cultivars (Table 2). The TSS:TA ratio was significantly higher in outer canopy fruit while TA was significantly higher in inner canopy fruit in all three cultivars. Outer canopy 'Granny Smith' and 'Golden Delicious' fruit were significantly firmer than inner canopy fruit while no difference was found in 'Starking' (Table 2). Starch breakdown was significantly advanced for inner canopy 'Granny Smith' and 'Golden Delicious' while no difference was found in 'Starking'. DMC, was higher for outer canopy fruit in all three cultivars, but only significantly so for 'Granny Smith'.

Pigment concentrations and external appearance

Anthocyanin concentrations were significantly higher and the sun-exposed sides of outer canopy fruit were significantly redder in all three cultivars (Table 3, 4). Carotenoid concentrations in outer canopy fruit were significantly higher in 'Starking' only. The chlorophyll concentration was significantly lower and the ground colour significantly more yellow in outer canopy 'Golden Delicious' and 'Granny Smith' fruit (Table 3, 4).

Carbohydrates and reducing sugars

Outer canopy 'Granny Smith' fruit had significantly higher concentrations of sucrose, fructose and sorbitol, outer canopy 'Starking' fruit had significantly higher concentrations of glucose, fructose and sorbitol, while outer canopy 'Golden Delicious' fruit had significantly higher concentrations of all sugars (i.e. sucrose, glucose, fructose and sorbitol) (Table 5). Total sugar concentrations were significantly higher in outer canopy fruit canopy in all three cultivars.

Ascorbic acid, total phenolics and antioxidant capacity

Apple peel in all three cultivars had higher ascorbic acid concentrations and total phenolics as well as higher antioxidant capacities than apple flesh (Table 6, 7). In both flesh and peel samples of all three cultivars, outer canopy fruit had a significantly higher antioxidant capacity than inner canopy fruit.

Ascorbic acid concentrations in the peel of all three cultivars were significantly higher in outer canopy fruit (Table 7). Although only significant in 'Granny Smith', there was a trend of higher ascorbic acid concentrations in the flesh of outer canopy fruit.

Total phenolics were measured using the colormetrical Folin-Ciocalteu (FC) method and by analysing the apple extract using UV light and measuring absorbance by phenolics at 280 nm (direct spectral absorbance analysis). The two methods gave different results, although some trends were similar (Table 6, 7). Analysis via direct spectral absorbance analysis (UV) indicated no significant difference in the total phenolics of the apple flesh at different canopy positions in all three cultivars. Phenolic concentrations were significantly higher in outer canopy than in inner canopy 'Granny Smith' and 'Starking' peel. In contrast, the FC method indicated significantly higher phenolic concentrations in the flesh and in the peel of outer canopy fruit in all three cultivars.

Mineral concentrations

Mineral analysis was performed on 'Granny Smith' only. Generally, inner canopy fruit had higher mineral concentrations. B, Ca and Mg occurred at higher levels in the peel of inner canopy fruit (Table 8). Significantly higher N, P, K, Mg, Cu, B and Mn levels were found in the flesh of inner canopy fruit (Table 9). Percentage dry matter concentration was included as covariate in the statistical analysis to account for the effect of dilution on mineral concentrations. Despite the significance of the covariate for N, P, Mg, B and Mn in apple flesh, the effect of canopy position on mineral concentration remained significant with the exception of Mg (Table 9). Inner and outer canopy fruit were of similar size and therefore fruit mass was not used as covariate.

DISCUSSION

The position of apple fruit in the canopy influences their appearance and chemical composition. Pigment, phenolic, ascorbic acid, carbohydrate and mineral concentrations as well as the antioxidant capacity of fruit were all affected by canopy position. The differences are primarily because of the microclimatic differences experienced in the different portions of the canopy. As found by Fouché et al. (2010), outer canopy fruit received more light and experienced higher temperatures than inner canopy fruit. Leaves in the outer canopy absorb more light, and therefore enhanced synthesis of photoassimilates compared to inner canopy leaves (Johnson and Lakso, 1986). The translocation sugar, sorbitol, was significantly higher in outer canopy fruit of all three cultivars indicating that more carbohydrates were transported to these fruit. Along with sucrose, sorbitol is the main photosynthetic product and translocation sugar in apples (Morandi et al., 2008; Zhou et al., 2006). In addition to sorbitol, outer canopy 'Granny Smith' fruit were also higher in sucrose and fructose, 'Starking' was higher in glucose and fructose and 'Golden Delicious' was higher in all sugars compared to inner canopy fruit. In the fruit, sorbitol is converted to fructose via sorbitol dehydrogenase while sucrose is metabolised to glucose and fructose by invertases and sucrose synthase (Zhou et al., 2006).

The contribution of sugars to TSS varies from 56% to 72% (Fourie et al., 1991). Higher sugar concentrations in the outside canopy fruit should therefore translate to higher TSS for these fruit, as we observed. Improved light exposure and higher temperatures lead to higher sugars and TSS in apple fruit (Nilsson and Gustavsson, 2007; Solomakhin and Blanke, 2010). Outer canopy fruit accumulate more dry matter (Nilsson and Gustavsson, 2007; Robinson et al., 1983). The DMC is an important quality metric for apples because consumers prefer apples with a high DMC (Palmer et al., 2010). DMC is influenced by light exposure (Scurlock et al., 1985) in that fruit exposed to higher irradiance will have higher DMC. Light is a contributing factor to fruit size and a linear relationship between fruit size and light exposure has been established (Robinson et al., 1983). The lack of a positional effect on fruit size in our study may be due to the selective removal of small fruit during hand thinning.

Canopy position affects the appearance of fruit due to irradiance effects on pigment concentrations in the peel. Inner canopy 'Granny Smith' and 'Golden Delicious' fruit had higher chlorophyll concentrations. This is contrary to research by Hirst et al. (1990) who found that shaded 'Granny Smith' fruit were paler green in colour. Improving light distribution in low density 'Granny Smith' orchards by pruning improved green colouration of 'Granny Smith' (Fouché et al., 2010). However, chlorophyll in apple peel is degraded at high irradiance and high temperatures (Felicetti and Schrader, 2008). This explains the lighter ground colour of outer canopy 'Granny Smith' and 'Golden Delicious' fruit. No difference in chlorophyll concentration was observed between the inside and outside canopy, though outer canopy 'Starking' fruit were higher in carotenoids. Jakopic et al. (2009) found no differences in chlorophyll and carotenoid concentrations between inner and outer canopy 'Fuji' apples, while Ma and Cheng (2003) report outer canopy fruit to be lower in chlorophyll and higher in carotenoid concentrations. Outer canopy fruit in all three cultivars had higher anthocyanin concentrations and were redder on their sun-exposed sides. This was expected as we selected outer canopy 'Golden Delicious' and 'Granny Smith' fruit with a red blush. 'Starking' outer canopy fruit were darker red than inner canopy fruit. High light exposure and cool temperatures promote anthocyanin synthesis in apple peel (Saure, 1990, Steyn et al., 2005). Hence, apple peel from the sun-exposed outer canopy generally has higher anthocyanin concentrations and is redder than inner canopy peel (Awad et al., 2001, Jakopic et al., 2009).

The peel of outer canopy fruit have higher phenolic concentrations as light is an important regulatory factor in the synthesis of phenolics in the peel (Awad et al., 2001; Jakopic et al., 2009; Takos et al., 2006). Enclosing 'Delicious' and 'Royal Gala' apples in opaque bags lowered the concentrations of most phenolic compounds, including anthocyanins and flavonols, in the peel (Chen et al., 2012). Apple peel from the upper portions of the canopy had greater phenolic concentrations in three out of four cultivars (Drogoudi and Pantelidis, 2011). The effect of canopy position on phenols in the flesh appears to be more complex. Our results are in agreement with Drogoudi and Pantelidis (2011) who found higher total phenolics in the flesh of ‘Fuji Kiku’ and ‘Imperial D.R.D’ in the upper canopy, compared to the shaded inner canopy. In contrast, Hagen et al. (2007) found no difference in the phenolic concentration in apple flesh between sun-exposed and shaded apples. Chlorogenic acid, phloridzin and four flavanols were identified as the major phenols in apple flesh (Chen et al., 2012; Zhang et al., 2010). The concentration of chlorogenic acid was barely affected by bagging, suggesting that light is not an important regulatory factor for this phenol. Bagging reduced the concentration of flavanols in the apple flesh in ‘Golden Delicious’ and ‘Red Delicious’, but not in ‘Royal Gala’ (Chen et al., 2012). On the contrary, bagging increased phloridzin concentrations in ‘Red Delicious’. These studies show that factors affecting metabolism of phenols in apple flesh may be cultivar specific and that not all phenolic compounds respond uniformly to light exposure (Chen et al., 2012).

The two methods of phenolic quantification used in this research, viz. the Folin-Ciocalteu (FC) method and the direct absorbance (UV) method, gave similar results for the peel of ‘Granny Smith’ and ‘Starking’. According to the FC method, outer canopy fruit flesh and peel had higher phenolic concentrations. However, opposing results were obtained for ‘Golden Delicious’ peel and apple flesh in all three cultivars where the UV method indicated no difference between inner and outer canopy fruit. Hagen et al. (2007) who found no difference in total phenolic concentrations in the flesh of sun exposed and shaded apples quantified phenolics with the FC method. However, Drogoudi and Pantelidis (2011), also using the FC method, found higher phenolic concentrations in apple flesh harvested from the upper canopy in two of four cultivars. The FC method is a commonly used standard method recommended for total phenol quantification (Robards, 2003). Since all phenolic compounds absorb light at 280 nm (Mateos et al., 2001), absorbance at this wavelength has been used for HPLC quantification of phenolics in apples (Escarpa and Gonzalez, 1998). However, some phenolic groups in apples absorb maximally at higher wavelengths. Quercetin glycosides in the cuticle absorb at 375 nm (Solovchenko and Merzlyak, 2003), chlorogenic acid mainly in apple flesh absorb at 350 nm and cyanidin galactosides absorb at 525 nm (Van der Sluis et al., 2001). It is possible that levels of these phenolic compounds could be underestimated by the spectrophotometric method.

Ascorbic acid levels appear to be higher in more exposed apple peel (Hagen et al., 2007; Ma and Cheng, 2004; Solomakhin and Blanke, 2010). Exposure of shaded apple peel to full sunlight led to an up regulation of the ascorbate glutathione cycle, which is an important pathway for the recycling of ascorbic acid (Ma and Cheng, 2004). Hence, the content and recycling of ascorbic acid is influenced by light. Light, however, does not affect ascorbic acid concentration and recycling in apple flesh (Li et al., 2008).

The antioxidant capacity of outer canopy peel is higher compared to shaded inner canopy peel (Drogoudi and Pantelidis, 2011; Hagen et al., 2007). Drogoudi and Pantelidis (2011) recorded greater antioxidant capacity in the flesh of apples harvested from the upper and middle portions of the canopy in two of four cultivars. Apple peel may have a 1.5 to 9.2 times greater total antioxidant capacity than apple flesh (Drogoudi et al., 2008). Consistent with the literature, the antioxidant capacity in our study was approximately 10 times higher in peel than in flesh and approximately 1.2 – 1.5 times higher in sun exposed than in shaded peel. Apple flesh from the outer canopy fruit was approximately 1.4 times higher in antioxidant capacity than in the inner canopy fruit. These differences in antioxidant capacity can be related to higher total phenolic (Chinnici et al., 2004) and ascorbic acid levels (Hagen et al., 2007). According to Drogoudi et al. (2008), ascorbic acid and phenolics are important antioxidants in apples and correlate positively with antioxidant capacity (r^2 = 0.75 and 0.91, respectively) in apple flesh. Ascorbic acid, in other research, accounted for as little as 0.4% of the antioxidant capacity in 'Red Delicious' fruit (Eberhardt et al., 2000). Further research is required to shed light on the regulation of light induced pathways in apple flesh.

With regards to temperature, strawberries grown in cool day and night temperatures were found to have the lowest antioxidant capacity. Increasing night temperatures increased antioxidant capacity while higher growth temperatures increased phenolics in the strawberries (Wang and Zheng, 2001). In blueberry and blackberry cultivars, antioxidants, polyphenols and ascorbic acid were affected by seasonal differences in climate and growing region. The effects were not consistent between cultivars and the genotypic effect was greater than the effect of environment (Howard et al., 2003; Reyes-Carmona et al., 2006). However, blackberry genotypes that were adapted to and thrived under more severe high temperature climates, consistently demonstrated high phenolic content as a possible protective adaptation (Reyes-Carmona et al., 2006). Warmer temperatures around bloom and fruit set had a positive correlation to phenolic production in 'Early Black' cranberries (Vanden Heuvel and Autio, 2008). 'Frost Satsuma' mandarins contained more ascorbic acid under cool temperatures and grapefruit grown in coastal areas had more ascorbic acid than fruit grown in the desert (Lee and Kader, 2000). In contrast to the berry and citrus data, higher phenolic levels were observed in a cooler season in 19 apple cultivars, whereas ascorbic acid was higher in a warmer season (Lata and Tomala, 2007). It should be noted that the results were highly cultivar and tissue type dependent. Differences were more pronounced in the peel than in the flesh.

The higher levels of pigments and UV-absorbing compounds as well as the higher antioxidant capacity of sun-exposed apple peel can be explained from a photoprotective perspective. The combination of high light, including high UV-radiation, and high temperatures in the outer canopy causes a significant amount of stress to plants and induces the formation of harmful reactive oxygen species (Foyer et al., 1994). Apple fruit exposed to such environments are prone to photodamage disorders such as sunburn (Schrader et al., 2003) and photobleaching of chlorophyll (Olszowka et al., 2003). Sun exposed apple peel acclimatizes to high irradiance by elevating enzyme activity in the xanthophyll cycle and the ascorbate glutathione pathway to meet the need for dissipating excess absorbed light and scavenging reactive oxygen species (Ma and Cheng, 2003). The ascorbate glutathion cycle plays an important photoprotective role by reducing oxidative stress brought about by the excess excitation energy and excessive reactive oxygen species in high light environments (Demmig-Adams and Adams III, 1992). Anthocyanins in apple peel are induced by high irradiance and low temperatures (Steyn et al., 2005). Although this pigment has a number of functions in fruit, the regulation of anthocyanins by high light and low temperature suggests anthocyanins in fruit peel has a primary photoprotective function (Steyn et al., 2009). They fulfil this function by protecting chlorophyll against photoinhibition and photobleaching by acting as a selective screen against excessive blue-green light (Smillie and Hetherington, 1999). Anthocyanins may also abate oxidative damage by reactive oxygen species and provide protection against harmful UV radiation (Hatier and Gould, 2009). Phenolics are important in plant protection as they strongly absorb UV radiation (Krauss et al., 1997), which is harmful to plants (Janssen et al., 1998). Phenolics in the cuticle of apple peel in both shaded and sun exposed apples filter a significant proportion of UV-A and UV-B radiation before it reaches epidermal and hypodermal cells (Solovchenko and Merzlyak, 2003). The moderate flavonoid content of shaded ‘Braeburn’ and both sun exposed and shaded ‘Granny Smith’ peel resulted in photodamage by UV-B radiation (Solovchenko and Schmitz-Eiberger, 2003). In contrast, the significantly greater accumulation of flavonoids in sun-exposed ‘Braeburn’ filtered most of the UV-B radiation, thus preventing damage to the photosynthetic machinery of the peel. Considering the above, the light dependent activation of key photoprotective and free radical scavenging enzymes and the light-induced expression of genes for phenolic synthesis in the apple peel (Takos et al., 2006; Steyn et al., 2005) seem to be the reason for the higher antioxidant capacity and potential increased health benefits of outer canopy apples.

The levels of N, P, K, Mg, Cu, B, Mn in the flesh and B, Ca, Mg in the peel were higher in inner than in outer canopy 'Granny Smith' fruit. This is contrary to Morandi et al. (2010) according to whom higher transpiration rates during the early stages of fruit development in outer canopy fruit may be a positive driving force for mineral nutrient accumulation. Shaded kiwifruit was found to accumulate less Ca than exposed fruit and this was attributed to higher xylem flows to exposed fruit (Montanaro et al., 2006). Also, the flavedo of outer canopy mandarins had higher concentrations of Ca and Mg, while inner canopy fruit had higher concentrations of K (Cronjé et al., 2011). The reason for the higher mineral concentrations in inner canopy fruit in our study is not known. Since both xylem and phloem transport is higher to outer canopy fruit (Morandi et al., 2011), these fruit are expected to generally accumulate more minerals. However, higher dry matter accumulation in outer canopy fruit may decrease mineral concentrations on a dry weight basis (Haynes and Goh, 1980). Percentage DMC was a significant covariate for N, P, Mg, B and Mn in the flesh, but did not abolish differences between canopy positions except for Mg. More research is required to study the influence of canopy position on nutrient concentrations in fruit.

CONCLUSION

This study confirms that the position of apples in the canopy affects their chemical composition. The chemical composition of apple peel appears to be particularly attuned to the environment. This makes sense considering that the fruit peel is the interface of the fruit with external environmental stimuli and that many peel components fulfil important roles in photoprotection. In the case of visible pigments in the peel, responses to light and temperature also affect the overall appearance of the fruit and may thereby affect consumer preference for the fruit.

Various phytochemicals in the apple peel such as ascorbic acid and phenolic compounds protect the fruit from reactive oxygen species. Phenolics also serve as a UV filter. An increase in light exposure leads to an up-regulation in ascorbic acid and various phenolic compounds in the peel, which in turn increase the nutritive value of the fruit. Light exposure also increases the antioxidant capacity of apple flesh. Anthocyanins, phenolics and ascorbic acid have high antioxidant activities and may provide protection against chronic diseases (Lila, 2004; Moyer et al., 2002; Dragsted et al., 1993).

Outer canopy fruit also accumulate more photo-assimilates and as a result contain more carbohydrates and sugars than inner canopy fruit. Hence, the organoleptic characteristics of inner and outer canopy fruit may not be the same. We need to assess how these positional differences in the chemical composition of fruit affect consumer preference and acceptability.

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TABLES

Table 1. The effect of canopy position (inside versus outside canopy) on the fruit size of 'Granny Smith', 'Golden Delicious' and 'Starking' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa determined after approximately one month storage at -0.5^{0}C.

	Fruit diameter (mm)	**Fruit weight (g)**
Granny Smith		
Inside Canopy	72.8 ^{NS}	166 ^{NS}
Outside Canopy	73.0	170
P-value	*0.9061*	*0.7554*
Starking		
Inside Canopy	67.6 ^{NS}	140 ^{NS}
Outside Canopy	67.0	132
P-value	*0.5312*	*0.3294*
Golden Delicious		
Inside Canopy	68.0 ^{NS}	144 ^{NS}
Outside Canopy	67.1	138
P-value	*0.3808*	*0.3260*

^{NS} Non-significant

Table 2. The effect of canopy position (inside versus outside canopy) on the various sugars in the apple flesh for 'Granny Smith', 'Golden Delicious' and 'Starking' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa after approximately one month storage at -0.5^{0}C.

	TSS (ºBrix)	TA (Malic acid%)	TSS:TA	Firmness (N)	Starch breakdown (%)	DMC (%)
Granny Smith						
Inside Canopy	11.29 b[z]	0.85 a	13.27 b	76.2 b	63 a	14.9 [NS]
Outside Canopy	13.14 a	0.75 b	17.40 a	84.7 a	40 b	15.9
P-value	*<0.0001*	*0.0042*	*<0.0001*	*0.0007*	*0.0055*	*0.4031*
Starking						
Inside Canopy	12.81 b	0.27 a	47.68 b	81.9 [NS]	63 b	12.5 [NS]
Outside Canopy	14.50 a	0.20 b	69.89 a	82.3	55 a	14.2
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*0.8820*	*0.4362*	*0.0676*
Golden Delicious						
Inside Canopy	14.23 b	0.43 a	32.97 b	61.5 b	65 a	10.8 b
Outside Canopy	16.55 a	0.38 b	40.67 a	66.0 a	48 b	12.3 a
P-value	*0.0006*	*<0.0001*	*0.0031*	*0.0031*	*0.0135*	*0.0149*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05 in the column.

Table 3. The effect of canopy position (inside versus outside canopy) on the pigment concentrations in the peel of 'Granny Smith', 'Golden Delicious' and 'Starking' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa.

	Anthocyanin ($\mu g{\cdot}g^{-1}$ FW)	**Carotenoid** ($\mu g{\cdot}g^{-1}$ FW)	**Chlorophyll** ($\mu g{\cdot}g^{-1}$ FW)
Granny Smith			
Inside Canopy	1.6 b[z]	35.4 [NS]	153.6 a
Outside Canopy	98.9 a	34.4	111.3 b
P-value	*<0.0001*	*0.5583*	*<0.0001*
Starking			
Inside Canopy	251.2 b	22.2 b	41.6 [NS]
Outside Canopy	735.6 a	32.9 a	49.8
P-value	*<0.0001*	*<0.0001*	*0.1293*
Golden Delicious			
Inside Canopy	0.0 b	26.4 [NS]	75.3 a
Outside Canopy	49.7 a	30.1	62.5 b
P-value	*<0.0001*	*0.0712*	*0.0139*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05 in the column.

Table 4. The effect of canopy position (inside versus outside canopy) on the physical appearance of ‘Granny Smith’, ‘Golden Delicious’ and ‘Starking’ apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa measured after approximately one month storage at -0.5^{0}C.

	Ground colour (colour chart)^x	**Blush (colour chart)^y**	**Hue (°)**
Granny Smith			
Inside Canopy	1.07 b^z	0.00^y b	118.3 a
Outside Canopy	1.46 a	4.06 a	81.0 b
P-value	*<0.0001*	*<0.0001*	*<0.0001*
Starking			
Inside Canopy	3.36^{NS}	8.50^w a	64.7 a
Outside Canopy	3.45	2.45 b	35.4 b
P-value	*0.4019*	*<0.0001*	*<0.0001*
Golden Delicious			
Inside Canopy	2.43 b	0.00^y b	112.3 a
Outside Canopy	2.83 a	3.99 a	81.3 b
P-value	*<0.0001*	*<0.0001*	*<0.0001*

^{w} Chart values 1-8 : where 1=no blush; 8=intense red blush

^{x} Chart values 0.5 – 5: where 0.5 = green; 5 = pale green/yellow

^{y} Chart values 1-12 : where 1=no blush; 12=intense red blush

^{z} Treatments with different letters differ significant at P<0.05

^{NS} Non-significant

Table 5. The effect of canopy position (inside versus outside canopy) on sugars levels in the apple flesh of 'Granny Smith', 'Golden Delicious' and 'Starking' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa .

	Sucrose ($mg \cdot g^{-1}$ FW)	Glucose ($mg \cdot g^{-1}$ FW)	Fructose ($mg \cdot g^{-1}$ FW)	Sorbitol ($mg \cdot g^{-1}$ FW)	Total sugars ($mg \cdot g^{-1}$ FW)
Granny Smith					
Inside Canopy	27.9 b[z]	20.8 [NS]	50.2 b	1.8 b	97.8 b
Outside Canopy	34.5 a	21.5	59.0 a	3.3 a	118.3 a
P-value	*<0.0001*	*0.3400*	*<0.0001*	*<0.0001*	*<0.0001*
Starking					
Inside Canopy	20.7 b	25.1 b	64.5 b	3.2 b	113.3 b
Outside Canopy	22.4 a	30.2 a	71.0 a	4.3 a	128.2 a
P-value	*0.0596*	*0.0004*	*0.0045*	*<0.0001*	*0.0005*
Golden Delicious					
Inside Canopy	28.7 b	19.4 b	73.7 b	3.2 b	125.1 b
Outside Canopy	32.7 a	25.4 a	85.8 a	4.3 a	148.3 a
P-value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05 in the column.

Table 6. The effect of canopy position (inside versus outside canopy) on antioxidants, ascorbic acid and phenolics (measured by two methods - FC and UV method) in the flesh of 'Granny Smith', 'Golden Delicious' and 'Starking' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa .

	Total ascorbic acid (mg· 100 g^{-1} FW)	Total phenolics (FC) (mg·100 g^{-1} FW)	Total phenolics (UV) (mg·100 g^{-1} FW)	Antioxidants (mg TEAC· g^{-1} FW)
Granny Smith				
Inside Canopy	19.6 b^{z}	91 b	80 ^{NS}	1.65 b
Outside Canopy	29.3 a	119 a	85	2.83 a
P-value	*<0.0001*	*<0.0001*	*0.7277*	*<0.0001*
Starking				
Inside Canopy	19.3 ^{NS}	121 b	103 ^{NS}	1.66 b
Outside Canopy	21.6	137 a	92.5	2.25 a
P-value	*0.5413*	*0.0064*	*0.3695*	*0.0007*
Golden Delicious				
Inside Canopy	20.6 ^{NS}	84 b	71 ^{NS}	1.76 b
Outside Canopy	22.6	114 a	74	2.25 a
P-value	*0.1265*	*<0.0001*	*0.5990*	*0.0011*

^{NS} Non-significant

^{z} Means with different letters differ significantly at P<0.05 in the column.

Table 7. The effect of canopy position (inside versus outside canopy) on antioxidants, ascorbic acid and phenolics (measured by two methods - FC and UV method) in the peel of 'Granny Smith', 'Golden Delicious' and 'Starking' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa .

	Total ascorbic acid ($mg \cdot 100\ g^{-1}$ FW)	**Total phenolics (FC) ($mg \cdot 100\ g^{-1}$ FW)**	**Total phenolics (UV) ($mg \cdot 100\ g^{-1}$ FW)**	**Antioxidants (mg TEAC/g^{-1} FW)**
Granny Smith				
Inside Canopy	289 b [z]	638 b	728 b	15.8 b
Outside Canopy	991 a	2183 a	1315 a	19.2 a
P-value	*<0.0001*	*<0.0001*	*0.0024*	*<0.0001*
Starking				
Inside Canopy	120 b	1019 b	735 b	18.5 b
Outside Canopy	167 a	1764 a	1293 a	21.6 a
P-value	*<0.0001*	*<0.0001*	*0.0003*	*<0.0001*
Golden Delicious				
Inside Canopy	80 b	1121 a	892 [NS]	13.2 b
Outside Canopy	610 a	1548 b	1298	21.4 a
P-value	*<0.0001*	*<0.0001*	*0.0831*	*<0.0001*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05 in the column.

Table 8: Effect of canopy position (inside versus outside canopy) on the nutrient concentration (on FW basis) in the peel of 'Granny Smith' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa.

	N (mg)	**P (mg)**	**K (mg)**	**Ca (mg)**	**Mg (mg)**	**C (g)**	**B (mg)**	**Na (mg)**	**Fe (µg)**	**Cu (µg)**	**Mn (µg)**	**Zn (µg)**
Inner Canopy	4.6 ^{NS}	0.87 ^{NS}	7.5 ^{NS}	1.44 a ^{z}	1.46 a	0.49 ^{NS}	0.094 a	0.42 ^{NS}	180 ^{NS}	12 ^{NS}	91 ^{NS}	62 ^{NS}
Outer Canopy	4.7	1.03	5.9	1.26 b	1.15 b	0.49	0.060 b	0.32	120	12	52	18
P-value	*0.5526*	*0.2227*	*0.1497*	*0.0026*	*<0.0001*	*0.5353*	*0.0322*	*0.1492*	*0.4250*	*0.9040*	*0.0589*	*0.1448*

^{NS} Non-significant

^{z} Means with different letters differ significantly at P<0.05 in the column.

Table 9. Effect of canopy position (inside versus outside canopy) on the nutrient concentration (on FW basis) in the flesh of 'Granny Smith' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa using dry matter concentration (DMC) as a covariate.

	N (mg)	**P (mg)**	**K (mg)**	**Ca (mg)**	**Mg (mg)**	**C (g)**	**B (mg)**	**Na (mg)**	**Mn (µg)**	**Fe (µg)**	**Cu (µg)**	**Zn (µg)**
Inner Canopy	4.76 a	0.61 a	6.7 a	0.35 ^{NS}	0.24 a	0.42 ^{NS}	0.049 a	0.62 ^{NS}	4.0 a	500 ^{NS}	8.0 a	20.0 ^{NS}
Outer Canopy	2.38 b	0.37 b	5.6 b	0.30	0.20 b	0.41	0.026 b	0.58	2.0 b	300	5.0 b	14.0
Pr>F	*<0.0001*	*<0.0001*	*0.0186*	*0.1454*	*0.0135*	*0.0712*	*0.0003*	*0.7291*	*<0.0001*	*0.0751*	*0.0177*	*0.5852*
Inner Canopy	4.76 a	0.60 a			0.24 ^{NS}		0.048 a		0.0042 a			
Outer Canopy	2.38 b	0.38 b			0.21		0.028 b		0.0023 b			
Pr>F												
%DMC	*0.0239*	*0.0051*			*0.0035*		*0.0073*		*0.0067*			
Canopy position	*0.0003*	*0.0009*			*0.1828*		*0.0037*		*<0.0001*			

^{NS} Non-significant

[z] Means with different letters differ significantly at P<0.05 in the column.

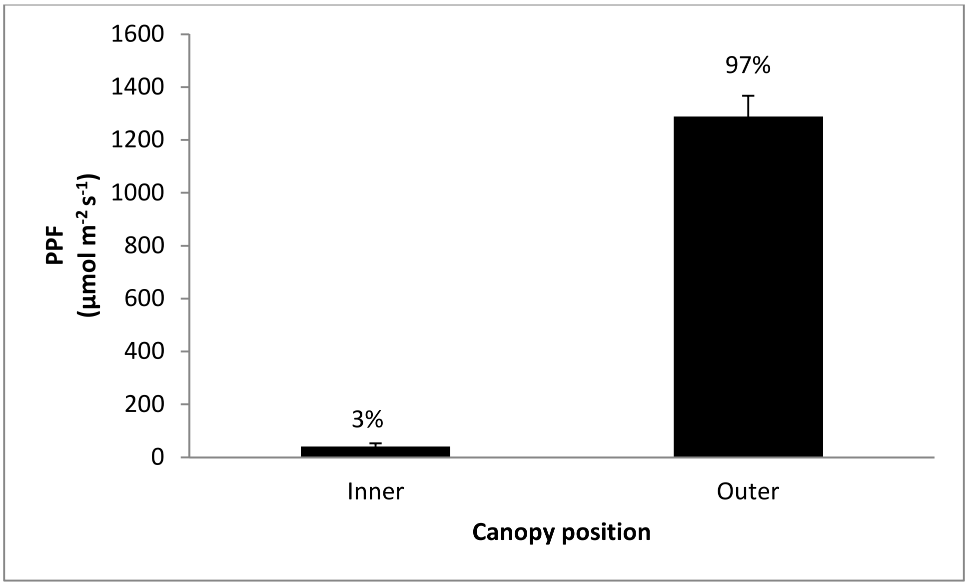

Fig. 1. The average photosynthetic photon flux (PPF) received by fruit from inner and outer canopy positions during the course of 1 March 2010 in a 'Starking' orchard in the Witzenberg Valley, Ceres. Values are means ± SE (n=10). The percentage PPF of full sunlight is indicated above each column.

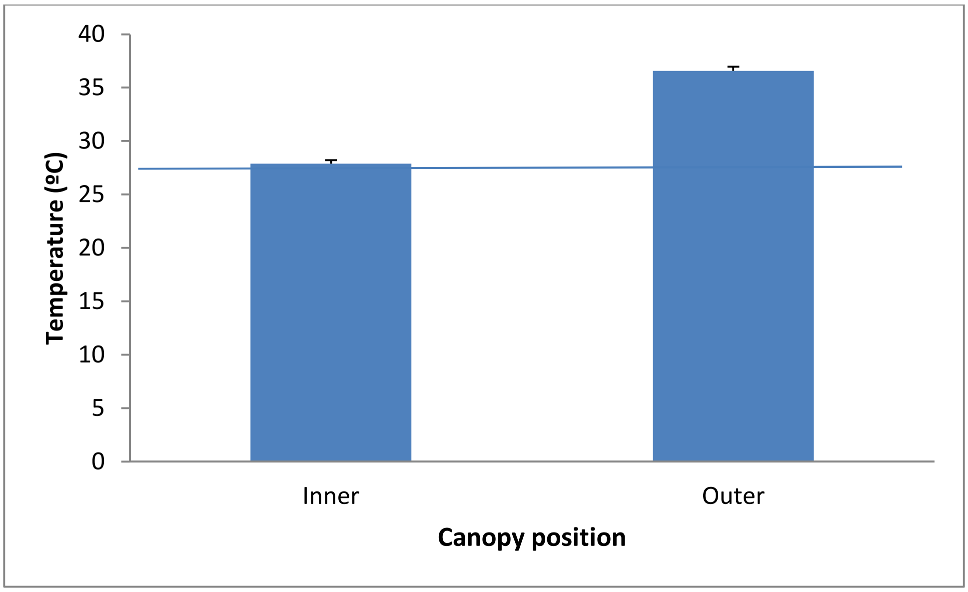

Fig. 2. Average peel temperatures of fruit from the inner and outer canopy positions during the course of an average day from 0900 HR to 1700 HR measured in a ‘Starking’ orchard on 1 March 2010. Values are means ± SE (n=10). The average ambient temperature of 27 ºC is indicated with a line.

RELATIONSHIP BETWEEN CANOPY POSITION AND FRUIT QUALITY AS IT PERTAINS TO CONSUMER LIKING

ABSTRACT

The microclimatic differences experienced at different positions in the tree canopy may influence the internal and external quality of the fruit. The aim of this study carried out over two seasons (2010/ 2011), was to evaluate the quality of apples from the inside versus the outside of the canopy for 'Starking', 'Golden Delicious' and 'Granny Smith' apples. Colour assessment was carried out and maturity indexing was performed by measuring flesh firmness and the percentage starch breakdown. Soluble solids concentration (TSS), titratable acidity (TA) and dry matter concentration (DMC) were determined. Descriptive sensory analysis using a trained panel of eight judges assessed the apple fruit for flavour and texture characteristics. The approximately 100 consumers who participated in the consumer study were presented with peeled slices of the apples, as well as photographs of the apples and they scored their liking for taste and appearance of the fruit, respectively, using a nine point hedonic scale. Results showed that consumers were able to discern the differences between inner and outer canopy fruit from the same cultivar. Preference for the taste of outside canopy fruit was higher compared to inside canopy fruit in all three cultivars. The appearance of outside canopy 'Starking' was preferred over the inside canopy fruit owing to their redder colour. On the contrary, the red blush on 'Granny Smith' and 'Golden Delicious' was not appreciated by consumers who preferred the appearance of inside canopy fruit. In all three cultivars, outer canopy fruit were generally found to be higher in TSS, TSS:TA ratio and DMC in both seasons while TA was lower in the first season only. There were significant differences in fruit quality between the seasons and associations using Principal Component Analysis (PCA) plots showed that the seasonal differences accounted for greater variation than differences brought about by canopy position. The PCA plots also indicated that outside canopy fruit in the three cultivars were generally associated with high TSS and TSS:TA ratio, sweetness and apple flavour while inside canopy fruit were associated with higher TA and sourness. The results from the consumer studies also gave insight into the significance and role of fruit colour in consumer acceptance.

INTRODUCTION

Fruit are exposed to different microclimatic conditions determined by their position in the tree canopy. The two main factors that vary highly in the canopy are light and temperature. Inner canopy fruit experience lower light and temperature conditions compared to outer canopy fruit. In a 'Granny Smith' orchard with a tree height and canopy width of approximately 3 m and 2.5 m, respectively, it was found that inner canopy fruit received only 2% (33 $\mu mol \cdot m^{-2} \cdot s^{-1}$) of full sun on average over the season compared to 10% (212 $\mu mol \cdot m^{-2} \cdot s^{-1}$) in the middle and 54% (962 $\mu mol \cdot m^{-2} \cdot s^{-1}$) in the outer canopy (Fouché et al., 2010). Peel temperatures of outer canopy fruit on the northern side of the rows were found to exceed air temperatures by approximately 5 ºC on average while fruit from the inner canopy did not differ from the ambient temperature.

The appearance of apples is generally influenced by the concentrations and distribution of pigments – chlorophylls, carotenoids and anthocyanins. A combination of high light conditions and cool temperatures has been found to enhance anthocyanin accumulation in apple fruit (Saure, 1990). Light has been found to be important in chlorophyll synthesis at the beginning of fruit development (Gorski and Creasy, 1977). However, as fruit mature, chlorophyll synthesis decreases and high light exposure will result in chlorophyll degradation exposing carotenoids (Knee, 1971). Inner canopy fruit which are deeply shaded and receiving as little as 2% of full sunlight are also low in chlorophyll concentration and lighter in green colour (Fouché et al., 2010).

In a market the first assessment of fruit by consumers is of a visual nature. Hence peel colour is an important quality attribute in determining consumer acceptance of apples (Telias et al., 2011). The red colour in apple peel is for many apple cultivars one of the most important factors in consumer acceptance (Saure, 1990). The intensity of red blush on the apple peel is an important consideration for the consumer in purchasing fruit and is also used as grading standards in retail outlets and when fruit is packed (Iglesias et al., 2008). Fruit may be downgraded due to insufficient red colour development. However, in some cases, red pigmentation is an undesirable feature for instance, any trace of blush in 'Granny Smith' apples results in degradation of the fruit (Hirst, 1990). Consumers use peel colour to identify apple cultivars, as well as their eating quality preferences, for example, consumers were found to associate red coloured apples with sweet sensory descriptors and green apples with grassy, acidic or sour sensory descriptors (Daillant-Spinnler et al., 1996).

The divergent environmental conditions that outer and inner canopy fruit are exposed to, may affect the appearance and overall eating quality of the fruit. This may have a bearing on consumer preference of apples of the same cultivar harvested at different canopy positions. Apart from peel colour, internal quality characteristics such as flavour, sweetness, sourness and texture attributes are the most important traits that determine consumer preference (Daillant-Spinnler et al., 1996; Jaeger et al., 1998). The sensory attributes that define apple fruit texture include firmness, crispness, mealiness and juiciness. Many researchers have illustrated the importance of juiciness as a texture attribute of fruit (Harker et al., 2002). Mealy apples are generally less liked than non-mealy apples (Jaeger et al., 1998). Harker et al. (2008) established that firmness is a dominant factor in consumer acceptance of apples and titratable acids and soluble solids play a role in defining quality for specific cultivars. The latter group found that for firm 'Red Delicious', 'Gala' and 'Braeburn' apples, increasing the soluble solids concentration increased consumer acceptability. For 'Golden Delicious', soft fruit with high soluble solids concentrations were rejected by consumers (Oraguzie et al., 2008), while high soluble solids provided no advantage or disadvantage for firm fruit (Harker et al., 2008). Consumer acceptability based on how the product tastes shows that soluble solids concentration is a useful tool to determine the minimum acceptable eating quality and is a satisfactory indicator of eating quality in many fruits including peaches, nectarine and apples (Crisosto et al., 2003; Harker et al., 2002). However, apple taste is more accurately determined by the concentration of soluble solids and acids and the balance between these two (Jackson, 2003).

Outside canopy apples have been found to have significantly higher dry matter, soluble solids and reducing sugars concentrations and lower titratable acidity than inner canopy fruit (Nilsson and Gustavsson, 2007). Krishnaprakash et al. (1983) found that apples at the top of the canopy had higher mean scores for colour, appearance and texture, but lower mean scores for juiciness, aroma, taste and soluble solids while there were no significant differences in acidity. In a study on the effect of hail nets on fruit quality, Solomakhin and Blanke (2010) observed that treatments without hail nets contained more soluble solids, were sweeter and had advanced starch breakdown or ripened faster. With regards to firmness; Robinson et al. (1983) reported an inverse relationship between firmness and irradiance. However, they concluded that the effect of light on firmness was indirect and due to the influence of light on maturity and fruit size. Although linear and curvilinear relationships could be established between canopy position, light and firmness in peaches, results were inconsistent (Lewallen and Marini, 2003).

This study was conducted over two seasons, viz. 2009-2010 and 2010-2011, with the aim to investigate the chemical, textural, sensory and consumer preference differences that may exist between inner and outer canopy fruit. Having established this, we also endeavoured to determine how the differences in apple quality brought about by canopy position may influence consumer preference for apple taste and appearance. Preference for apple taste will ultimately be determined by evaluating the eating quality and consumer preference. Preference for appearance will be determined by evaluating apple peel colour and consumer preference using photographs. We also aim to determine whether peel colour is a reliable indicator of quality and liking.

MATERIALS AND METHODS

Plant material

Three commercial apple cultivars were used for this study, viz. Granny Smith, which is dark green at harvest maturity, Golden Delicious, which is yellow-green at harvest maturity, and Starking, which vary from red-striped to green depending on canopy position. Fruit were sourced from Vastrap Farm, in the Witzenberg Valley, Ceres (latitude: 33^0 23’S, longitude: $19^0$19’E), Western Cape, South Africa. ‘Golden Delicious’ and ‘Starking’ were harvested at commercial maturity on 1 March 2010 and likewise ‘Granny Smith’ on 8 April 2010. In the second season, ‘Golden Delicious’ and ‘Starking’ were harvested on 23 March 2011 and ‘Granny Smith on 15 April 2011.

The ‘Granny Smith’ orchard on seedling rootstock was planted in 1974 in an N-S row orientation at a spacing of 6.71 m x 3.35 m. The ‘Golden Delicious’ orchard, also on seedling rootstock, was planted in 1960 at the same spacing and row orientation as ‘Granny Smith’. ‘Starking’ on seedling rootstock was planted in 1974 at a spacing of 5 m x 3 m and similar row orientation as the above-mentioned. These older open vase orchards were selected so as to maximise the contrast between inside and outside canopy fruit. For ‘Granny Smith’ and ‘Golden Delicious’, only fruit with red blush, mainly found at the top outer positions of the tree canopy, were harvested as the outside fruit. Fruit harvested from three consecutive trees represented a replicate and fifteen inside and outside fruit were harvested for each replicate. There were ten replicates in total per treatment.

Experimental design

The study was laid out as a complete randomised design with ten replications. Maturity analysis by assessing the percentage starch breakdown was carried out immediately after harvest. One fruit from each replicate (i.e., 10 fruit per canopy position) was randomly selected and assessed in order to determine whether outside and inside fruit differed in maturity. Since the intention was to use inside and outside fruit of comparable maturity, a further harvest would have been scheduled if the fruit differed in maturity. Fruit were stored at -0.5 ^{0}C for approximately two months before commencement of physical measurements and chemical analysis, as well as sensory analysis and consumer preference. Of the fourteen fruit remaining per replicate, four were allocated for the consumer panel, five were allocated for the trained panel, and five fruit were set aside for chemical and physical analyses that consisted of non-destructive and destructive measurements.

Physical measurements

Each fruit was weighed on an electronic balance and fruit diameter was determined using a set of digital Mitutoyo callipers (Mitutoyo, Japan).

The colour (hue angle) of each apple was measured using a colorimeter (Konica CR-400, Minolta Co. Ltd., Tokyo, Japan). On each fruit, hue angle was recorded at the reddest and least red (or greenest) position.

Percentage dry matter concentration (DMC) was determined by weighing a fresh sample of fruit and oven drying the fruit over a period of 72 hours at 45 ºC. Fruit were weighed immediately and returned into the oven for a further 24 hours and re-weighed to ensure all the moisture had evaporated. The following formula was used to calculate DMC as a percentage:

DMC (%) = (dry weight / fresh weight) * 100

Maturity indices

The percentage starch breakdown of the apples was determined by placing one half of the apple in an iodine solution and evaluating the starch breakdown using a starch conversion chart for pome fruit (Unifruco Research Services, Bellville, South Africa). Flesh firmness was measured using a penetrometer (Fruit Texture Analyser, GUSS Manufacturing (Pyt) Ltd., Strand, South Africa) fitted with an 11 mm diameter probe. Two readings were taken on opposite peeled sides of the fruit approximately halfway between the calyx and the stem. Slices of apple were placed in a juice extractor and the juice was used to determine the total soluble solids (TSS) concentration and the titratable acidity (TA). TSS was measured using a calibrated hand-held refractometer (TSS 0-32%, Model N1, Atago, Tokyo, Japan). TA was measured using an automated titrator (Tritino 719S and Sample Changer 674, Metrohm Ltd., Herisau, Switzerland) by titrating 5 g of juice from each apple sample with 0.1 M NaOH to a pH of 8.2. The TA is expressed as percentage malic acid.

Descriptive sensory analysis

Descriptive sensory analysis is a profiling technique used to determine the sensory attributes of various foods and beverages using a trained panel of judges. The judges were trained using the consensus method (Lawless and Heymann, 1997). A sensory panel consisting of eight judges was used for the sensory analysis. The panel used a 100 mm unstructured line scale, ranging from 0% on the far left and 100% on the far right end, to analyse the apple slices for the respective sensory attributes. Each treatment was replicated ten times and was tested over five days, two replicates each day. The treatments were presented to the judges in a completely randomised order. Each judge received an apple slice from the same apple; hence the sample size was an eighth of an apple. Each sample was coded with a three digit random code and samples were presented on petri dishes. Judges were seated in individual booths with computers at a room temperature of 21 ^{0}C. They were provided with a computer program (Compusense®, Guelph, Canada) for data entry. The judges used distilled water and unsalted fat free biscuits to refresh their palate.

Consumer preference

In 2010, ‘Starking’ and ‘Golden Delicious’ were tasted by 99 consumers and ‘Granny Smith’ was tasted by 97 consumers. In 2011, the second year of the study, ‘Starking’ and ‘Golden Delicious’ were tasted by 94 while ‘Granny Smith’ was tasted by 100 consumers.

Consumers were presented with each cultivar separately, hence they assessed the inside and outside treatment for each cultivar without influence of perhaps stronger or differing flavour attributes of the other cultivars. In the analyses, consumers were presented with a questionnaire divided into three sections. The first section consisted of the taste assessment of the apples samples presented to the consumer, the second section was a visual assessment of apple appearance, primarily colour, and the third section consisted of a general enquiry of the apple quality preferences and general socio-demographic information of the consumers.

Apple slices were coded with a three digit random code and presented peeled on open petri dishes in random order. In the taste assessment, consumers were asked to taste the fruit and to indicate, using a nine point hedonic scale, which term best described how they perceived the product that they have tasted. The nine point hedonic scale ranges from 1 – dislike extremely; 5 – neither like nor dislike and 9 – like extremely (Lawless and Heymann, 1997). Distilled water and unsalted, fat free biscuits were available for consumers to clean their palate between samples. A room temperature of 21 ^{0}C was maintained throughout the tasting.

Photographs of whole apple fruit were presented to the consumers for assessment (Fig. 1). Three photos of each treatment, presented in a randomized fashion, were used in the study. Consumers were presented with pictures of inside (without blush) and outside (with blush) whole apple fruit of the cultivars they had been presented with for the tasting assessment. They assessed the pictures using the nine point hedonic scale. These assessments were used to determine the degree of liking of appearance, as well as preference and acceptance.

Statistical procedures

The data for 'Starking', 'Granny Smith' and 'Golden Delicious' apples collected over the two years (viz. 2009-2010 and 2010-2011) were continuous and subjected to analysis of variance. The cultivars were analysed separately and were not statistically compared with each other. A Levene's test for homogeneity of variance was performed to test if the year variability in the observations were comparable in magnitude (Levene, 1960). A weighted analysis of variance was performed for the variables showing heterogeneity of variances in years. The reciprocal of the Mean Square Error (1/MSE) for each year for the variables showing heterogeneity of variances in years, was used as a weight. Combined analysis of variance was performed using SAS version 9.2 (SAS Institute Inc., 2008, Cary, NC, USA). The Shapiro-Wilk test was performed to test for non-normality (Shapiro and Wilk, 1965). Student's t-Least Significant Difference was calculated at the 5% significance level to compare treatment means. Principal Component Analysis (PCA) was carried out to identify variables that associate with certain treatments and Discriminant Analysis (DA) was used to classify treatments similar to each other (Rencher, 2002).

RESULTS

Fruit colour

Outer canopy 'Golden Delicious' and 'Granny Smith' fruit were redder than inner canopy fruit in both years, but the difference was more pronounced in 2010 (Table 1). Inner canopy 'Granny Smith' fruit were greener in 2010 than in 2011. 'Starking' fruit were redder in 2011 than in 2010 and outer canopy fruit were much redder than inner canopy fruit.

Physiochemical

In 'Golden Delicious' and 'Granny Smith', the percentage starch breakdown assessed at harvest was found to be higher for inner canopy fruit while for 'Starking' outer canopy fruit had higher starch breakdown. The starch breakdown in 2010 was more advanced than in 2011 (Table 2).

'Golden Delicious' from 2011 was firmer than 2010 with outer canopy fruit being slightly firmer than inner canopy fruit in both years (Table 3). Outer canopy fruit were nearly 2º BRIX higher in TSS, while TSS was ca. 3º BRIX higher in 2010 compared to 2011 (Table 3). TA was significantly higher for inner canopy fruit of 2010 while no difference was observed in 2011 (Table 3). Outer canopy fruit were higher in TSS:TA ratio and the ratio was higher in 2010 than in 2011.

In 'Starking', no differences were observed in firmness between inside and outside fruit for both years (Table 4). TSS values were approximately 2º BRIX higher in outside canopy fruit in both years. Higher TSS values were observed in 2010 compared to 2011 with a difference of nearly 2º BRIX between the years. TA was significantly higher for inside canopy of 2010 while no significant differences were observed in 2011. The much higher TSS and much lower TA values resulted in a high TSS:TA value in outer canopy 'Starking' of 2010 compared to all the other values. TSS:TA ratio in both years was higher for outside canopy fruit. The value for TSS outer canopy fruit from 2011 was statistically not different to that of the inner canopy fruit from 2010. This explains the year and treatment interaction observed (Table 4).

'Granny Smith' outer canopy fruit was firmer in both years and years differed significantly with lower firmness in 2010 fruit (Table 5). TSS was more or less 2º BRIX and 1.5º BRIX higher for outer canopy fruit in 2010 and 2011, respectively. There were no significant differences observed between the years. TA in the second season was slightly lower compared to the first season. There was no significant difference for TA in 2011 between inner and outer canopy fruit; however, in 2010, inner canopy fruit were more acid. The lack of a coherent trend in treatments over the two seasons is the reason for the interaction observed for TA. The TSS:TA ratio was significantly higher for outside canopy fruit in both years.

The dry matter concentration (DMC) was higher for outer canopy fruit in all three cultivars. Differences were also observed between the years where 2011 recorded higher DMC for 'Starking' and 'Granny Smith' while DMC for 'Golden Delicious' was higher in 2010 (Table 6).

Descriptive sensory analysis

Sensory analysis for 'Golden Delicious' fruit showed that 2011 fruit were higher in all sensory attributes than 2010 fruit except sweet taste where no difference was observed between the years (Table 7). Outer canopy fruit were sweeter and of higher apple flavour than inner canopy fruit while inner canopy fruit were higher in sourness. The textural attributes hardness, juiciness, crispness and crunchiness were all higher for outer canopy fruit.

The apple flavour and sweet taste of 'Granny Smith' were perceived to be higher in 2011 while sourness, crispness, hardness and juiciness were higher in 2010 (Table 8). Outer canopy fruit were found to be higher in sweet taste and hardness and lower in sourness. Crunchiness was perceived to be higher for outer canopy fruit of 2011 (Table 9).

For 'Starking' all attributes were higher in 2011 than in 2010 (Table 10). Outer canopy 'Starking' had higher apple flavour and sweet taste while inner canopy fruit were higher in sourness. Textural attributes of crispness, crunchiness and hardness were not affected by canopy position (Table 10). No differences were observed between canopy positions in 2010 while outer canopy fruit were perceived to be juicier in 2011 (Table 11).

Consumer preference

Socio-demographics.

There were two evaluation dates for apple tasting at Stellenbosch University. On 14 April 2010 and 27 April 2011 consumers tasted 'Starking' and 'Golden Delicious' while on 17 May 2010 and 4 May 2011 consumers tasted the 'Granny Smith' apples.

In 2010, 'Starking' and 'Golden Delicious' were tasted by 99 consumers of which 26% were male. Three age groups were predominant, viz. 18 to 21 years of age (29%); 22 to 29 years of age (46%); and 30 to 40 years of age (25%). The majority (90%) of consumers claimed to consume apples once or more per week while the rest of the consumers consume apples at least twice a month. The 'Granny Smith' tasting attracted 97 consumers of which 68% were female. The three age groups present in the study were 18 to 21 years of age (27%), 22 to 29 years of age (47%) and 30 to 40 years of age (26%). Of these consumers, 18% consume apples at least twice a month and the rest consume apples once or more each week.

In 2011, 'Starking' and 'Golden Delicious' were tasted by 94 consumers of whom 70% were female. The majority of the tasters were 18 to 21 years of age or 22 to 29 years of age each group comprising 34%, 18% were 30 to 40 years of age and 13% were of the above 40 years age group. Apples are consumed at least once a week by 75% of the consumers. 'Granny Smith' fruit were tasted by 100 consumers comprising 71% females. Similar to the first tasting, the majority of the tasters were of the 18 to 21 years of age (46 %) and 22 to 29 years of age (38 %) age groups. Only 10% and 6% were of the 30 to 40 years of age and above 41 years of age group, respectively. The majority (90%) of the consumers stated that they consume apples at least once or more per week.

Consumer liking

Consumers preferred the taste of outer canopy fruit over inner canopy fruit in all three cultivars (Table 12). The taste of 'Golden Delicious' and 'Starking' in 2010 were preferred over that of 2011 while no difference in preference was observed over the years for 'Granny Smith'. Consumers preferred the appearance of inside canopy 'Golden Delicious' and 'Granny Smith' apples and the outside fruit of 'Starking' apples, but no differences were observed between the years (Table 12).

Without tasting the products, consumers were asked their opinions on certain apple attributes using a nine point hedonic scale. In the first year of the study, crispness and juiciness were considered most important followed by sweet taste and apple flavour. Least in the line of importance was sour taste (Table 13). In the second year of the study, consumers indicated their preference for apples that are high in apple flavour and juiciness and harder in texture. This was followed by their preference for apples with above average sweetness and below average sourness, while soft and mealy apples were undesired. The opinions of preferences for apple appearance in both years, though significant, did not follow any clear pattern (Table 14). In both years consumers gave the highest preference scores for the appearance of 'Golden Delicious' apples. In 2010, this was followed by blushed and red apples, which obtained similar preference scores. The appearance of 'Starking' apples, green apples and 'Granny

Smith' apples were least preferred in that order. In 2011, consumers subsequently indicated equal preference for the appearance of blushed and green apples; followed by red and green apples. 'Starking' apples were least preferred in 2011.

Correlations

The Principal Component Analysis (PCA) for 'Starking' explains approximately 88% of the variation in the bi-plot considering the first two factors or principal components (Fig. 2). Taste liking was closely associated to TSS and TSS:TA ratio. Outside canopy fruit for both years were plotted in the top half of the PCA together with photo–liking and were strongly associated with taste liking, sweetness, juiciness, apple flavour, TSS, the TSS:TA ratio and DMC. Inner canopy 'Starking' for both years was plotted opposite outer canopy fruit, in the bottom half of the PCA together with TA, sourness and firmness. 'Starking' from both years was clearly separated along the vertical axis (F1) explaining approximately 59% of the variation. The variation brought about by the canopy position along the horizontal axis (F2) explains approximately 29% of the variation.

The PCA plot for 'Granny Smith' explains approximately 96% of the variation in the bi-plot (Fig. 3). For 'Granny Smith', taste-liking was closely associated with outer canopy fruit and with TSS and TSS:TA ratio, DMC as well as the textural attributes firmness, hardness, crispness and juiciness. The influence of the season is apparent with 2011 fruit being associated with sweetness and 2010 fruit more associated with sourness and TA, which lie border line on the axis separating the inner and outer canopy fruit. Photo-liking was associated with inner canopy fruit. Differences due to season were clearly separated by the vertical axis (F1) explaining approximately 62% of the variation. The variation brought about by the canopy position was separated by the horizontal axis (F2) explaining approximately 34% of the variation.

The PCA plot for 'Golden Delicious' explains approximately 95% of the variation in the bi-plot (Fig. 4). 'Golden Delicious' taste-liking was closely associated with outside canopy fruit in both years and to the attributes TSS, TSS:TA ratio, DMC, sweetness and all the textural attributes. Inner canopy fruit were closely associated to sourness, TA and photo-liking. Similar to the other two bi-plots, differences due to season are clearly separated by the vertical axis (F1) explaining approximately 59% of the variation. The variation due to canopy position is separated along the horizontal axis (F2) explaining approximately 36% of the variation.

Discriminant analysis (Fig. 5) carried out on sensory characteristics agree with PCA maps in that the variation between seasons is greater than canopy differences observed. Results show discriminating factors seasonally are mainly textural except for 'Starking' where flavour is also discriminating. The main factor discriminating inner and outer canopy fruit is sweetness except for 'Granny Smith' where hardness is also a discriminating factor.

DISCUSSION

Physiochemical

The differences observed between the fruit harvested from the inner and outer canopy of the tree are primarily because of the microclimatic differences experienced (Paper 1). Fouché et al. (2010) also made similar observations. Outer canopy leaves and fruit intercept more light, which results in the enhancement of the synthesis of photo-assimilates (Johnson and Lakso, 1986). This results in higher carbohydrates and soluble sugars accumulating in fruit that are supplied by leaves that are exposed to more light (Robinson et al., 1983), as has been reported in a number of fruits including peaches (Lewallen and Marini, 2003) and apples (Nilsson and Gustavsson, 2007). Generally, fruit exposed to more light are lower in acids and higher in soluble solids (Nilsson and Gustavsson, 2007; Solomakhin and Blanke, 2010). Soluble solids are also positively correlated to irradiance levels in peaches (Feng-li et al., 2008). In this research, outer canopy fruit in all three cultivars had higher dry matter concentration (DMC). DMC is an important holistic measurement as it is an indicator of physiological and metabolic processes that contribute to the final composition of the fruit (Harker et al., 2009) and is an important factor for consumer liking in kiwi fruit (Jaeger et al., 2011). DMC could be a potential indicator of apple fruit quality to predict the sensory potential of apple fruit (Palmer et al., 2010). 'Royal Gala' apples with higher DMC had higher TSS, TA and firmness and consumers also showed higher preference for these apples (Palmer et al., 2010).

The response of the fruit to the canopy microclimatic environment is also subject to the general environmental conditions in that season. Nilsson and Gustavsson (2007) found that difference in TSS between inner and outer canopy fruit was reduced and the TA was increased in the second year of their study due to higher temperatures in this compared to the first season. The results of our research generally agree with these earlier findings. Seasonal differences were observed between 2010 and 2011 fruit in all three cultivars. PCA maps (Fig. 2, 3, 4) all illustrate that the variation found between the years accounts for a greater percentage of total variance in consumer preference for taste and appearance than the variation found between the inner and outer canopy. This shows that the macro-climate had an overbearing effect on the canopy microclimatic conditions. In all three cultivars, outer canopy treatments had higher DMC, TSS and TSS:TA ratios. DMC, TSS and the TSS:TA ratio were higher in 2010 than in 2011 for 'Golden Delicious' while 'Granny Smith' did not show season differences for TSS, though DMC was higher in 2011. TA in all three cultivars was only higher for inner canopy fruit in 2010. In 2011, there were no significant differences observed for TA in all three cultivars. It is likely that differences observed between the years for TSS and TA were brought about by seasonal climatic differences as was observed by Nilsson and Gustavsson (2007).

For 'Starking', canopy position did not influence flesh firmness in either of the years studied. However, 'Granny Smith' and 'Golden Delicious' had higher flesh firmness in the outer canopy fruit of both years. This may illustrate a relationship between light or canopy position and flesh firmness for these two cultivars. A study investigating the relationship between flesh firmness and canopy position in peaches found that results were inconsistent (Lewallen and Marini, 2003). In earlier studies on apples, Seeley et al. (1980) concluded that light conditions did not influence firmness. Robinson et al. (1983) having found an inverse relationship between irradiance and firmness in apples, concluded that light indirectly influenced firmness due to its effect on maturity and fruit size. The differences in firmness observed in 'Golden Delicious' and 'Granny Smith' may indicate differences in maturity of these fruit in which case it is worth noting that though these difference are significant, they are of very small magnitude. 'Starking' fruit were generally of the same maturity (based on firmness) between canopy positions and across both years. 'Granny Smith' fruit from 2011 were picked slightly firmer and therefore less mature than in 2010. Maturity based on starch breakdown assessed at harvest show that in all three cultivars, 2010 fruit were more mature, being more advanced in starch breakdown despite being harvested much sooner than in 2011. In agreement with the firmness data, no difference in starch breakdown was observed for 'Starking' inner and outer canopy fruit, while starch breakdown was higher for inner canopy fruit for 'Golden Delicious' and 'Granny Smith' suggesting that these were more advanced in maturity. Bearing in mind that these outer canopy fruit were found to have higher TSS and higher DMC, these fruit may have higher starch concentration at harvest and this may explain why starch breakdown was more advanced for 'Golden Delicious' and 'Granny Smith' inner canopy fruit. Barrit et al. (1987) found that fruit at the top of the canopy, receiving more light, had higher starch levels compared to fruit in the middle and bottom positions of the canopy. Seeley et al. (1980) made similar observations as they found a positive correlation between light levels and starch concentration. Fruits under heavy shading were found to contain small amounts of starch in a thin ring near the fruit peel while fruit that were on fully exposed limbs had starch distributed throughout the cortex (Robinson et al., 1983). In a later study, the effect of light environment and harvest time on ‘Delicious’ apples, starch ratings were not consistently affected by light levels within the canopy and the researchers concluded that starch rating is not influenced by light levels in the canopy (Campbell and Marini, 1992). Starch maturity indexing was found to not be significantly different for shaded and sun exposed fruit in ‘Gala’ apples in a study investigating how sunlight affects internal ring cracking (Opara et al., 1998).

Hue angle is a general numerical measurement for colour, in this case development of redder colour. Outer canopy ‘Starking’ fruit were redder on their reddest side compared to inner canopy fruit. ‘Golden Delicious’ and ‘Granny Smith’ formed a red blush on the side of the fruit most exposed to direct sunlight. Fruit appearance is therefore influenced by canopy position mainly due to the difference in sunlight exposure between shaded and sun exposed fruit. Shaded fruit did not develop a red blush in ‘Golden Delicious’ and ‘Granny Smith’ and for ‘Starking’ these fruit were of a pale red colour. This is because the higher irradiance in the outer canopy enhances anthocyanin development in apple peel (Awad, 2001; Steyn et al., 2004).

Descriptive sensory analysis

The differences between inside and outside canopy fruit were clearly discernible by the trained panel of judges – some very small differences of only a few points on the 100 mm intensity scale. Some of these small differences between inside and outside canopy fruit were statistically different and the variances between the judges for each attribute were small.

Apple flavour was found to be enhanced for outer canopy fruit for ‘Golden Delicious’ and ‘Starking’. Flavour is a complex subject that is determined by how taste and olfactory sensations act simultaneously on the brain (Spence et al., 2010; Yahia, 1994). Apple flavour including aroma is primarily a result of a complex mixture of esters, alcohols, aldehydes and ketones (Dixon and Hewett, 2000) and differences between cultivars are immense (Poll, 1981). It is also perceived in terms of sweetness, sourness, bitterness, astringency (Yahia, 1994). In a study on peaches, flavour was found to be influenced by environmental conditions in that every 1 ºC increase in temperature resulted in a 0.17 unit increase in consumer liking on a 5 point hedonic scale (Topp and Sherman, 1989). In postharvest studies, low temperatures are reported to delay the development of aroma volatiles in apples (Yahia, 1994) and intermittent warming of apples increased the production of volatiles (Wills and McGlasson, 1970). A review on apple flavour by Yahia (1994) reports on how apple flavour is influenced by several pre-harvest and postharvest factors. However, there appears to be a need for research on the influence of canopy position on apple flavour. Since, from these previous reports, temperature appears to be the dominant climatic factor, it may be that the higher temperatures outer canopy fruit are exposed to enhance production of volatiles, as well as the various taste factors, e.g. higher TSS, may also be contributing factors to the flavour of the outer canopy fruit apple. For 'Granny Smith', Pearson's significant correlation coefficients were found between apple flavour and sweet taste at r^2 = 0.980. Interestingly for 'Starking' and 'Golden Delicious' apples significant correlation coefficients were found between apple flavour and juiciness at r^2 = 0.970 and r^2 = 0.974, respectively.

Sweet taste was more pronounced in outer canopy fruit while sour taste was more pronounced in inner canopy fruit for all cultivars. This corresponds well with the chemical data where TSS and the TSS:TA ratio were higher for outer canopy fruit in comparison to inner canopy fruit. There appears to be a weaker relationship between TA and the sourness attribute. Although sourness was perceived to be higher for inner canopy fruit in both seasons, TA only corresponded to this in 2010. This is most probably due to fact that in 2010 all three cultivars were more advanced in maturity as discussed in the previous physiochemical section. Significant Pearson correlation coefficients were found between TA and starch breakdown were correlated at r^2 = 0.959 in 'Granny Smith' apples, emphasizing the importance of maturity on fruit quality. Significant correlations were also found between DMC and sweet taste attribute at r^2 = 0.963; as well as a negative correlation between sourness and TSS at r^2 = -0.974 in 'Starking' apples.

Textural attributes were influenced by canopy position. 'Starking' outer canopy fruit were juicier while no differences in any other textural attributes were observed between inner and outer canopy 'Starking' fruit. This agrees with absence of a canopy difference in the physiochemical measure of firmness for this cultivar. 'Granny Smith' and 'Golden Delicious' outer canopy fruit were found to be harder than inner canopy fruit in both years. This corresponds to firmness measured in the physiochemical observations. 'Golden Delicious' fruit from the outer canopy was also found to be juicier, more crisp and crunchy. Hence, the outer canopy 'Golden Delicious' fruit were perceived to be higher in all textural attributes than the inner canopy fruit. Instrumental firmness measurements correlated significantly with textural attributes for 'Golden Delicious' apples with correlations between firmness and crispness at $r^2 = 0.983$; firmness and crunchiness at $r^2 = 0.975$; and, firmness and hardness at $r^2 = 0.981$.

Consumer preference

The consumer preference for the taste of outer canopy fruit is due to the internal chemical quality, as well as the eating quality of the fruit. The results of the chemical and sensory analysis do explain the reason why consumers preferred the taste of outer canopy fruit over inner canopy fruit. Outer canopy fruit were higher in TSS, TSS:TA ratio, DMC and were perceived to be sweeter in all three cultivars. Textural differences were cultivar-specific, with 'Starking' showing no differences in texture compared to 'Golden Delicious' where outer canopy fruit were higher in all textural attributes. Enhanced apple flavour for 'Starking' and 'Golden Delicious' outer canopy fruit is another reason why outer canopy fruit were preferred for these cultivars. In agreement with previous studies on consumer eating quality preferences in apples (Harker, 2001; Jackson, 2003), PCA bi-plots show that taste-liking is strongly associated with TSS; TSS:TA ratio and apple flavour. In addition, this research confirms that DMC can be used as an indicator of apple fruit quality within a cultivar, as was suggested by Palmer et al. (2010). 'Starking' and 'Golden Delicious' PCAs clearly show that outer canopy fruit were more associated with textural attributes compared to inner canopy fruit that associated with sourness and TA. The importance of fruit firmness and texture in consumer preference has been reported (Harker et al., 2008, Jaeger et al., 1998) where consumers indicated that they prefer crisp, juicy apples as well as sweet taste and apple flavour and to a lesser extent sour tasting fruit. The results are similar to the consumer's opinions of various apple characteristics in this study. Daillant-Spinnler et al. (1996) found that red cultivars were associated with sweet sensory descriptors and green cultivars were associated with sour or acidic taste descriptors. These results are echoed here. The inner canopy fruit did not develop much red colour and were associated with sourness, while outer canopy fruit, which developed redder colour, were associated with sweet sensory descriptors. Significant Pearson's correlation coefficients at 0.05 significance level were also found between taste liking and TSS:TA ratio at $r^2 = 0.976$ and a negative correlation between taste liking and sourness at $r^2 = -0.966$ for 'Golden Delicious' apples. For 'Granny Smith' similarly a negative correlation between taste liking and sourness attribute at r^2 = -0.987 and a positive correlation between taste liking and TSS at r^2 = 0.966.

The assessment of consumer preference of apple appearance showed that for ‘Starking’, the appearance of outer canopy fruit was preferred, most likely due to the redder colour of these fruit. For this cultivar, fruit with insufficient red colour are downgraded and consumers are likely to associate redder colour with increased quality. Improving red colouration of apple fruit has been a research priority for fruit technologists and various methods such as using reflective films and fruit bagging (Ju, 1998; Ju et al., 1999) have been devised to ensure better red colouration of apples. Appearance liking and taste liking for consumers correspond for ‘Starking’ where consumers liked both the taste and appearance of the outer canopy fruit.

The appearance of the blushed ‘Golden Delicious’ and ‘Granny Smith’ outer canopy fruit were preferred less by consumers compared to the non-blushed inner canopy fruit. For these two cultivars, consumers preferred the taste of outer canopy fruit, but indicated a higher preference for the appearance of inner canopy fruit. The negative correlation between taste liking and preference for appearance is clear in the PCA (Fig. 3, 4). Consumers did not know which treatments they tasted as peeled fruit were used in the assessments and taste and photo assessments were carried out independently. It has been reported that appearance provides the first impression of the fruit that will either attract or repel the consumer (Kays, 1998). ‘Granny Smith’ and ‘Golden Delicious’ are traditionally marketed without a red blush. Consumers are generally not familiar with the blushed form of these cultivars. Therefore it is highly likely that a consumer would be reluctant to indicate preference for a product they are not well familiar with. Preference for taste, however, revealed that these very same consumers preferred the taste of the blushed outer canopy fruit due to the sweeter taste and higher apple flavour of these fruit. However, the small consumer segment that prefers sour and dislikes sweet apples (Anreza van der Merwe, unpublished data) may display a taste preference for inner canopy fruit. Outer canopy ‘Golden Delicious’ and ‘Granny Smith’ fruit that develop a red blush is mostly downgraded for juicing or other processing needs. This research has revealed that the basis for culling blushed outer canopy fruit is purely aesthetic, as these fruit tasted better than inner canopy fruit and were preferred by consumers. The reason consumers preferred the appearance of inner canopy fruit is probably because these cultivars are marketed without the red blush (Hirst et al., 1990) thereby illustrating the importance of other factors such as marketing and familiarity with the product on consumer preference. It has been found that apart from appearance and taste attributes, familiarity, habit, social interactions, media, advertising, cost, availability, time constraints and personal ideology also play a role in consumer preference (Pollard et al., 2002).

Fruit colour in consumer preference

A question remains as to the reliability of apple peel colour as an indicator of fruit eating and internal quality. In nature, fruit colour has important visual functions in attracting consumers and signalling fruit maturity, nutrition and health benefits as well as taste (Steyn, 2012). For example, in 'Brooks' cherries, consumer acceptance was related to cherry peel colour and light red cherries had the lowest consumer acceptance while dark red cherries had the highest consumer acceptance (Crisosto et al., 2002). The darker red cherries were found to be sweeter with enhanced cherry flavour. These results are echoed in 'Starking' apples in this research, where redder 'Starking' were high in TSS, TSS:TA ratio, sweetness and flavour perception and were better preferred by consumers. Johnson and Clydesdale (1982) discovered that when they coloured odourless solutions red, consumers easily detected the presence of sucrose than when they were uncoloured. They also found that increasing the red colour intensity of odourless and cherry flavoured solutions significantly increased sweetness perception. The transition and natural colour progression from green to yellow and red in many fruits, may explain why red colouration is associated with sweetness and green colouration in foods is more associated with sourness (Maga, 1974). For 'Starking', a striped red cultivar, increasing red colour coverage on the fruit increases consumer preference. The reason for this may be that red colour increases sweetness perception as has been observed in various beverages including aqueous solutions (Johnson and Clydesdale, 1982), strawberry flavoured beverages (Johnson et al., 1983) and cherry flavoured beverages (Johnson et al., 1982). Hence it seems that the extent of red pigmentation provides a true signal to consumers of the eating quality of the fruit.

Blushed 'Granny Smith' also had better eating quality and a higher consumer taste preference. However, consumers preferred the appearance of the greener inner canopy fruit over the blushed outer canopy fruit. 'Granny Smith' is one of the most familiar apple cultivars and is distinguished from other cultivars by its tartness (Warrington, 1994), therefore consumers are most probably drawn to this cultivar for this characteristic. It is possible that a fully green coloured 'Granny Smith' best signals to the consumer the chemical and sensory qualities they are looking for in the fruit. . It is clear that the main hindrance for the consumer was that the blushed 'Granny Smith' and 'Golden Delicious' were inappropriately coloured, based on their expectations and previous experience. Therefore, even though better tasting, the appearance of these fruit received a lower preference score. In a study aimed at correlating taste and visual assessments of apples, it was found that 'Red Delicious' apples were rejected on appearance based on a bad reputation that they have little overall taste. However, on taste assessments of these fruit, consumers liked the taste of the apples (Schechter, 2010). For 'Jonagold' apples, consumers liked their appearance, but did not like their taste. This may be because 'Jonagold', a tart apple, is mistaken for sweet apple due to its red appearance (Schechter, 2010). These results indicate that consumers may struggle to visually distinguish better tasting apples; however, it also shows that there are learned associations between apple colour and taste. Daillant-Spinnler et al. (1996) found that consumers associated green apples with sour sensory attributes and red apples with sweet sensory attributes. In a Danish study with children it was found that those who reported that they like red apples indeed had high preference for the taste of the red apples, and those who reported liking for green apples had a high preference for the taste of green apples, thus showing consistency. If children preferred red apples they would not prefer green apples (Thybo et al., 2004). This illustrates that even at young ages people have learnt associations and expectations of fruit based on their colour. The importance of colour on flavour and taste perceptions of various foods, beverages and yoghurts has also been reported (Spence et al., 2010, Calvo et al., 2001). When consumers were asked to taste flavoured drinks, appropriate colouring (lime flavoured coloured green) resulted in higher correct identification of flavour while inappropriate colour, e.g. lime flavour drink coloured orange, resulted in lower percentage of correct responses (Zampini et al., 2007).

Fruit colour seems to be a good indicator of eating quality, as has been observed in this research. The redder fruit from the outer canopy contained higher TSS and were preferred by consumers on taste compared to inner canopy fruit that did not or developed less red colour. In the same vein, consumer's preference for apples does not reside in fruit colour alone (Steyn, 2012). Other factors such as the consumer's previous experiences and learned associations as well as the fruit consumers grew up eating all have a strong bearing on consumer preference (Pollard et al., 2002).

CONCLUSION

This research has revealed that inner and outer canopy fruit do differ in their appearance, chemical and sensory characteristics and these differences, though small in some cases, affect consumer liking. These differences are primarily due to the microclimatic differences between the inner and outer canopy. Consumers prefer the eating quality and taste of outer canopy fruit compared to inner canopy fruit in all three cultivars. The appearance of outer canopy fruit was not preferred in the traditionally “green” cultivars and this may be due to the unfamiliarity of consumers with this presentation of the fruit. It is interesting to note that the apples with the best eating quality are culled in the case of ‘Golden Delicious’ and ‘Granny Smith’. However, industry could stand to benefit from marketing the blushed (outer canopy) fruit of these two cultivars. Apple fruit that develop redder colour do have better internal quality. Colour is an important factor in fruit quality and consumer preference; however, apart from colour, other factors such as marketing and familiarity also play an important role in consumer preference for appearance. We found that consumers did gravitate towards the fruit colour they are familiar with, for example, a uniform green coloured ‘Granny Smith’ apple.

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Table 1. The effect of canopy position (inner canopy versus outer canopy fruit) on hue angles of outer and inner canopy 'Golden Delicious', 'Starking' and 'Granny Smith' fruit harvested in 2010 and 2011 at Vastrap Farm in Ceres, Western Cape, South Africa; measured after approximately one month storage at -0.5 ^{0}C.

Year	**Position**	**Golden Delicious (Hue angle)**	**Starking (Hue angle)**	**Granny Smith (Hue angle)**
2010	Inside Canopy	112.3 a[z]	64.7 a	118.3 a
	Outside Canopy	81.3 c	35.4 b	81.0 d
2011	Inside Canopy	112.2 a	58.1 a	114.1 b
	Outside Canopy	94.9 b	21.3 b	89.8 c
P value				
Year		*<0.0001*	*0.0003*	*0.0525*
Position		*<0.0001*	*<0.0001*	*<0.0001*
Y*P		*<0.0001*	*0.1292*	*<0.0001*

[z] Means with different letters differ significantly at P<0.05 in the column.

Table. 2 The effect of canopy position (inner canopy versus outer canopy fruit) on the % starch breakdown: SB (%) of ‘Golden Delicious’, ‘Granny Smith’ and ‘Starking’ harvested in 2010 and 2011 at Vastrap Farm in Ceres, Western Cape, South Africa measured on the day of harvest.

Year	Canopy Position	Golden Delicious SB (%)	Granny Smith SB (%)	Starking SB (%)
2010	Inside	65.0 a[z]	63.0 a	63.5 a
	Outside	48.0 b	40.5 b	55.2 a
2011	Inside	59.0 a	30.3 bc	16.1 b
	Outside	35.0 c	25.6 c	30.1 b
P value				
Year		*0.0004*	*<0.0001*	*<0.0001*
Position		*<0.0001*	*0.0048*	*0.0248*
Y*P		*0.1396*	*0.0278*	*0.0820*

[z] Means with different letters differ significantly at P<0.05 in the column.

Table 3. The effect of canopy position (inner canopy versus outer canopy fruit) on firmness, titratable acidity (TA), total soluble solids (TSS) and TSS:TA ratio for 'Golden Delicious' harvested in 2010 and 2011 at Vastrap Farm in Ceres, Western Cape, South Africa measured after approximately one month storage at -0.5 ^{0}C.

Year	**Canopy Position**	**Firmness (N)**	**TSS Brix (%)**	**TA Malic acid (%)**	**TSS:TA**
2010	Inside	61.7 d[z]	14.2 b	0.43 a	33.0 b
	Outside	63.7 c	15.9 a	0.39 b	40.7 a
2011	Inside	73.5 b	11.2 d	0.41 a	26.9 c
	Outside	79.4 a	13.4 c	0.42 a	31.8 b
P value					
Year		*<0.0001*	*<0.0001*	*0.3369*	*<0.0001*
Position		*<0.0001*	*<0.0001*	*0.0522*	*<0.0001*
Y*P		*0.0486*	*0.2701*	*0.0079*	*0.1769*

[z] Means with different letters differ significantly at P<0.05 in the column.

Table 4. The effect of canopy position (inner canopy versus outer canopy fruit) on firmness, titratable acidity (TA), total soluble solids (TSS) and TSS:TA ratio for 'Starking' harvested in 2010 and 2011 at Vastrap Farm in Ceres, Western Cape, South Africa measured after approximately one month storage at -0.5 ^{0}C.

Year	**Canopy Position**	**Firmness (N)**	**TSS Brix (%)**	**TA Malic acid (%)**	**TSS:TA**
2010	Inside	82.3 ^{NS}	12.8 b ^{z}	0.27 a	47.7 b
	Outside	82.3	14.5 a	0.21 b	69.9 a
2011	Inside	82.3	10.4 c	0.28 a	36.5 c
	Outside	82.3	13.0 b	0.27 a	48.4 b
P value					
Year		*0.9340*	*<0.0001*	*<0.0001*	*<0.0001*
Position		*0.9162*	*<0.0001*	*<0.0001*	*<0.0001*
Y*P		*0.7748*	*0.0076*	*0.0009*	*0.0078*

^{NS} Non-significant

^{z} Means with different letters differ significantly at P<0.05 in the column.

Table 5. The effect of canopy position (inner canopy versus outer canopy fruit) on firmness, titratable acidity, TSS and TSS:TA ratio for 'Granny Smith' harvested in 2010 and 2011 at Vastrap Farm in Ceres, Western Cape, South Africa measured after approximately one month storage at -0.5 ^{0}C.

Year	Canopy Position	Firmness (N)	TSS Brix (%)	TA Malic acid (%)	TSS:TA
2010	Inside	76.4 c[z]	11.3 b	0.85 a	13.3 c
	Outside	84.3 a	13.1 a	0.75 b	17.4 ab
2011	Inside	79.4 b	11.5 b	0.67 c	17.0 b
	Outside	86.2 a	12.9 a	0.71 bc	18.3 a
P value					
Year		*0.0283*	*0.8243*	*<0.0001*	*<0.0001*
Position		*<0.0001*	*<0.0001*	*0.1340*	*<0.0001*
Y*P		*0.4726*	*0.0682*	*0.0017*	*0.0004*

[z] Means with different letters differ significantly at P<0.05 in the column.

Table 6. The effect of canopy position (inner canopy versus outer canopy fruit) on the dry matter concentration: DMC (%) of 'Golden Delicious', 'Granny Smith' and 'Starking' harvested in 2010 and 2011 at Vastrap Farm in Ceres, Western Cape, South Africa measured after approximately one month storage at -0.5 ^{0}C.

Year	**Canopy Position**	**Golden Delicious DMC (%)**	**Granny Smith DMC (%)**	**Starking DMC (%)**
Year	2010	15.4 a[z]	11.5 b	13.3 b
	2011	14.3 b	14.6 a	15.0 a
Canopy Position	Inside	13.9 b	12.3 b	13.1 b
	Outside	15.8 a	14.1 a	15.3 a
P value				
Year		*0.0300*	*<0.0001*	*0.0001*
Position		*0.0004*	*<0.0001*	*<0.0001*
Y*P		*0.7370*	*0.3837*	*0.2236*

[z] Means with different letters differ significantly at P<0.05 in the column.

Table 7. The effect of canopy position (inner canopy versus outer canopy fruit) on the overall means of sensory characteristics of 'Golden Delicious' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa; measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2010 and 2011.

		Apple flavour	**Sweet taste**	**Sour Taste**	**Crispness**	**Crunchiness**	**Hardness**	**Juiciness**
Year	2010	49 b[z]	52 [NS]	38 b	41 b	33 b	32 b	49 b
	2011	58 a	54	43 a	58 a	58 a	55 a	59 a
Canopy position	Inside	52 b	50 b	43 a	49 b	45 b	44 b	53 b
	Outside	56 a	57 a	38 b	52 a	47 a	46 a	55 a
P value								
Year		*<0.0001*	*0.1444*	*0.0025*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Position		*<0.0001*	*<0.0001*	*0.0100*	*0.0073*	*0.0046*	*0.0002*	*0.0169*
Y*P		*0.0504*	*0.6987*	*0.7212*	*0.9798*	*0.4639*	*0.5450*	*0.5330*

[NS] Non-significant

[z] Treatments with different letters differ significant at P<0.05

Table 8. The effect of canopy position (inner canopy versus outer canopy fruit) on the overall means of sensory characteristics of 'Granny Smith' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa; measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2010 and 2011.

		Apple flavour	**Sweet taste**	**Sour taste**	**Crispness**	**Hardness**	**Juiciness**
Year	2010	49 b[z]	35 b	73 a	69 a	62 a	69 a
	2011	59 a	56 a	56 b	64 b	60 b	63 b
Canopy position	Inside	54 [NS]	44 b	67 a	66 [NS]	59 b	65 [NS]
	Outside	55	48 a	61 b	67	62 a	66
P value							
Year		*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0034*	*<0.0001*
Position		*0.0785*	*0.0058*	*0.0077*	*0.2765*	*0.0003*	*0.6534*
Y*P		*0.2713*	*0.1864*	*0.5887*	*0.1699*	*0.2436*	*0.2844*

[NS] Non-significant

[z] Treatments with different letters differ significant at P<0.05

Table 9**.** The effect of canopy position (inner canopy versus outer canopy fruit) on the crunchiness of 'Granny Smith' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa; measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2010 and 2011.

Year	**Canopy Position**	**Granny Smith Crunchiness**
2010	Inside	49 c[z]
	Outside	49 c
2011	Inside	63 b
	Outside	65 a
P value		
Year		*<0.0001*
Position		*0.1342*
Y*P		*0.0265*

[z] Means with different letters differ significantly at P<0.05

Table 10. The effect of canopy position (inner canopy versus outer canopy fruit) on the overall means of sensory characteristics of ‘Starking’ apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa; measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2010 and 2011.

		Apple flavour	**Sweet taste**	**Sour taste**	**Crispness**	**Crunchiness**	**Hardness**
Year	2010	34 b [z]	44 b	26 b	50 b	39 b	39 b
	2011	52 a	57 a	33 a	61 a	60 a	55 a
Canopy position	Inside	39 b	42 b	29 a	56 [NS]	50 [NS]	48 [NS]
	Outside	49 a	60 a	25 b	56	51	47
P value							
Year		*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Position		*<0.0001*	*<0.0001*	*0.0012*	*0.5453*	*0.4577*	*0.3965*
Y*P		*0.2183*	*0.1081*	*0.2159*	*0.4581*	*0.0841*	*0.3165*

[NS] Non-significant

[z] Treatments with different letters differ significant at P<0.05

Table 11. The effect of canopy position (inner canopy versus outer canopy fruit) on the juiciness of 'Starking' apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa; measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2010 and 2011.

Year	**Canopy Position**	**Starking Juiciness**
2010	Inside	55 c[z]
	Outside	57 bc
2011	Inside	59 b
	Outside	64 a
P value		
Year		*<0.0001*
Position		*0.0003*
Y*P		*0.0455*

[z] Means with different letters differ significantly at P<0.05.

Table 12. The effect of canopy position (inner canopy versus outer canopy fruit) on the taste and appearance liking of Stellenbosch consumers for ‘Golden Delicious’, ‘Starking’ and ‘Granny Smith’ apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa in 2010 and 2011.

		Golden Delicious		Granny Smith		Starking	
		Taste	Appearance	Taste	Appearance	Taste	Appearance
Year	2010	6.8 a	6.5 [NS]	6.5 [NS]	6.5 [NS]	7.1 a	6.4 [NS]
	2011	6.4 b	6.6	6.5	6.6	5.9 b	6.9
Canopy position	Inside	6.4 b	7.1 a	6.4 b	6.9 a	6.1 b	5.9 b
	Outside	6.8 a	6.0 b	6.7 a	6.2 b	7.0 a	7.4 a
P value							
Year		*0.0087*	*0.2475*	*0.8425*	*0.6736*	*<0.0001*	*0.0653*
Position		*0.0008*	*<0.0001*	*0.0133*	*<0.0001*	*<0.0001*	*<0.0001*
Y*P		*0.3277*	*0.5078*	*0.1049*	*0.4797*	*0.7275*	*0.0980*

[NS] Non-significant

[z] Treatments with different letters differ significant at P<0.05

Table 13. Consumers opinions data for 2010 and 2011 on the degree of liking for various apple sensory characteristics that are considered most important for consumers.

Sensory characteristics	**2010**	**2011**
Crisp apples	7.9 a[z]	-
Hard apples	-	7.0 b
Juicy apples	7.7 a	7.1 ab
Sweet tasting apples	7.4 b	6.5 c
Apple flavour	7.3 b	7.3 a
Sour tasting apples	6.3 c	4.8 d
Mealy apples	-	2.1 e
P value	*<0.0001*	*<0.0001*

[z] Means with different letters differ significantly at P<0.05.

Table 14. Consumers opinions data for 2010 and 2011 on the degree of liking for apple peel appearance for cultivars evaluated in this research as well as the general appearance characteristics in apples.

Apple peel appearance	**2010**		**2011**	
Golden Delicious	6.7	a [z]	6.7	a
Blush apples	6.4	ab	6.5	ab
Red apple	6.4	ab	6.2	bc
Starking	6.3	abc	6.1	c
Green apples	6.2	bc	6.5	ab
Granny Smith	6.0	c	6.2	bc
P value	*0.0231*		*0.0084*	

[z] Means with different letters differ significantly at P<0.05.

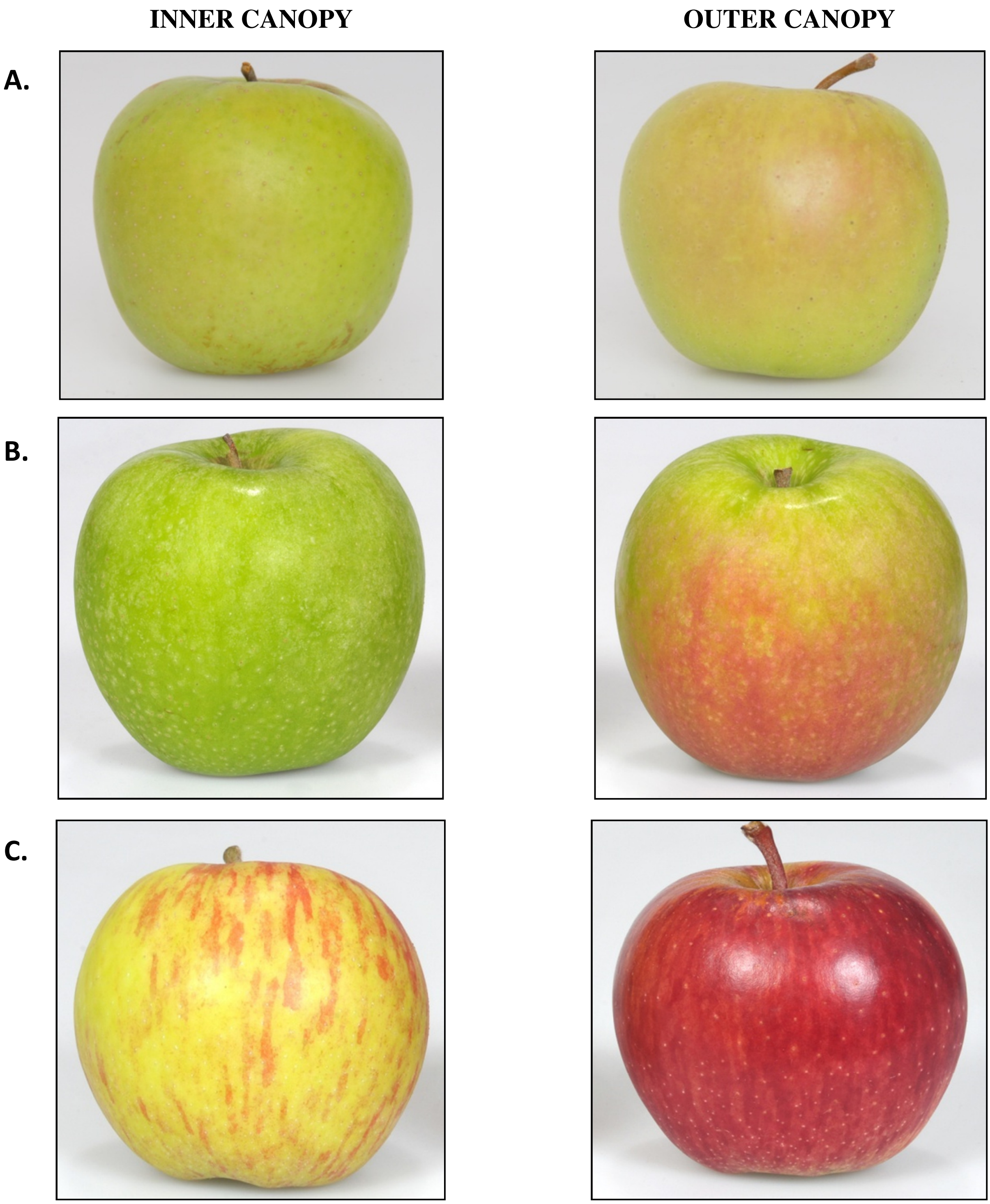

Fig. 1. Images of inner and outer canopy fruit of 'Golden Delicious' (A), 'Granny Smith' (B) and 'Starking' (C) harvested from Ceres.

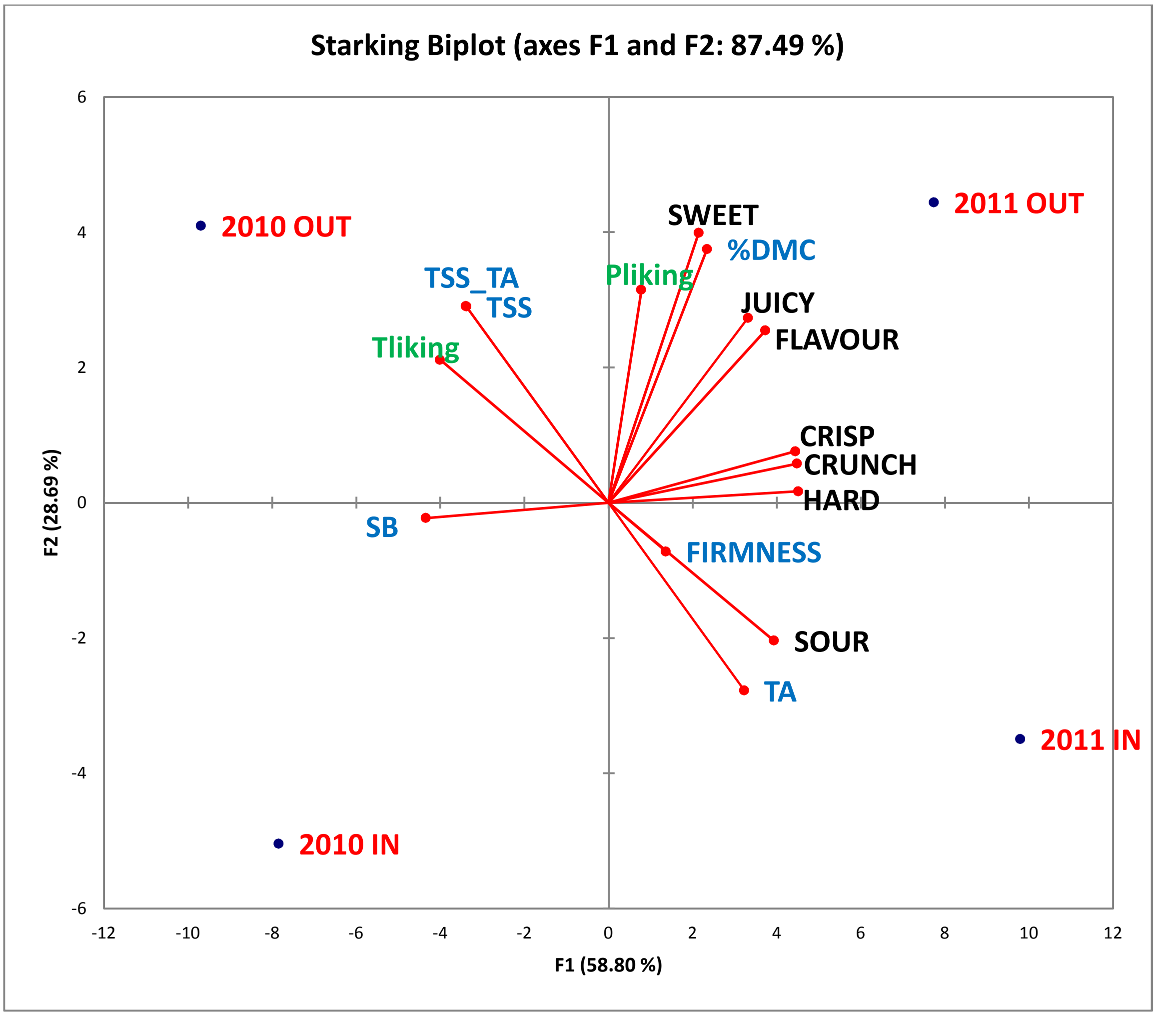

Fig. 2. Principal Component Analysis (PCA) bi-plot indicating the position of consumer preference for taste (Tliking) and photo liking (Pliking) in relation to the sensory attributes (black) and chemical composition (blue) of inside and outside canopy 'Starking' apple fruit harvested in the years 2010 and 2011 (red) where SB – starch breakdown, DMC - dry matter concentration (%).

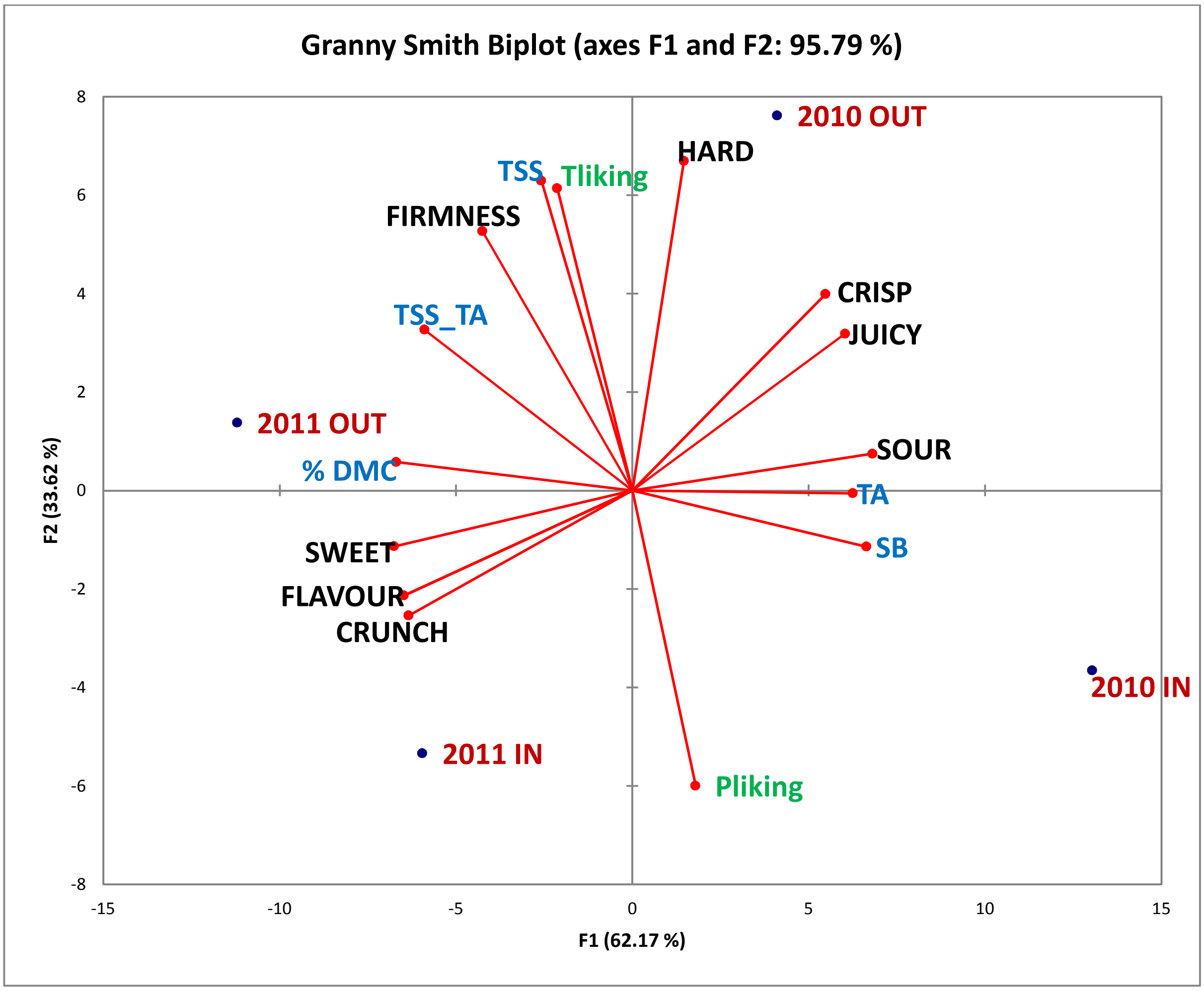

Fig. 3. Principal Component Analysis (PCA) bi-plot indicating the position of consumer preference for taste (Tliking) and photo liking (Pliking) in relation to the sensory attributes (black) and chemical composition (blue) of inside and outside canopy 'Granny Smith' apple fruit harvested in the years 2010 and 2011 (red) where SB – starch breakdown, DMC - dry matter concentration (%).

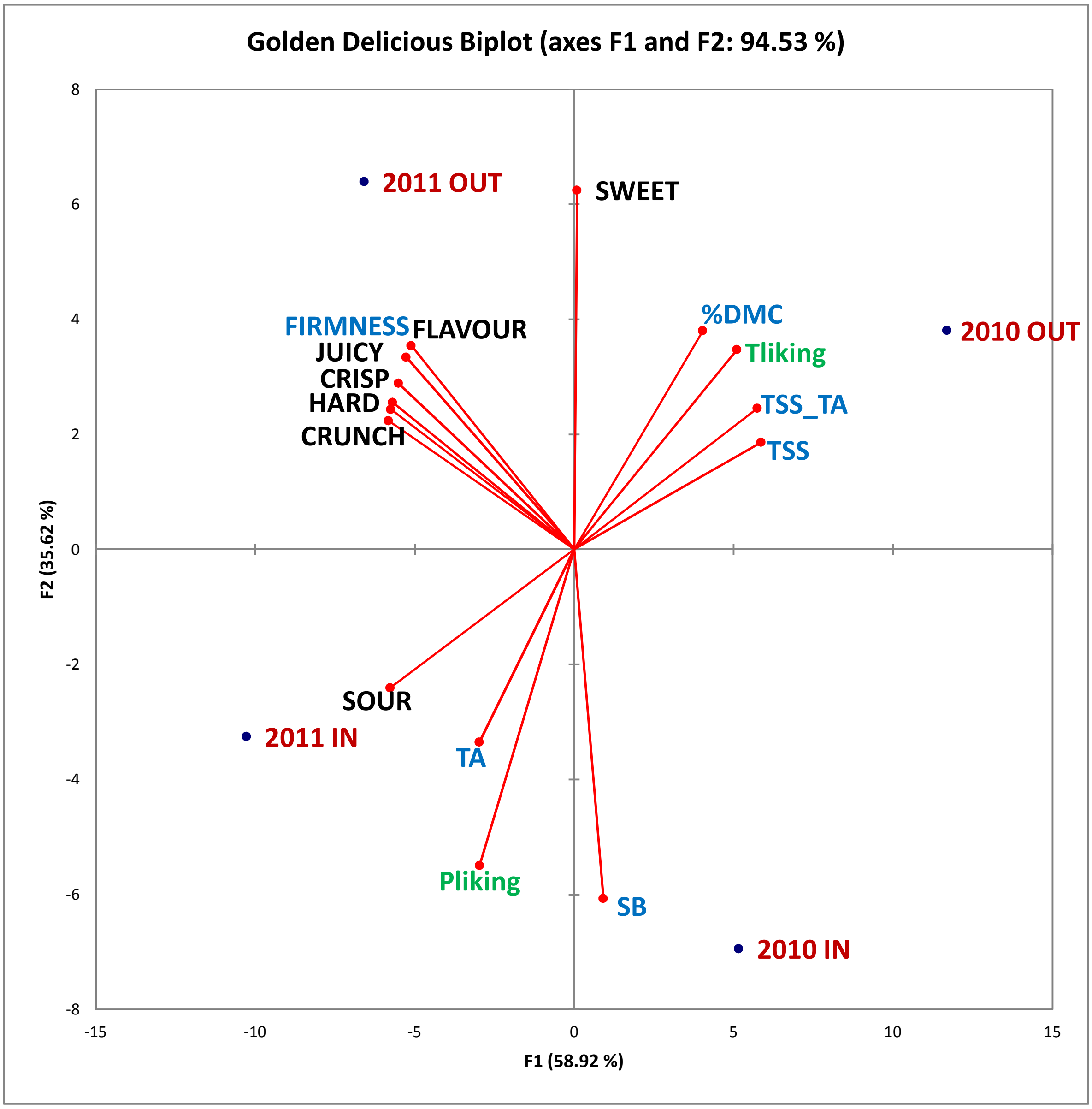

Fig. 4. Principal Component Analysis (PCA) bi-plot indicating the position of consumer preference for taste (Tliking) and photo liking (Pliking) in relation to the sensory attributes (black) and chemical composition (blue) of inside and outside canopy 'Golden Delicious' apple fruit harvested in the years 2010 and 2011 (red) where SB – starch breakdown, DMC - dry matter concentration (%).

<table>
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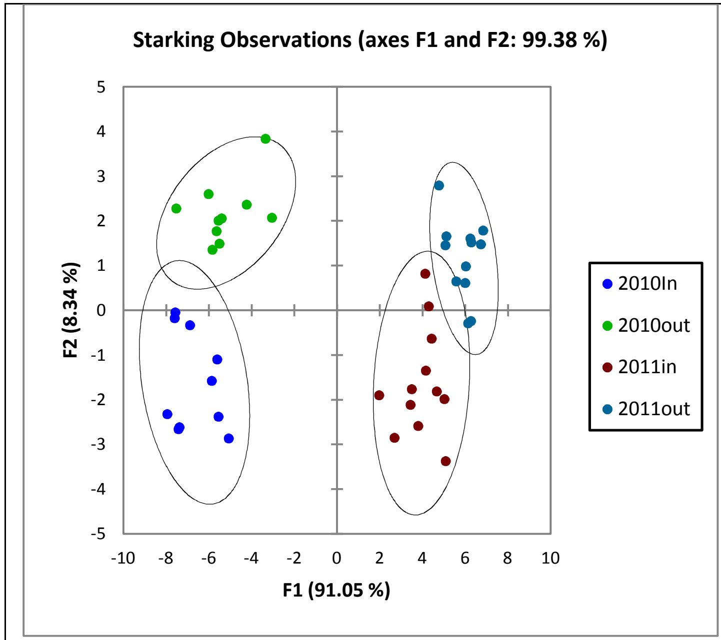
<td>

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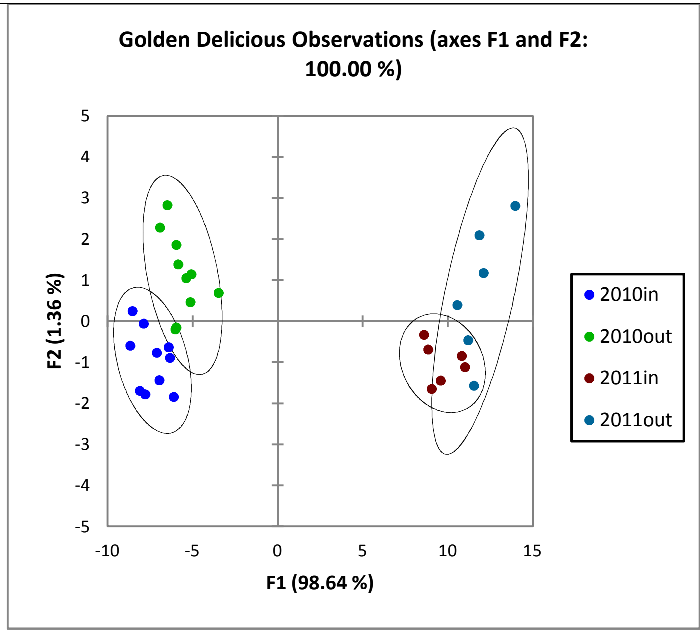
<td>

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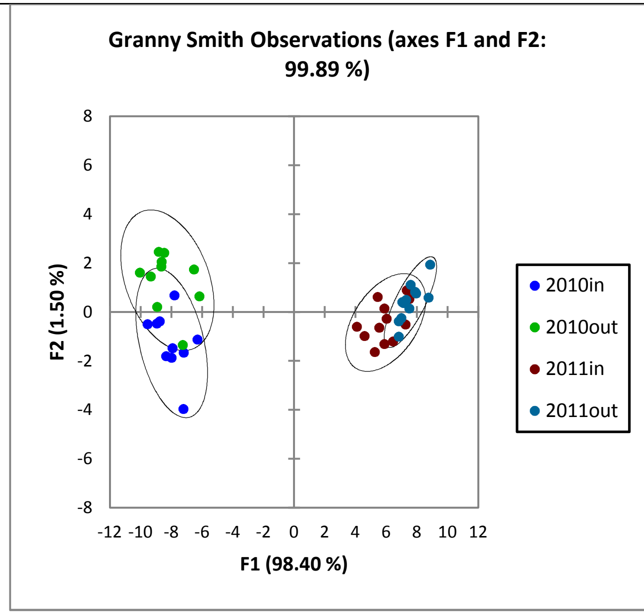
<td>

C</td>
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<tr>
<td>Significant discriminating functions along the F1 and F2 axes:
F1: flavour, crunchiness, juiciness
F2: sweetness</td>
<td>Significant discriminating functions along the F1 and F2 axes:

F1: crunchiness
F2: sweetness</td>
<td>Significant discriminating functions along the F1 and F2 axes:
F1: crispness, crunchiness, juiciness
F2: sweetness, hardness</td>
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</table>

Fig. 5. Discriminant analysis (DA) observation maps for **A.** ‘Starking’ **B.** ‘Golden Delicious’ and **C.** ‘Granny Smith’ based on the results of the descriptive sensory analysis. The coloured dots inside each cluster resemble the replicates of each treatment as described in the key.

THE CONSISTENCY OF THE RELATIONSHIP BETWEEN CANOPY POSITION AND FRUIT QUALITY OF GOLDEN DELICIOUS APPLES FROM DIFFERENT ORCHARDS

ABSTRACT

Outer canopy apple fruit, which experience higher light and temperature conditions, are higher in total soluble solids (TSS) and dry matter concentration (DMC), lower in acids and develop redder colouration on the sun exposed side compared to inner canopy fruit. These fruit have superior eating quality resulting in higher taste preference from consumers. In this study we endeavoured to establish the consistency of these results by assessing instrumental quality parameters, sensory attributes and consumer preference for taste and appearance for inner and outer canopy 'Golden Delicious' fruit from five farms in the same agro-ecological region . The results of the physiochemical and sensory analyses were consistent with previous findings. Consumers could distinguish between inner and outer canopy fruit from orchards with wider tree spacing and bigger canopies, preferring the outer canopy fruit. However, at a higher planting density and smaller canopy size, consumers failed to distinguish between the treatments and no taste preference differences were observed for inner and outer canopy fruit. Therefore, it would generally not be necessary to separate inner and outer canopy fruit for marketing purposes. Preferences for appearance show that even though consumers generally shun the appearance of blushed 'Golden Delicious', a fruit with the correct blush intensity may be acceptable to consumers. Considering that the taste preference for blushed 'Golden Delicious' fruit is similar or higher than for inner canopy fruit, this product could be quite successful when sold in a niche market.

INTRODUCTION

Fruit quality is pertinent to consumer satisfaction. Fruit at different positions in a canopy may differ in quality due to differences in the microclimate within a canopy. The main environmental factors of concern are light and temperature with outer canopy fruit receiving more light and experiencing higher temperatures than inner canopy fruit (Fouché et al., 2010, Paper 1). The effects of canopy microclimate on the chemical and eating quality of apples have been addressed extensively in the previous papers of this study. Outer canopy fruit, which were most exposed to light, had better eating quality and higher taste preference from consumers. Similarly, researchers have also found that outside canopy apples are generally higher in dry matter, soluble solids and reducing sugars concentrations and lower in titratable acidity than inner canopy fruit (Nilsson and Gustavsson, 2007; Paper 2). The apple peel colour, which is influenced by light and temperature (Awad et al., 2001; Gorski and Creasy, 1977; Knee, 1971; Saure, 1990), is also influenced by canopy position (Krishnaprakash et al., 1983). Consumer acceptability of these fruit varied based on consumer familiarity (Paper 2). While darker red 'Starking' were preferred by consumers, a red blush on typically green 'Granny Smith' or yellow 'Golden Delicious', an appearance that is unfamiliar to most consumers, were shunned (Paper 2).

The importance of light harvesting and light penetration in any orchard system cannot be over-emphasized (Wünsche and Lakso, 2000). Fruit flesh dry matter concentration (DMC) is directly linked to light exposure and has been described by Scurlock et al. (1985) as a function of photosynthetic active radiation, percentage of incident light, photosynthetic conversion of light energy into biomass and respiratory carbon loss. DMC is an important holistic measurement as it is an indicator of physiological and metabolic processes that contribute to the final composition of the fruit (Harker et al., 2009). Apples with higher DMC have also been found to have higher consumer preference (Palmer et al., 2010). Hence, the most important means to improve crop quality in any orchard system is to improve DMC (Wünsche and Lakso, 2000).

Orchard location in itself has an impact on apple fruit quality. 'Golden Delicious' apples from orchards at higher altitudes in South Tyrol in Italy have better qualitative characteristics (Rizzolo and Visai, 1990) and contain higher quantities of volatiles (Ferrandino et al., 2001). In an extensive study of location influences on the quality traits of peaches in Australia, it was observed that fruit size, firmness and flavour were particularly affected by mean temperature changes across locations (Topp and Sherman, 1989). Flavour, rated on a five point hedonic scale, was found to increase by 0.17 units for every 1 ºC increase in temperature. However, researchers in Ireland found no differences in soluble solids, titratable acidity, colour, firmness and fruit weight in 'Golden Delicious' assessed from seven different locations over five seasons (Gormley et al., 1981). It seems that factors that vary with season from site to site such as climate, level of pollination and disease incidence have a greater influence on fruit quality than "fixed effects" such as soil type.

In this paper we endeavour to see whether the effect of canopy position on fruit eating quality remains constant between apples harvested at different orchards in the same agro-ecological region. We investigated the chemical and eating quality of inner and outer canopy 'Golden Delicious' fruit harvested from five orchards in the Ceres region and also assessed the consumer preference for the taste and appearance of these apples. These findings will indicate if indeed it is important to differentiate between inside and outside canopy fruit in order to increase consumer satisfaction. This research will also enable the market to assess the potential to develop a niche market for blushed 'Granny Smith' and 'Golden Delicious' apples.

MATERIALS AND METHODS

Plant material

'Golden Delicious' sourced from five farms in the Ceres region (Warm and Koue Bokkeveld) of the Western Cape, South Africa were harvested at commercial maturity (Table 1). The outer canopy fruit were harvested from the top and outermost portion of the canopy. The inner canopy treatments were harvested from the shaded innermost regions in the lower sections of the canopy.

Experimental design

The study was laid out as a 5 x 2 factorial design with two factors, viz. canopy position and farm location. Canopy position had two levels; inner and outer canopy fruit and five farm locations were used. Six replicates of fruit were harvested with a row in the orchard representing a replicate, and 15 outside and inside canopy fruit were harvested for each replicate. Maturity analysis by assessing the percentage starch breakdown was carried out immediately after harvest. One fruit from each replicate (i.e., 6 fruit per canopy position) was randomly selected and assessed in order to determine whether outside and inside fruit differed in maturity. Since the intention was to use inside and outside fruit of comparable maturity, a further harvest would have been scheduled if the fruit differed in maturity. Fruit were stored at -0.5 ^{0}C for approximately one month before commencement of physical measurements, chemical analysis, sensory analysis and consumer panel assessment. Of the fourteen fruit remaining per replicate, four were allocated for the consumer panel, five were allocated for the trained panel, and five fruit were set aside for chemical and physical analyses that consisted of non-destructive and destructive measurements.

Physical measurements

Each fruit was weighed on an electronic balance and fruit diameter was determined using a set of digital Mitutoyo callipers (Mitutoyo, Japan).

The colour in the form of hue angles of each apple was measured using a colorimeter (Konica CR-400, Minolta Co. Ltd., Tokyo, Japan). Peel assessments of blush intensity, sunburn and background colour were measured using the appropriate colour charts (Unifruco Research Services, Bellville, South Africa). Colour was measured on the most exposed sides of fruit.

Percentage dry matter concentration (DMC) was determined by weighing a fresh sample of fruit flesh and oven drying the flesh over a period of 72 hours at 45 ºC. Samples were weighed immediately and returned into the oven for a further 24 hours and re-weighed to ensure all the moisture had evaporated. The following formula was used to calculate DMC as a percentage:

DMC (%) = (dry weight / fresh weight) * 100

Maturity indices were determined as described in Paper 2.

Descriptive sensory analysis

A sensory panel consisting of eight judges, trained using the consensus method (Lawless and Heymann, 1997) and tested for consistency, was used for the sensory analysis. The panel used a 100 mm unstructured line, which ranged from 0% on the far left and 100% on the far right, and this scale was used to analyse the apple slices for the respective sensory attributes. Judges were trained over all replicates for a day before the test. The ten treatments were analysed each day over three consecutive days. There were six replicates in total and two replicates were assessed each day. Samples were presented to judges according to the methodology described in Paper 2.

Consumer preference

Approximately 100 target consumers were sourced. In the analysis consumers were presented with a questionnaire primarily divided into two parts. The first part consisted of the sensory assessment of the apples samples presented to the consumer while the second part was an assessment of apple appearance, primarily colour.

Consumers were presented with 10 peeled apple slices in total (i.e. one slice of the inside and outside treatment from each of the five farms). Apple slices were coded with a three digit random code and presented peeled on open petri dishes in random order. Consumers were asked to taste the fruit and to indicate their liking according to the procedure described in Paper 2. Consumers were also presented with pictures of inside (without blush) and outside (with blush) whole apple fruit from each of the farms and asked to indicate their preference of appearance as described in Paper 2.

Statistical procedures

All data was analysed using analysis of variance (ANOVA) using SAS version 9.2 (SAS Institute Inc., 2008, Cary, NC, USA). The Shapiro-Wilk test was performed to test for non-normality (Shapiro and Wilk, 1965). Student's t-Least Significant Difference was calculated at the 5% significance level to compare treatment means. Pearson's correlations were performed between instrumental, sensory and chemical attributes. Principal Component Analysis (PCA) was carried out to identify variables that associate with certain treatments (Rencher, 2002).

RESULTS

Maturity indices

On all five farms starch breakdown assessed at harvest was significantly higher for the inner canopy fruit (Table 2). The interaction observed between farm and canopy position is brought about by the much lower starch breakdown from Nooitgedacht farm, with the inner canopy treatment from this farm statistically similar to the outer canopy positions of the other farms. Outer canopy fruit were firmer at Nooitgedacht and Crispy farms only, while no significant differences between positions were observed at the other farms as indicated by the significant interaction between canopy position and farm (Table 2).

The results for starch breakdown imply that inner canopy fruit from all farms were of advanced maturity. However, firmness results confirm this in two of the five farms, viz. Nooitgedacht and Crispy; while the rest of the farms showed no differences in maturity for inner and canopy treatments.

Fruit weight and diameter

Inner and outer canopy fruit did not differ in both fruit weight and diameter, although differences were observed between the farms (Table 3). The smallest fruit were harvested from Nooitgedacht farm followed by Kromfontein and Lindeshof farms with the biggest fruit coming from Vastrap and Crispy farms.

Physiochemical measurements

No differences in density were observed between both farms and canopy positions (Table 4). Outer canopy fruit were of higher DMC and ca 2º BRIX higher in TSS. These fruit were lower in TA concentration and the TSS:TA ratio was also higher for outer canopy fruit. These variables also differed significantly between the farms. DMC was highest for Nooitgedacht and Vastrap farms in that order while Crispy, Lindeshof and Kromfontein were all statistically similar. TSS was distinctly highest in fruit from Nooitgedacht, followed by Vastrap and Crispy farms between which there was no significant difference. The farms with the lowest TSS concentrations were Kromfontein and Lindeshof. TA was highest for Crispy apples followed by Vastrap, Kromfontein, Lindeshof and Nooitgedacht, descending in that order. Fruit from Nooitgedacht had the highest TSS:TA ratio while no differences were observed between the other farms (Table 4).

Colour measurements

Colour measurements were taken on the best (reddest or greenest for outer and inner canopy fruit, respectively) coloured side of the apple. No differences in ground colour were observed between inner and outer canopy fruit for all farms except Lindeshof where outer canopy fruit were lighter green in colour. Red blush was only detected in outer canopy fruit. The reddest blush was recorded at Nooitgedacht then Lindeshof, Vastrap, and the least at Crispy and Kromfontein farms. Sunburn incidence was only detected in outer canopy fruit and differences between farms for this variable were not of horticultural significance. Hue angles were lower for the outer canopy fruit in all five farms. The interaction for hue angles is because the difference between inner and outer canopy fruit from all five farms were significantly different except for Crispy farm (Table 5).

Descriptive sensory analysis

No differences were found for apple flavour between canopy position and farms (Table 6). Outer canopy fruit were perceived to be slightly sweeter, less sour and slightly less juicy than inner canopy fruit (Table 6). Farms were also statistically different for these variables. Fruit from Nooitgedacht and Lindeshof were highest in sweetness and sweeter than fruit from Crispy and Kromfontein. Vastrap fruit were also sweeter than Kromfontein fruit. Kromfontein and Crispy fruit were perceived to be more sour than Nooitgedacht fruit. Fruit from Crispy farm was perceived to be slightly less juicy with no differences observed between the remaining four farms.

Inner canopy fruit from Nooitgedacht and Kromfontein were found to be significantly more crispy and crunchy than outer canopy fruit (Table 7). For the other three farms no differences were found between inner and outer canopy fruit in crispness or crunchiness. No differences were observed in hardness for canopy position in all farms except Vastrap and Kromfontein where inner canopy fruit were found to be respectively softer and harder than outer canopy fruit (Table 7).

Consumer preference

Fruit were tasted by 120 consumers of whom 65% were female. The three age groups were 18 to 21 years of age (65%), 22 to 29 years of age (28%) and 30 to 40 years of age (17%). Seventy two percent of consumers claimed to consume apples once or more per week, while the rest consume apples at least twice a month.

Significant interaction between farm and canopy position was found for consumer liking of both eating quality (taste liking) and appearance (photo liking) (Table 8). With regards to taste liking, Nooitgedacht and Crispy farms did not show significant differences between fruit from inner and outer canopy positions. However, inner and outer canopy positions differed significantly for fruit from Lindeshof, Vastrap and Kromfontein farms where outer canopy fruit were deemed tastier. Lindeshof and Vastrap farms both displayed a larger mean difference between inner and outer canopy treatments than the other farms. Outer canopy Vastrap and Lindeshof fruit, with the highest preference scores, were most preferred over other samples. While the inner canopy fruit from these farms, obtaining the lowest preference scores, were least preferred of all the samples.

The appearance of inner canopy fruit was preferred in all farms except for Kromfontein (Table 8). Fruit from the farms differed in appearance, notably size and blush intensity (Fig. 1). Fruit from Nooitgedacht appear smaller than the fruit from the other farms and the outer canopy fruit from Vastrap has the most intense blush of all the outer canopy treatment photos. Inner canopy fruit from Vastrap and outer canopy fruit from Nooitgedacht respectively had the highest and lowest liking scores overall. For outer canopy photos, Kromfontein had the highest score for appearance, but not significantly higher than Lindeshof (Table 8).

Correlations

Correlations using a Principal Component Analysis (PCA) explained 78% of the variation in taste preferences (Fig. 2). The observation plot shows that the inner and outer canopy fruit are clearly separated along the vertical axis, which explains the most variation (55%). It can also be seen from this plot that the inner and outer fruit from Crispy farms are the only ones not separated along the horizontal axis explaining 23% of the variation. However, inner and outer canopy fruit from the different farms do not group together in distinct outer and inner canopy groups. Outer canopy fruit of Lindeshof and Vastrap, which were preferred to other samples, seemed to associate with apple flavour while being at separate ends of the plot than TA, starch breakdown and the inner canopy fruit of these two farms, which received low preference scores.

DISCUSSION

The effect of canopy position on fruit quality is being dealt with extensively in this thesis. In Paper 1 we investigated in detail the chemical qualities of inner and outer canopy fruit of three apple cultivars, viz. Starking, Granny Smith and Golden Delicious. Paper 2 reveals how these fruit quality differences impact consumers in a two-year consumer preference study. In this paper, we evaluated ‘Golden Delicious’ fruit from five farms in order to determine the consistency of the fruit quality and consumer preference differences that have been observed between inner and outer canopy fruit (Paper 2).

Physiochemical

While differences in firmness between farms and canopy positions were insubstantial, there appears to be a trend in all the farms that the starch breakdown was higher for inner canopy fruit. In Paper 2 we also found this trend for two seasons in ‘Golden Delicious’ and in one season for ‘Granny Smith’ while no differences were found for ‘Starking’. The starch index when compared to firmness and TSS is a more reliable parameter for predicting harvest dates and assessing maturity, this was found for ‘Granny Smith’ apples (Reid et al., 1982). Seeley et al. (1980) found a positive correlation between light and starch concentration while Barrit et al. (1987) found that fruit receiving more light had higher starch concentrations than fruit from the middle and bottom of the canopy. We corroborate this in Paper 1 where it was found that outer canopy fruit contained higher carbohydrate concentrations than inner canopy fruit. This data show that outer canopy fruit accumulate more starch, thereby decreasing the reliability of the starch breakdown test to assess the maturity of inner and outer canopy fruit.

Other researchers, however, have found no clear relationship between light or canopy position and starch breakdown (Campbell and Marini, 1992).

Regardless of the fact that farms differed in fruit quality, we found a consistent trend in the physiochemical results between inner and outer canopy fruit from the five farms. Outer canopy fruit tended to be higher in TSS, TSS:TA ratio, DMC and lower in TA. In Paper 2 we found that in all three cultivars used, the outer canopy fruit, which are exposed to more sunlight and higher temperatures (Fouché et al., 2010), were also lower in acids and higher in DMC, TSS and TSS:TA ratio compared to the inner canopy fruit. As discussed in Paper 2, outer canopy fruit receiving more light, synthesize more photo-assimilates resulting in greater carbohydrate accumulation in these fruits, resulting in higher TSS concentrations (Johnson and Lakso, 1986; Robinson et al., 1983). DMC is also a function of light exposure (Scurlock et al., 1985), hence fruit exposed to higher irradiance will have higher DMC. The physiochemical results relating to canopy position from the five farms agree with previous research studies where outer canopy fruit were reported to be higher in TSS and lower in acids (Nilsson and Gustavsson, 2007). The results from the five farms also show that the chemical quality of inner and outer canopy fruit can be expected to be consistent at various farm locations.

The appearance of the fruit was also influenced by canopy position. Outer canopy fruit that were exposed to higher irradiance were more red due to anthocyanin synthesis in the peel brought about by the higher light environment (Awad et al., 2001; Fouché et al., 2010). These results were consistent between farms and cultivars (Paper 2). Sunburn was also found on outer canopy fruit from all the farms. At higher irradiance and temperature sunburn browning occurs in apple peel (Schrader et al., 2003).

Literature shows that the differences in fruit quality observed between farms can be attributed to the farm location and how the orchard system employed at each location affects light interception and distribution. The amount of light intercepted in an orchard is of paramount importance to fruit quality and depends on orchard management practices that include the tree spacing, tree shape, tree height, row orientation as well as the leaf area index (Jackson, 1980; Lakso, 1994; Wagenmakers, 1991). This is because there is a fundamental relationship between accumulated light intercepted by a crop and dry matter production (Monteith, 1977) and this has been found to be true for apple orchard systems (Palmer, 1989a). Orchard systems and tree size in the five farms were not constant and this could have contributed towards differences observed between farms. Three of the farms had a plant spacing of 1.5 m x 4 m; while two farms had a plant spacing of 6.71 m x 3.36 m (Table 1). Row orientation of the Lindeshof orchard was east-west, while other orchards had a north-south orientation (Table 1).

Row orientation has been found to influence light distribution in orchards, but its effects have been found to depend on other factors such as tree height and latitude (Palmer, 1989b). In the Southern hemisphere, light is mainly intercepted on the north side of east-west rows and the light distribution in the canopy of orchards planted in east-west row orientation have also been reported to be poorer than of orchards planted in north-south row orientation (Middleton and McWaters, 2001). These differences have a bearing on fruit quality, for instance, Fouché et al. (2010) did not find any differences in sunburn and blush for the east and west sides of the north-south orientated rows while the north facing side of the east-west rows had significantly more sunburn than the south facing side. Apple peel quality differences between outer and inner canopy fruit were found for the Lindeshof orchard, which is planted in east-west row orientation, while no differences were found for the other farms planted in a north-south row orientation. Lindeshof outer canopy fruit were found to be lighter green in ground colour compared to the inner canopy fruit. The higher irradiance on the northern side and poorer light distribution of the east-west rows possibly resulted in the difference observed in background colour at Lindeshof farm. Chlorophyll is degraded at high irradiance (Felicetti and Schrader, 2008), resulting in lighter green peel colour.

Though farms were situated in the same region, differences in altitude may result in the average temperatures decreasing by an average of 0.5 °C (high humidity) to 1 °C (low humidity) for every 100 m increase in elevation (FAO Climpag, 2002). Differences in altitude of the five farms are displayed in Table 1. In previous research, 'Golden Delicious' apples from orchards at higher altitudes in Italy have been found to contain higher quantities of volatiles (Ferrandino et al., 2001). Location influences on the quality traits of peaches in Australia revealed that fruit size, firmness and flavour were particularly affected by mean temperature changes across locations (Topp and Sherman, 1989). However, researchers in Ireland found no differences in TSS, TA, colour, firmness and fruit weight in 'Golden Delicious' assessed from seven different locations over five seasons (Gormley et al., 1981).

Nooitgedacht farm, which is situated at the highest altitude of 1002 m above sea level, produced fruit that were distinctly higher in DMC, TSS and TSS:TA ratio. It is possible that the reason these fruit had higher DMC, TSS and TSS:TA ratio than the other farms may be because they were smaller. De Salvador et al. (2006) found that fruit from heavier cropping trees were smaller, firmer and higher in TSS. Therefore the variation in fruit size between farms, which was absent between canopy position, could also be a contributing factor for the variations in the other fruit quality parameters.

Descriptive sensory analysis

Sweet taste was more pronounced in outer canopy fruit while sour taste was more pronounced for inner canopy fruit. This corresponds well with the chemical data where TSS and the TSS: TA ratio was higher for outer canopy fruit. This also agrees with the data from Paper 2 and we can appreciate the consistency of these results in all five farms; therefore we can validate the sensory characteristics of outer canopy apple fruit in this respect. Fruit from Nooitgedacht farm were the sweetest and least sour. This corresponds well with physiochemical data where fruit from this farm were highest in DMC, TSS, TSS:TA ratio and had the lowest TA.

Apple flavour was not affected by canopy position in any of the farms although outer canopy 'Golden Delicious' were perceived to have higher apple flavour in Paper 2. The inconsistency of these results indicate that there may be more factors - which are difficult to isolate or identify in this study alone - that may influence flavour other than canopy position. Flavour was comparable between farms, though research on peaches has found that temperature differences at farm locations influenced flavour, and for every 1 ºC increase in temperature it resulted in a 0.17 unit increase in consumer liking on a 5 point hedonic scale (Topp and Sherman, 1989).

Textural attributes were not consistently influenced by canopy position over the five farms. This may be because differences in firmness, the important instrumental measurement correlated to textural attributes, was insignificant for canopy position in three of the five farms. However, at Nooitgedacht and Crispy farms where outer canopy fruit were slightly firmer, these results did not reflect in the sensory textural attributes. This is unlike in Paper 2, where outer canopy 'Golden Delicious' fruit were higher in the ranking of textural attributes and the data correlated well with firmness physiochemical results.

Consumer preference

The higher consumer taste liking for outer canopy fruit of some farms was due to the higher TSS, TSS:TA ratio and DMC in these fruit as was observed in the physiochemical results.

The PCA bi-plot corroborated this, showing that taste-liking was strongly associated with apple flavour, as well as TSS; TSS:TA ratio; sweetness, firmness and DMC. 'Royal Gala' apples that were higher in DMC were preferred by consumers and were also higher in TSS, TA and firmness (Palmer et al., 2010). DMC, which is an important measurement of apple fruit quality and a good indicator of consumer preference (Harker et al., 2009), correlated (r^2 = 0.692) with taste liking. Taste liking also correlated positively with the apple flavour, sweetness and TSS (r^2 of 0.74, 0.67 and 0.72, respectively).

In three of the five farms, viz. Vastrap, Lindeshof and Kromfontein, taste preference for outer canopy fruit was significantly higher while the other two farms showed no significant differences. Consumer taste liking appears to correlate well with the plant spacing at the different farms. It can be seen from results that fruit from Nooitgedacht, Crispy and Kromfontein where tree spacing is 4 m x 1.5 m, had the smallest difference for taste liking (0.2, 0.2 and 0.3, respectively) between inner outer canopy fruit. Vastrap and Lindeshof, where trees are spaced 6.71 m x 3.35 m, displayed greater variance in taste liking between inner and outer canopy fruit (1.5 and 1.9, respectively). This is because plant spacing has a bearing on the canopy size of the tree. Smaller plant spacing result in trees with smaller canopy widths and the difference between the inner and outer canopy microclimate diminishes as the canopy width decreases. High density orchards make better use of PAR than conventional low density plantings because the rate of light interception with orchard age is greater and light distribution in the canopy is better, resulting in higher productivity (Hampson et al., 2002). The importance of light to fruit quality has been discussed in the physiochemical section. Each chemical attribute is analysed individually in the physiochemical and descriptive sensory analysis. However, when a consumer tastes the fruit, he bases his liking on the overall taste and every attribute comes together to impact on how the fruit will be enjoyed by the consumer. From the consumer preferences, it can be seen that where canopies are smaller due to high density plantings, they can barely taste the difference between inner and outer canopy fruit. As the canopy size increases and the microclimatic differences between the inner and outer canopy portions are magnified, the difference in taste liking increases Where the differences in overall taste quality are picked up between inner and outer canopy, consumer preference is higher for outer canopy fruit as also observed over two seasons and for three cultivars (Paper 2).

The consumer preference for appearance shows the lack of popularity among consumers for the outer canopy 'Golden Delicious' fruit. In all except one farm, consumers preferred the appearance of inner canopy fruit. In Paper 2, we found that the inner canopy fruit had higher consumer preference for appearance and this is because green cultivars such as Granny Smith are traditionally marketed without a red blush (Hirst, 1990). This also holds true for 'Golden Delicious' apples. It has been documented that the previous experiences of the consumer and learned associations all have a strong bearing on consumer preference (Pollard et al., 2002).

What really captured consumer attention for the outer canopy Kromfontein fruit, which was the only outer canopy fruit that were preferred by the consumers? By examining the photographs presented to the consumers (Fig. 1), it appears that the blush on each apple is distinctly different. This was not done intentionally; effort was made to select the best representative of an outer canopy fruit from each farm. By visually analysing each photograph, we find some of the short falls of the outer canopy fruit that may have affected the consumer. Lindeshof and Crispy outer canopy fruit do not have a clearly visible blush and appear more yellow and slightly sunburnt. On the contrary, Vastrap outer canopy fruit developed a beautiful, intense red blush. The blush on the Nooitgedacht fruit seemed to compete with the sunburn yellow peel colour and therefore it did not show clearly. The desired blush appearance on the Kromfontein outer canopy fruit is a subtle pink blush. Therefore, there appears to be an opportunity for a blushed 'Golden Delicious' apple given that the blush intensity is correct. The results also give insight into some of the challenges the producers may face in commercializing blushed outer canopy 'Golden Delicious' apples. Too much red blush and sunburn seem to be the main deterrents for the preference of outer canopy fruit. Therefore consumer preference does not rest on fruit colour alone (Steyn, 2012). Although fruit colour can be used as an indicator of fruit quality, research shows that learned associations also have a huge impact in consumer preference, for example when 'Jonagold', a tart apple, is mistaken for a sweet apple due to its red appearance (Schechter, 2010). The findings for consumer preference for appearance from our research generally corroborated those discussed in Paper 2 where outer canopy fruit, which developed some red colour, are rejected on the basis of appearance though they, depending on the canopy size, enjoyed higher taste preference and were of better chemical and eating quality.

CONCLUSION

We can conclude that the effect of canopy position on fruit quality is consistent as shown in physiochemical and descriptive sensory analysis, and was largely dependent on the orchard system. Use of orchard systems that maximise light penetration into the canopy may reduce the differences observed between inner and outer canopy fruit. These differences can be discerned by consumers. On the whole we found that outer canopy fruit had the qualities that gave them good eating quality and higher consumer taste preference. This was shown in Paper 2, where three different cultivars also showed these results. The consistencies of these results validated this fact. These results also showed that there may be a place for blushed 'Golden Delicious' apples in the market. We also confirm that culling blushed outer canopy fruit is purely aesthetic, and now results even show that consumers would accept a blushed 'Golden Delicious' apple; however, more consumer surveys may need to be done in order to determine the intensity of blush that would be acceptable to consumers.

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Table 1. The details of the location of the farms from which fruit were harvested.

Farm	Latitude	Longitude	Altitude (m)	Plant Spacing (m)	Harvest date
Nooitgedacht	33º 13´ 01" S	19º 19´ 34" E	1002	4 x 1.5	7/3/2011
Lindeshof	32º 59´ 47" S	19º 18´ 10" E	916	6.71 x 3.36	7/3/2011
Vastrap	33º 15´ 08" S	19º 14´ 41" E	917	6.71 x 3.35	28/2/2011
Crispy	33º 16´ 46" S	19º 19´ 34" E	535	4 x 1.5	11/2/2011
Kromfontein	32º 59´ 47" S	19º 18´ 10" E	950	4 x 1.5	7/3/2011

Table 2. The effect of canopy position (inner canopy versus outer canopy fruit) on % starch breakdown and firmness of 'Golden Delicious' apples harvested from five different locations in Ceres, Western Cape, South Africa.

Farm	Canopy Position	Starch breakdown (%)	Firmness (N)
Nooitgedacht	In	52 c[z]	73 c
	Out	14 f	79 ab
Lindeshof	In	73 b	76 bc
	Out	43 cde	76 bc
Vastrap	In	86 a	72 c
	Out	42 de	76 abc
Crispy	In	91 a	72 c
	Out	38 e	80 a
Kromfontein	In	95 a	76 abc
	Out	51 cd	78 ab
P value			
Farm		*<0.0001*	*0.0153*
Position		*<0.0001*	*<0.0001*
F x P		*0.0016*	*0.0147*

[z] Means with different letters differ significantly at P<0.05.

Table 3. The effect of canopy position (inner canopy versus outer canopy fruit) on fruit weight and diameter of 'Golden Delicious' apples harvested from five different locations in Ceres, Western Cape, South Africa.

Treatment		**Fruit weight (g)**		**Fruit diameter(mm)**	
Farm	Nooitgedacht	109.6	d[z]	61.8	c
	Lindeshof	122.6	bc	65.1	ab
	Vastrap	136.5	a	66.5	a
	Crispy	131.1	ab	66.8	a
	Kromfontein	116.9	cd	63.8	bc
Canopy Position	In	121.4	NS	64.6	NS
	Out	125.2		65.0	
P value					
Farm		*<0.0001*		*0.0002*	
Position		*0.2145*		*0.5936*	
F x P		*0.3075*		*0.3590*	

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05.

Table 4. The effect of canopy position (inner canopy versus outer canopy fruit) on flesh density and dry matter concentration, titratable acidity (TA), total soluble solids (TSS) and TSS:TA ratio for 'Golden Delicious' harvested from five different locations in Ceres, Western Cape, South Africa.

Treatment		Density (g cm^{-3})	DMC (%)	TSS (° Brix)	TA (% Malic acid)	TSS/TA
Farm	Nooitgedacht	0.160 ^{NS}	16.0 a^{z}	13.3 a	0.34 c	40.6 a
	Lindeshof	0.159	13.8 c	11.9 c	0.36 bc	34.2 b
	Vastrap	0.160	14.6 b	12.7 b	0.39 ab	32.8 b
	Crispy	0.158	14.1 c	12.6 b	0.42 a	30.5 b
	Kromfontein	0.165	13.6 c	12.0 c	0.38 b	32.9 b
Canopy Position	In	0.162 ^{NS}	12.9 b^{z}	11.4 b	0.40 b	28.6 b
	Out	0.159	16.0 a	13.6 a	0.35 a	39.7 a
P value						
Farm		*0.4392*	*<0.0001*	*<0.0001*	*0.0009*	*0.0002*
Position		*0.3046*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
F x P		*0.4543*	*0.1364*	*0.8038*	*0.2034*	*0.2650*

^{NS} Non-significant

^{z} Means with different letters differ significantly at P<0.05.

Table 5. The effect of canopy position (inner canopy versus outer canopy fruit) on the ground colour, blush and sunburn occurrence of 'Golden Delicious' apples harvested from five different locations in the Ceres farming district of the Western Cape.

Farm	**Canopy Position**	**Ground colour**	**Blush**	**Sunburn**	**Hue Angle (◦)**
Nooitgedacht	In	2.5 bc [z]	0 e	0 c	112.9 bc [z]
	Out	2.7 ab	9 a	6 ab	110.7 e
Lindeshof	In	2.5 bc	0 e	0 c	113.1 ab
	Out	2.9 a	6 b	7 a	109.9 f
Vastrap	In	2.6 bc	0 e	0 c	113.3 ab
	Out	2.3 cd	5 c	6 ab	111.7 d
Crispy	In	2.4 cd	0 e	0 c	112.2 cd
	Out	2.2 d	2 d	4 b	111.7 d
Kromfontein	In	2.6 bc	0 e	0 c	113.7 a
	Out	2.5 bc	3 cd	7 a	112.1 cd
P value					
Farm		*0.0106*	*<0.0001*	*0.0970*	*<0.0001*
Position		*0.6489*	*<0.0001*	*<0.0001*	*<0.0001*
F x P		*0.0087*	*<0.0001*	*0.0970*	*0.0006*

[z] Means with different letters differ significantly at P<0.05.

Table 6. The effect of canopy position (inner canopy versus outer canopy fruit) on the overall means of sensory characteristics of 'Golden Delicious' apples harvested at five different farms in Ceres, Western Cape, South Africa; measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2010 and 2011.

		Apple flavour	Sweet taste	Sour taste	Juiciness
Farm	Nooitgedacht	54 NS	58 a z	34 b	55 a
	Lindeshof	54	56 a	37 ab	56 a
	Vastrap	53	55 ab	37 ab	56 a
	Crispy	52	51 bc	39 a	52 b
	Kromfontein	51	50 c	40 a	55 a
Canopy Position	In	53 NS	51 b z	40 a	57 a
	Out	52	58 a	34 b	53 b
P value					
Farm		*0.0806*	*0.0019*	*0.0457*	*0.0051*
Position		*0.2172*	*<0.0001*	*<0.0001*	*<0.0001*
F x P		*0.1050*	*0.1240*	*0.0897*	*0.5664*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05.

Table 7**.** The effect of canopy position (inner canopy versus outer canopy fruit) on the overall means of sensory characteristics of 'Golden Delicious' apples harvested at five different farms in Ceres, Western Cape, South Africa; measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2010 and 2011.

Farm	**Canopy Position**	**Crispness**		**Crunchiness**		**Hardness**	
Nooitgedacht	In	56	abcd[z]	55	abcd	48	abcd
	Out	50	e	50	e	46	d
Lindeshof	In	56	abcd	54	abcd	47	bcd
	Out	58	ab	56	abc	50	abc
Vastrap	In	56	abcd	54	bcd	47	cd
	Out	57	abc	57	ab	50	ab
Crispy	In	54	bcde	52	cde	46	d
	Out	52	de	51	de	47	bcd
Kromfontein	In	59	a	58	a	51	a
	Out	53	cde	53	bcde	47	cd
P value							
Farm		*0.0366*		*0.0302*		*0.2497*	
Position		*0.0532*		*0.1478*		*0.6478*	
F x P		*0.0406*		*0.0182*		*0.0101*	

[z] Means with different letters differ significantly at P<0.05.

Table 8. The effect of canopy position (inner canopy versus outer canopy fruit) on the taste and photo liking for Stellenbosch consumers of ‘Golden Delicious’ apples from five farms in the Ceres region

Farm	**Position**	**Taste liking**		**Photo liking**	
Nooitgedacht	In	6.6	bc [z]	6.8	b
	Out	6.4	cd	4.8	e
Lindeshof	In	5.1	g	6.9	b
	Out	7.0	ab	5.9	cd
Vastrap	In	5.6	f	7.4	a
	Out	7.1	a	5.7	d
Crispy	In	6.1	de	6.9	b
	Out	6.3	cd	5.6	d
Kromfontein	In	5.8	ef	5.8	d
	Out	6.1	d	6.3	c
P value					
Farm		*0.0003*		*<0.0001*	
Position		*<0.0001*		*<0.0001*	
F x P		*<0.0001*		*<0.0001*	

[z] Means with different letters differ significantly at P<0.05.

	
a. Lindeshof outer fruit	b. Lindeshof inner fruit
	
c. Vastrap outer fruit	d. Vastrap inner fruit
	
e. Kromfontein outer fruit	f. Kromfontein inner fruit
	
g. Crispy outer fruit	h. Crispy inner fruit
	
i. Nooitgedacht outer fruit	j. Nooitegdacht inner fruit

Fig. 1. Photo images presented to consumers for the inner and outer canopy fruit from five farms: Crispy, Lindeshof, Kromfontein, Nooitgedacht and Vastrap; in the Ceres region of the Western Cape.

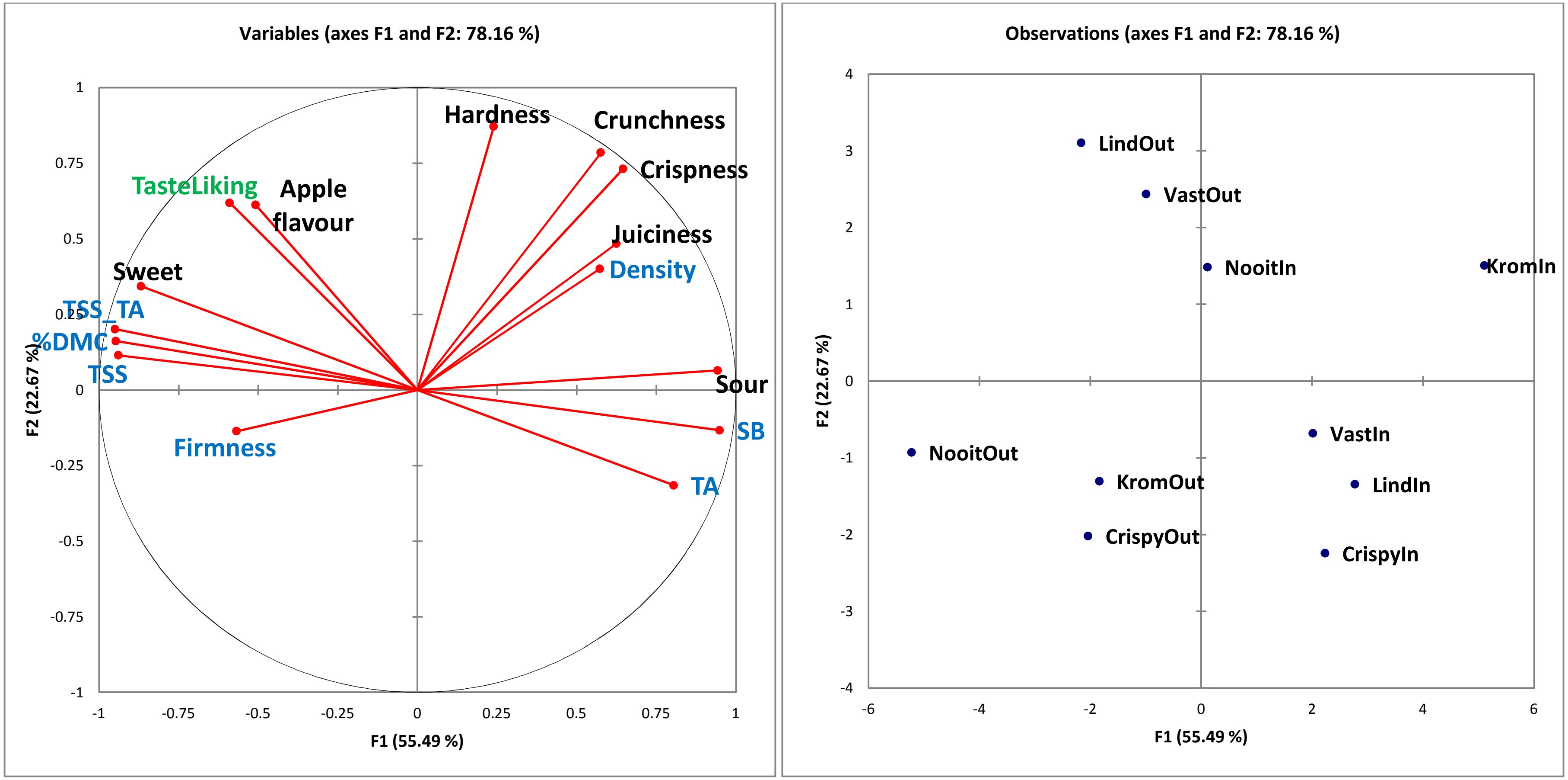

Fig. 2. Principle Component Analysis (PCA) for 'Golden Delicious' apples from the inner and outer canopy positions harvested from 5 different locations in the Ceres Valley, Western Cape, South Africa. The PCA: variables (right) and observations (left) plots; indicating the position of consumer taste preference (Tliking) in relation to the sensory attributes (black) and chemical composition (blue) where SB – starch breakdown and DMC - dry matter concentration as a percentage.

THE EFFECT OF FAMILIARITY ON CONSUMER PREFERENCE FOR APPLES FROM DIFFERENT CANOPY POSITIONS

Abstract

Consumer preference for the taste and appearance of 'Granny Smith, 'Golden Delicious' and 'Starking' apples from the inner and outer canopy as well as sunburnt 'Golden Delicious' fruit were assessed by two consumer groups from Ceres and Stellenbosch. With regards to ethnicity, Stellenbosch consumers were predominantly white and Ceres consumers were black and coloured farm labourers. Consumers in Stellenbosch are less familiar with sunburnt fruit and blushed fruit of green cultivars, unlike Ceres consumers who are exposed to all apple fruit on the tree. Apple consumption was not the same in both locations with 96% of the consumers in Ceres compared to 23% in Stellenbosch eating apples more than three times a week. Differences in consumer preference for the taste and appearance of the apples were attributed to differences in exposure and familiarity as well as ethnicity. In both locations, the taste and appearance of outer canopy 'Starking' was preferred. We believe that consumers perceive red fruit to be sweeter, and in the case of 'Starking' they are right. The taste of sunburnt fruit was preferred by a larger segment of the consumer from both locations, but the appearance of these fruit was preferred by only some Ceres consumers. A segment of the consumers in Ceres preferred the taste and appearance of the blushed outer canopy 'Granny Smith' fruit, whereas no Stellenbosch consumers preferred these fruit. Our results support our hypothesis that Ceres consumers who are more familiar with the taste attributes of undesirable – from a marketing perspective – sunburnt and blushed fruit of green cultivars have a higher preference for the appearance of these fruit. However, preference scores are also affected by the general apple taste preferences of consumers. Generally black and coloured consumers showed higher taste preference for sweeter tasting apples.

INTRODUCTION

The position of a fruit in a canopy affects fruit quality characteristics. Inner canopy fruit experience lower light and temperature environments than exposed outer canopy fruit (Paper 1; Fouché et al., 2010). These fruit are higher in titratable acidity (TA) and lower in TSS, percentage dry matter concentration (DMC) and TSS:TA ratio (Paper 2; Nilsson and

Gustavsson, 2007). Outer canopy fruit develop redder colouration on the sun-exposed side of the fruit due to enhanced anthocyanin synthesis, which is promoted by higher irradiance (Awad et al., 2001). These outer canopy fruit are also prone to sunburn. At higher irradiance and temperature, sunburn browning occurs in apple peel (Schrader et al., 2003). Sunburnt apples are either rejected or downgraded on the basis of appearance (Schrader et al., 2004). However, TSS and the TSS:TA ratio have been reported to increase with sunburn severity (Racsko et al., 2005). In South Africa it was estimated that cullage due to sunburn was approximately 10% to 50% (Bergh et al., 1980).

In Papers 2 and 3, we found that the appearance of outer canopy 'Granny Smith' and 'Golden Delicious' fruit was less preferred by consumers compared to inner canopy fruit. On tasting, however, outer canopy fruit were preferred by these consumers. For 'Starking' fruit, both the taste and appearance of the outer canopy apples were preferred over those from the inner canopy. We explain this dichotomy through the unfamiliarity of consumers with the blushed appearance of 'Granny Smith' and 'Golden Delicious' fruit. Fruit quality is defined as all those characteristics that lead to consumer satisfaction with the product (Jaeger et al., 2002). Internal quality characteristics such as flavour, sweetness, sourness and textural attributes are the most important traits that determine consumer eating quality preference in apples (Daillant-Spinnler et al., 1996; Jaeger et al., 1998). Colour, size, shape, form and absence of defects are all factors used to visually assess the quality of fruit (Estes and Smith, 1996; Kays, 1998). In addition, Pollard et al. (2002) reports that factors such as familiarity, habit, social interactions, media, advertising, cost, availability, time constraints and personal ideology play a role in consumer preference of foods. In a study with students in the US, Taiwanese students gave higher preference scores for salty aqueous solutions due to their higher familiarity with salty solutions such as soy sauce (Bertino et al., 1983). Another cross-cultural study with Australian and Japanese consumers revealed how dietary experience influences consumer preference on various foods brought about by Japanese preference for foods with high sour and 'umami' tastes (Prescott, 1998). In other food studies, the effect of previous experience on food choice have been documented. For infants, a positive correlation exists between preference for salted food and the number of experiences of high sodium foods prior to testing (Harris and Booth, 2007). In a study on pork, consumers with prior experience with 'free range' pork more favourably assessed the sensory characteristics of this product (Oude Ophuis, 1993). Showing pictures of fruits to toddlers resulted in an increase in their willingness to taste familiar and unfamiliar fruits and vegetables (Houston-Price et al., 2009).

The objective of this paper was to determine how "inexperienced" Stellenbosch consumers and "experienced" consumers from Paardekloof farm in Ceres respond to the taste and appearance of 'Golden Delicious', 'Granny Smith' and 'Starking' inner and outer canopy fruit as well as sunburnt outer canopy 'Golden Delicious' fruit. The consumers from Paardekloof farm in Ceres are viewed as more experienced in this research because they work in apple orchards and are exposed to all apples on the tree compared to the average consumer who is unfamiliar with blushed and sunburnt 'Golden Delicious' and 'Granny Smith' fruit. Our hypothesis is that the "experienced" consumers, being more familiar with the taste and appearance of blushed and sunburnt outer canopy fruit, will show a higher preference for the appearance of these fruit compared to "inexperienced" Stellenbosch consumers.

MATERIALS AND METHODS

Plant material and experimental design

'Golden Delicious' and 'Starking' were harvested on 23 March 2011 and 'Granny Smith' on 15 April 2011 at Paardekloof farm in the Witzenberg Valley, Ceres (latitude: 33^0 23'S, longitude: $19^0$19'E). The background on the orchards used was presented in Paper 1.

The study was laid out as a complete randomised design with twelve replications. Fruit harvested from three consecutive trees represented a replicate and fifteen inside and outside fruit were harvested for each replicate. For 'Golden Delicious', there were three treatments, viz. inner canopy fruit, outer canopy fruit and outer canopy fruit with sunburn. Outer and inner canopy fruit were used for 'Granny Smith' and 'Starking'.

Physical and descriptive sensory analysis

Maturity indices and physical measurements were carried out as specified in Paper 2.

The descriptive sensory analysis was carried out as specified in Paper 2. Each cultivar was tested separately. The panel of eight judges assessed the twelve replicates over two days, 11 and 12 May 2011, six replicates each day.

Consumer preference

Two consumer groups were used in this study. One group of consumers comprised mainly students and professionals residing in Stellenbosch, Western Cape. 'Granny Smith' apples were tasted on 16 May 2011 by one set of consumers, while 'Golden Delicious' and 'Starking' were tasted on 17 May 2011 by a different set of consumers. The second group of consumers comprised farm workers from Paardekloof farm in Ceres, Western Cape. Consumers tasted all three cultivars separately on 20 May 2011.

The consumer study in Stellenbosch was carried out as specified in Paper 2 while a preliminary investigation showed that the farm workers would require help in understanding and filling out the questionnaire during the survey due to their low literacy levels. Therefore the consumers at Paardekloof farm were assisted in the study, which was carried out in the form of an interview with trained assistants who fluently spoke the mother tongue of the consumers (Afrikaans and Xhosa). The consumers were presented with the exact same questionnaire, photographs (Fig. 4) and treatments as the Stellenbosch consumers.

Statistical procedures

The data for 'Starking', 'Granny Smith' and 'Golden Delicious' apples were analysed by analysis of variance (ANOVA) using SAS version 9.2 (SAS Institute Inc., 2008, Cary, NC, USA). The Shapiro-Wilk test was performed to test for non-normality (Shapiro and Wilk, 1965). Student's t-Least Significant Difference was calculated at the 5% significance level to compare treatment means. Principal Component Analysis (PCA) was carried out to identify variables that associate with certain treatments (Rencher, 2002).

RESULTS

Colour measurements were taken on the best coloured side of the apple, i.e., the reddest or greenest side of the fruit for outer and inner canopy fruit respectively. Sunburnt 'Golden Delicious' fruit were significantly lighter in ground colour than inner and outer canopy fruit (Table 1). Inner and outer canopy fruit did not differ for this variable. Outer canopy fruit were redder than inner canopy and sunburnt fruit. Outer canopy 'Granny Smith' fruit had a lighter green ground colour and higher red colouration than inner canopy fruit. 'Starking' outer canopy fruit were redder than inner canopy fruit while canopy position did not affect ground colour (Table 1).

Physiochemical

Outer canopy and sunburnt 'Golden Delicious' fruit had similar and higher firmness and TSS than inner canopy fruit (Table 2). TA was equal for inner and outer canopy fruit and higher than for sunburnt fruit. The TSS:TA ratio and DMC were highest for sunburnt fruit, followed by outer canopy fruit while inner canopy fruit had the lowest levels.

Outer canopy 'Granny Smith' fruit were higher in firmness (Table 2). TSS was 1.4° BRIX higher in outer canopy fruit and there was no difference in TA. The DMC and TSS:TA ratio were significantly higher in outer canopy fruit.

No difference in firmness were observed between inner and outer canopy 'Starking' fruit (Table 2). TSS was approximately 3° BRIX higher in outer canopy fruit while no significant difference was observed for TA. The TSS:TA ratio and DMC were higher in outer canopy fruit.

Descriptive sensory analysis

Sunburnt 'Golden Delicious' fruit were highest in sweetness and lowest in apple flavour, sourness, crispness, crunchiness and juiciness (Table 3). Inner and outer canopy fruit did not differ in sourness, crispness, crunchiness and juiciness. However, outer canopy fruit were sweeter than inner canopy fruit and were the highest in flavour. Outer canopy fruit were hardest and there was no difference in hardness between inner canopy and sunburnt fruit.

'Granny Smith' outer canopy fruit were higher in apple flavour, sweetness, crunchiness, and hardness (Table 3). Inner canopy fruit were sourer while canopy position did not affect juiciness and crispness.

'Starking' outer canopy fruit were higher in apple flavour, sweetness, crispness, crunchiness and juiciness, while inner canopy fruit were higher in sourness and did not differ in hardness from outer canopy fruit (Table 3).

Consumer preference

Socio-demographics

'Granny Smith' apples were tasted on 16 May 2011 by one set of consumers (Stellenbosch1, N=94) while 'Golden Delicious' and 'Starking' were tasted on 17 May 2011 by a different set of consumers (Stellenbosch2, N=100). All three cultivars were tasted on 20 May 2011 by 117 Ceres consumers.

Stellenbosch1 and Stellenbosch2 consumer demographics were very similar and average data for the two groups are presented. Regarding age, 40% were in the 18 to 22 age range, 14% in the 32 to 41 age range and 10% in the 41+ age group, respectively (Table 4). On average, 35% were in the 23-31 age range and 70% of the participants were female. 86% of the consumers were white and 14% black (Fig. 1). With regard to regularity of apple consumption, 25% of the consumers eat apples 5 to 7 times per week, 20% 3 to 4 times per week, 34% once a week and 19% at least once a month (Fig. 2).

In Ceres, 81% of consumers were male and 27%, 26%, 32% and 15% were in the 41+, 32 to 41, 23 to 31 and 18 to 22 year age ranges, respectively (Table 4). Approximately 62% of consumers were black and 38% coloured (Fig. 1). Results show that 83% of the consumers in Ceres eat apples 5 to 7 times per week, 14% eat apples 3 to 4 times per week, 3% eat apples once a week and 1% eat apples at least once a month (Fig. 2).

Consumer liking

Consumer preference for ‘Golden Delicious’ showed significant interaction between location and treatment for taste liking (Table 5), but not for appearance liking (Table 6). Consumers from Ceres preferred the taste of sunburnt and outer canopy fruit while inner canopy fruit were preferred significantly less. For Stellenbosch consumers, there were no significant differences between treatments (Table 5). There was no difference between Ceres and Stellenbosch consumers for appearance liking. The appearance of inner canopy fruit had the highest consumer preference followed by outer canopy fruit. Sunburnt fruit were least preferred. (Table 6).

There was no difference in taste liking for inner and outer canopy ‘Granny Smith’ apples, but Stellenbosch consumers gave higher preference ratings than Ceres consumers (Table 7). The appearance of inner canopy fruit was preferred and as with the taste liking results, Stellenbosch consumers showed higher preference for these apples than consumers from Ceres (Table 7).

Significant interactions were obtained for taste and appearance liking results of 'Starking' fruit. The taste and appearance of outer canopy fruit was preferred by both consumer sets. However, the differences between inner and outer canopy fruit were larger for Ceres (Table 8).

Opinions

Consumers were asked to share information on their preference of some important apple sensory characteristics. Consumers from Ceres indicated a high preference for strong apple flavour and juiciness, followed by sweet taste. The preference for hard apples was intermediate (Table 9). Stellenbosch consumers indicated a high preference for apple flavour, hardness and juiciness followed by sweet taste. Both consumer groups indicated a dislike for sourness and mealiness (Table 9).

Opinions were sought on preferred apple appearance characteristics. Consumers from Ceres gave the highest rating to yellow-green 'Golden Delicious' and red apples (Table 10). This was followed by 'Starking' and then by blushed apples. Least in the preference for appearance was 'Granny Smith' and green apples. Stellenbosch consumers indicated equal preference for the appearance of blushed and 'Golden Delicious' apples, followed by red and green apples. 'Starking' apples were least preferred.

Consumers were asked to rate the importance of colour, price, shape and size to them when purchasing apples. Stellenbosch consumers indicated that colour is the most important while the other factors are of lesser, but equal importance. Consumers from Ceres indicated that colour is more important than shape and price while size is more important than price (Table 11).

Correlations

The Principal Component Analysis (PCA) for 'Golden Delicious' inner, outer and sunburnt fruit for Ceres and Stellenbosch consumers explains 100% of the variation (Fig. 3). Inner and outer canopy fruit are separated from the sunburnt fruit along the F1 axis explaining 71% of the variation. Sunburnt fruit and inner canopy fruit are separated on the F2 axis explaining 29% of the variation. Taste liking for the Ceres and Stellenbosch consumers is very closely correlated and the taste liking for both consumer groups associates with sweetness, TSS:TA ratio, TSS and firmness. It is interesting to note that taste liking is situated in the quadrant between outer canopy and sunburnt fruit, separated from outer canopy fruit along the F1 axis and from sunburnt fruit along the F2 axis. Taste liking associates negatively with sourness and inner canopy fruit. Inner canopy fruit associate with sourness, sunburnt fruit with DMC and outer canopy fruit with apple flavour and the textural attributes juiciness, crispness, crunchiness and hardness.

Clusters

Clusters were found for Stellenbosch and Ceres consumers for both the appearance and taste preferences. The demographic breakdown of the age range, ethnic group and gender of the individuals that make up each cluster are indicated (Tables 12-17). Generally, the differences observed between clusters were attributed to treatments while no patterns were observed for ethnicity, age and gender between the clusters.

'Golden Delicious' appearance liking segmented into three clusters for both consumer groups. For Stellenbosch, the first cluster (48% of consumers) showed no difference in preference for inner, outer and sunburnt fruit (Table 12a). Consumers in the second cluster (37%) preferred the appearance of inner canopy fruit followed by outer canopy fruit and lastly by sunburnt fruit. Consumers of the third cluster (15%) preferred the appearance of inner canopy fruit while there was no difference between outer canopy and sunburnt fruit. For Ceres, the clusters were quite different. The first cluster (40% of consumers) preferred the appearance of sunburnt fruit, followed by outer canopy fruit and lastly inner canopy fruit. The second cluster (35%) equally preferred the appearance of inner and sunburnt fruit and least preferred the appearance of outer canopy fruit. The third cluster (25%) preferred the appearance of inner and outer canopy fruit and least preferred the appearance of sunburnt fruit (Table 12b).

In Stellenbosch, the first cluster (45% of consumers) for taste liking of 'Golden Delicious' preferred sunburnt fruit followed by outer canopy fruit and lastly inner canopy fruit. The second cluster (26% of consumers) showed equal preference for inner and outer canopy fruit while the taste of sunburnt fruit was least preferred. The third cluster (30% of consumers) preferred the taste of sunburnt fruit while there was no difference in taste preference for inner and outer canopy fruit (Table 13a). In Ceres, the first cluster (54% of consumers) showed no taste liking differences between inner, outer and sunburnt fruit. The second cluster (18% of consumers) preferred outer canopy fruit while there was no taste liking difference between sunburnt and inner canopy fruit. The third cluster (28% of consumers) preferred the taste of sunburnt fruit, followed by outer canopy fruit and lastly inner canopy fruit (Table 13b).

Appearance liking for Stellenbosch 'Granny Smith' apples revealed 4 clusters. All clusters preferred the appearance of inner canopy fruit. The differences between these clusters were brought about by differences in the hedonic ratings for the canopy positions and in the higher scores awarded by some consumers. For example, cluster 1 (39% of consumers) preferred inner canopy fruit (8.5), but outer canopy fruit also received a high preference score (6.9). This is also the case in cluster 2, except that they gave lower scores. Cluster 3 consumers also preferred inner canopy fruit, but fruit of both canopy positions were disliked. The 32% of consumers of cluster 4 clearly had higher preference for inner canopy fruit and disliked the outer canopy fruit (Table 14a). Ceres consumers were segmented into 3 clusters for appearance liking. The first cluster (32% of consumers) preferred the appearance of inner canopy fruit. 44% of consumers in the second cluster did not show a preference difference between inner and outer canopy fruit, and 24% of consumers in the third cluster preferred the outer canopy fruit. (Table 14b).

Stellenbosch consumers segmented into three clusters for taste liking of 'Granny Smith' (Table 15). None of the clusters showed a difference in taste liking between inner and outer canopy fruit (Table 15a). The clusters differ in the difference in the hedonic ratings between inner and outer canopy fruit. In cluster 1, both canopy positions received an equal rating of 7.4 while cluster 3 had a difference of 0.7 between canopy positions. Although cluster 2 had a large difference of 4.5 between treatments, this cluster consisted of only 6% of the consumers and this could be the reason why the difference was not significant. Both products were disliked in cluster 3. The first cluster for Ceres (18% of consumers) showed a substantial preference for the taste of outer canopy fruit. The second cluster (29% of consumers) showed no preference difference between inner and outer canopy fruit. The third cluster (53% of consumers) gave very low scores for the fruit and preferred the taste of inner canopy fruit (Table 15b).

'Starking' appearance liking segmented into three clusters for both consumer groups. Clusters 1 and 2 in Stellenbosch (88% of consumers) preferred the appearance of the outer canopy 'Starking' (Table 16a). Cluster 2 had a greater difference in hedonic ratings between canopy positions (2.9) compared to cluster 1 (0.8). Cluster 1 also gave higher scores than cluster 2. The third cluster (12% of consumers) did not show a difference in their liking of the appearance of inner and outer canopy 'Starking'. For Ceres consumers, the first cluster (12 % of consumers) preferred the appearance of inner canopy 'Starking'. Clusters 2 and 3 (29% and 59% of consumers, respectively) indicated a preference for the appearance of outer canopy fruit. Cluster 2 consumers gave very low ratings for the inner canopy fruit compared to cluster 3. (Table 16b).

In Stellenbosch for 'Starking' taste liking, clusters 1 and 2 (46% and 18% of consumers, respectively) showed no differential preference for canopy position (Table 17a). Cluster 1 consumers gave high hedonic ratings while cluster 2 consumers gave very low hedonic ratings. The third cluster (36% of consumers) preferred the taste of outer canopy fruit. In Ceres, clusters 1 and 2 (35% and 43% of the consumers, respectively) preferred the taste of outer canopy fruit. Cluster 1 gave particularly low scores for inner canopy fruit thereby differentiating the two clusters. The third cluster (22% of the consumers) preferred inner canopy fruit. The consumers in the third cluster gave very low preference ratings for both treatments (Table 17b).

DISCUSSION

Physiochemical

The physiochemical differences observed between inner and outer canopy fruit were discussed in detail in Paper 2 and Paper 3. Therefore, we focus the discussion in this paper on sunburnt fruit and on where the physiochemistry of outer and inner canopy fruit differs from the previous papers.

The more exposed fruit in all three cultivars were higher in TSS, TSS:TA ratio and DMC (Paper 2; Paper 3; Nilsson and Gustavsson, 2007; Solomakhin and Blanke, 2010). Outer canopy fruit receive higher light and temperature conditions (Fouché et al., 2010; Paper 1) resulting in higher soluble sugar and total carbohydrate levels in fruit that are exposed to more light (Robinson et al., 1983). Sunburnt fruit situated in the outer canopy experience excessive light and temperature stress resulting in a characteristic yellowing of browning of the apple peel (Schrader et al., 2003). The sunburnt fruit harvested for this research displayed sunburn browning (Schrader et al., 2009). Sunburnt fruit were higher in TSS:TA ratio and DMC than outer canopy fruit without sunburn, though no differences were observed between these fruit in TSS. The higher DMC of sunburnt fruit is attributed to water loss from sunburnt fruit tissues resulting in the concentration of dry matter (Racsko et al., 2005). Contrary to our results, Schrader et al. (2009) and Makereza (2011) found that TSS in apples increased with sunburn severity. No differences were found in TA between inner and outer canopy fruit in all three cultivars. Seasonal differences in temperature can affect the relationship between TSS and TA in fruit (Nilsson and Gustavsson, 2007, Paper 2). Generally, acid concentrations tend to be higher in inner canopy fruit (Nilsson and Gustavsson, 2007; Robinson et al., 1983), while shading with hail nets did not affect acid levels (Solomakhin and Blanke, 2010). The sunburnt fruit had lower TA. This is consistent with previous research (Makeredza, 2011; Schrader et al., 2009).

No differences in firmness were observed between outer canopy and sunburnt fruit. Makeredza (2011) found that as sunburn fruit are firmer than those without sunburn. Racsko et al. (2005) attributed this to the fact that sunburnt cells perish, loose water and harden. In our study, the sunburn severity was not such that cells died.

Sunburnt fruit were lighter in background colour than outer and inner canopy fruit. Excessive light exposure results in more chlorophyll degradation in the apple peel (Felicetti and Schrader, 2008). Sunburnt fruit did not develop much red colouration. This is because the fruit surface temperatures required for sunburn are too high to allow accumulation of anthocyanins and may also result in anthocyanin degradation (Steyn et al., 2005).

Descriptive sensory analysis

The sensory characteristics of inner and outer canopy fruit were discussed extensively in Paper 2 and Paper 3. The main focus here will be on sensory characteristics of sunburnt fruit and any differences of inner and outer canopy fruit from previous observations.

Consistent with physiochemical data and the results reported in Papers 2 and 3, outer canopy fruit of all three cultivars were sweeter in taste while sour taste was perceived to be higher in inner canopy ‘Granny Smith’ and ‘Starking’ fruit. Sunburnt fruit were high in sweetness, but comparatively low in all other attributes. The higher sweetness corresponds well with the higher TSS:TA ratio and DMC of these fruit. Sunburnt fruit were perceived to be harder than inner canopy fruit and of equal hardness as outer canopy fruit, but were significantly lower than inner and outer canopy fruit in all other textural attributes. A spongy texture (not assessed) was also perceived in some of the sunburn fruit samples. Woolf and Ferguson (2000) attributed the poor textural characteristics of sunburnt fruit to a loss in cell turgor.

Apple flavour was perceived to be very low in sunburnt fruit. The effect of canopy position on apple flavour has not been consistent (Paper 2, Paper 3). Apple flavour is reported to be influenced by several pre-harvest and postharvest factors (Yahia, 1994). However, research on the effect of canopy position or sunburn on apple flavour is lacking. The PCA (Fig. 3) for 'Golden Delicious' confirm that the taste of sunburnt fruit associated with sweet taste and less strongly with textural attributes and apple flavour, all of which are strongly associated with the outer canopy treatment. Textural attributes were influenced by the inner and outer canopy positions and corresponded well to firmness physiochemical results.

Consumer preference

Consumer demographics

Consumers from Stellenbosch and Ceres differed mainly in their level of apple consumption, which is an indicator of the level of familiarity with apples. In a season, Ceres consumers eat apples more frequently than the Stellenbosch consumers (Fig. 2) and therefore can be viewed as being more experienced apple consumers. On average 96% of the judges in Ceres compared to 23% of the judges in Stellenbosch consume apples more than three times each week. This is because the consumers in Ceres work in apple orchards, mostly as apple harvesters and these fruit are therefore more readily available to them.

The demographic composition of these two consumer groups differed with regard to ethnicity (Fig. 1a and 1b) and gender (Table 4). Stellenbosch consumers were 70% female while the Ceres consumers were 81% male. With regards to ethnic group, Stellenbosch consumers were 86% white and 14% black (predominantly white consumer group) while the consumers in Ceres were 38% coloured and 62% black (a black and coloured consumer group).

Consumer preference - general

The hypothesis of this paper is that the "experienced" Ceres consumers, being more familiar with the blushed and sunburnt fruit from the outer canopy, will show higher preference for the appearance of these fruit compared to the "inexperienced" Stellenbosch consumer. As in Paper 2, the appearance of outer canopy 'Starking' and inner canopy 'Golden Delicious' and 'Granny Smith' was preferred. However, average data can be deceptive when interpreting consumer data since we know that different clusters of consumers exist with different preferences for apple appearance and taste (Anreza Van der Merwe, unpublished). Cluster analysis becomes useful in understanding the consumers' responses as it reveals the segments in the consumer sample that have similar preferences (homogeneous classes) and shows the underlying patterns that cannot be distinguished from the average data (Baker and Crosbie, 1993; Hagerty, 1985). On the basis of the ANOVA, ethnical differences in taste preferences were more apparent than differences in taste liking between the two locations. Generally, consumers preferred the taste of outer canopy fruit, although there are clear clusters of consumers who apparently preferred inner canopy fruit. Considering appearance and taste results, there seems to be a clear dichotomy for some Stellenbosch consumers who prefer the taste of sunburnt 'Golden Delicious' and outer canopy 'Golden Delicious' and 'Granny Smith' fruit, but not the appearance of these fruit. It is appears that a lack familiarity of these fruit could be the reason for the divergence. These results are discussed in more detail in the following section.

Consumer preference - appearance

The higher preference of Stellenbosch consumers for the appearance of inner canopy 'Granny Smith' fruit may be explained by their unfamiliarity with the blushed form of this cultivar. In addition, they may attach a lower value to these fruit as blushed 'Granny Smith' apples are sold at a lower price as second grade fruit. 'Granny Smith' apples are generally marketed without a red blush (Hirst et al., 1990). Similar results for preference for appearance were obtained in Paper 2. While cluster analysis confirms this result, some consumers rated both inner and outer canopy fruit using the bottom part of the hedonic scale ('dislike'). These consumers probably would not buy 'Granny Smith' apples, unless being left with no choice whereby they would choose the inner canopy fruit, on the basis of appearance. 'Granny Smith' appearance liking for Ceres shows a different trend. Although Ceres consumers also showed a general preference for the appearance of inner canopy fruit, cluster analysis revealed a considerable (43%) segment of consumers who equally liked the appearance of inner and outer canopy fruit. Ceres consumers are also quite familiar with market standards for fruit as they are involved in grading fruit in the orchard. Therefore it is possible that some Ceres consumers did not indicate a preference for blushed 'Granny Smith' fruit since they know that it is commercially downgraded. One Ceres consumer segment (24%) did indicate a preference for the appearance of blushed outer canopy fruit, but they used the bottom part of the scale, suggesting that they generally 'dislike' 'Granny Smith'. These are probably the consumers with an aversion to sour apples and faced with a choice, they would probably prefer the sweeter outer canopy fruit. These consumers may know from experience that blushed 'Granny Smith' apples are sweeter than inner canopy fruit.

ANOVA indicated that consumer from both locations preferred the appearance of inner canopy 'Golden Delicious' fruit, followed by the blushed outer canopy fruit while sunburnt fruit were least preferred. However, cluster analysis suggests some differences in the consumer liking pattern for the two locations. For Stellenbosch consumers, two clusters (52% of consumers) preferred inner canopy fruit while a substantial third cluster showed no difference in appearance liking between sunburnt, inner and outer canopy fruit. For Ceres, two clusters most preferred sunburnt fruit, and the smallest cluster (25% consumers) least preferred sunburnt fruit. As discussed for 'Granny Smith', Stellenbosch consumers are less familiar with the blushed and sunburnt 'Golden Delicious' as sunburnt fruit are not marketed while blushed 'Golden Delicious' is uncommon on the market. However, familiarity played a role for Ceres consumers who are more exposed to all the fruit on a tree. These consumers know from experience that sunburnt and blushed 'Golden Delicious' fruit are sweeter than inner canopy fruit.

Appearance liking and taste liking for consumers correspond for 'Starking' where generally consumers liked both the taste and appearance of the outer canopy fruit in both consumer groups. Similar results were obtained in Paper 2. On average, the appearance of outer canopy 'Starking' fruit were preferred by consumers of both locations. The two larger clusters for each location had higher preference for the darker red outer canopy fruit, while a smaller segment making up the third cluster either did not show a preference (Stellenbosch) or preferred the inner canopy fruit (Ceres). Commercially, 'Starking' fruit with insufficient red colour are downgraded and consumers are likely to associate redder colour with increased quality (Crisosto et al., 2002; Steyn, 2012). Daillant-Spinnler et al. (1996) reported that consumers associate red apples with sweet sensory descriptors. Therefore, the redder the colouration, the higher the sweetness perception of the fruit is likely to be (Clydesdale, 1993). Since 'Starking' is a characteristic sweet apple, consumers would probably prefer it for the sweet attribute.

Consumer preference - taste

There were differences in the consumer taste liking of 'Granny Smith' in Ceres and Stellenbosch. Stellenbosch consumers gave higher preference scores than the Ceres consumers. The generally higher preference scores of Stellenbosch consumers compared to Ceres consumers indicate that the latter consumers do not particularly enjoy this cultivar.

Black and coloured consumers generally have a higher preference for sweet tasting apples while white consumers generally prefer sour tasting apples (Anreza Van der Merwe, unpublished data). Opinions data confirm that sweetness is an important taste attribute for Ceres consumers while sourness is disliked (Table 9). In confirmation of the taste preference results, consumers in Ceres generally gave lower appearance preference scores for 'Granny Smith' compared to Stellenbosch consumers. On average, both Stellenbosch and Ceres consumers showed no preference for the taste of either inner or outer canopy fruit. Results in Paper 2, however, show that consumers prefer the taste of sweeter and more flavoursome outer canopy 'Granny Smith'. Only a small cluster (18% of consumers) from Ceres preferred the taste of outer canopy 'Granny Smith' over inner canopy fruit. Since 'Granny Smith' is a characteristic high acid apple (Warrington, 1994), perhaps the acid concentration is an important fruit quality characteristic for this cultivar. However, no differences were found between inner and outer canopy for TA, though the inner canopy fruit were perceived to be more sour.

Similar responses for the taste liking of 'Golden Delicious' apples were obtained for both locations. However, Ceres consumers, in line with their fondness of sweetness, showed a clear preference for sunburnt and outer canopy fruit. The cluster analysis gave more insight as to how consumers responded to these fruits. In both locations there was a cluster of consumers who most preferred the taste of sunburnt fruit. A group of Ceres consumers preferred outer canopy fruit while some Ceres consumers liked all the fruit equally. Stellenbosch had a cluster where sunburnt fruit were the least preferred. Sunburnt fruit were high in sweetness due to the highest concentration of dry matter, TSS:TA ratio and the least amounts of TA. These fruit had the lowest apple flavour and juiciness as well as low values for other textural attributes. It seems that consumers that were able to distinguish between the taste of the sunburnt, outer and inner canopy fruit either preferred the sunburnt fruit because it was much sweeter or disliked it because it was lacking in apple flavour and textural attributes. Fruit firmness and texture are important quality characterics that determine consumer preference (Harker et al., 2008, Jaeger et al., 1998). Outer canopy fruit are preferred because even though they are not as sweet as the sunburnt fruit, they are sweeter than the inner canopy treatment and are higher in textural attributes. Where consumers were able to distinguish their liking between treatments, inner canopy fruit did not appear highest on the preference score in any cluster. The PCA (Fig. 3) showed that taste liking of Ceres and

Stellenbosch consumers was very similar. It also showed that taste liking for 'Golden Delicious' was strongly associated with sweetness, TSS, TSS:TA ratio and firmness.

Consumers from both locations on average preferred the sweeter taste and higher apple flavour of outer canopy 'Starking' fruit. However, only one cluster (34% of consumers) of Stellenbosch consumers showed higher preference for outer canopy fruit, whereas for Ceres two clusters (86% of consumers) preferred outer canopy fruit. This can be attributed to the higher proportion of black and coloured consumers in Ceres. Van der Merwe (unpublished data) found that these consumers generally have a greater preference for sweet apples compared to white consumers. Opinion results also showed that red colour was more important to Ceres consumers than Stellenbosch consumers. A small cluster of consumers from both consumer groups gave very low ratings for both inner and outer canopy 'Starking'. A small segment of consumers in the black, white and coloured ethnic groups prefer acidic apples (Anreza Van der Merwe, unpublished data).

Consumer preference and familiarity

Consumers commonly make purchase decisions based on knowledge that is stored in their memories from previous experience (Brucks, 1985). Experience is defined as the summation of a consumer's past related consumption activities (Alba and Hutchinson, 1987). Experience is an important factor especially when dealing with fresh foods, especially those marketed without a reference to a brand image (Oude Ophuis, 1985).

The role of experience in the preference for 'Granny Smith' appears to be masked by the differences in the general taste preferences of the predominanly white Stellenbosch and black and coloured Ceres consumers. Ceres consumers gave very low scores for this cultivar compared to Stellenbosch consumers due to their general dislike for sour apples. Even so, cluster analysis show that some Ceres consumers prefer the taste and appearance of the blushed outer 'Granny Smith', probably because they know that these fruit are usually sweeter than inner canopy fruit. Clusters show that Ceres consumers preferred the appearance and taste of sunburnt and outer canopy 'Golden Delicious' fruit. Some Stellenbosch consumers preferred the taste of the sunburnt fruit, but it is apparent that unlike some Ceres consumers, they cannot associate the taste with the appearance of the fruit.

Through consumption and other experiences with products, a consumer builds their self-confidence with the product (Park and Lessig, 1981). Stellenbosch consumers lack experience with blushed fruit of green cultivars as well as exposure to sunburn fruit and therefore do not have much confidence in these products when presented with photographs of them. However, upon tasting, some consumers actually preferred the taste of these products. Novel foods are initially rejected (Birch and Marlin, 1982), but preference increases with exposure to these foods (Pliner, 1982). Therefore, more exposure of consumers to blushed ‘Granny Smith’ and ‘Golden Delicious’ fruit may lead to an increase in preference. Both consumer groups preferred the taste and appearance of outer canopy ‘Starking’ fruit . This is not surprising as both consumer groups are well accustomed to red apples. As for cherries, consumers may associate more intense red colouration with higher fruit quality and better taste (Crisosto et al., 2002).

Fruit colour is a very important factor in determining consumer preference. Consumers may develop some learned associations between fruit colour and fruit quality (Daillant-Spinnler et al., 1996) and even at a young age, people begin to develop preference for different coloured apples (Thybo et al., 2004). However, some of these associations may be misleading. Consumers mistakenly identified ‘Jonagold’, a tart apple, as a sweet apple due to its red colour (Schechter, 2010). The rejection of sunburnt and blushed apples on appearance while showing preference for their taste falls in the same category.

As observed in our research, consumer preference for apples does not reside in fruit colour alone (Steyn, 2012). Factors such as familiarity and learned associations have a strong bearing on consumer preference (Pollard et al., 2002; Clydesdale, 1993). Previous studies (Harris and Booth, 2007; Houston-Price et al., 2009; Oude Ophuis, 1993) all highlight the effect of exposure and previous experience on consumer preference as illustrated by the comparison of Ceres and Stellenbosch consumers. In a study comparing Danish and British consumers, there were no cross-cultural differences between the preferences of these consumer groups to three apple cultivars. This was attributed to the similar degree of familiarity of both consumer groups with these cultivars (Jaeger, 1998). This is what we observe with ‘Starking’ in our research.

CONCLUSION

Familiarity plays an important role in consumer preference. The appearance of ‘Golden Delicious’ sunburnt and blushed fruit were disliked by Stellenbosch consumers. However, a considerably portion of Ceres consumers preferred the appearance of sunburnt fruit due to familiarity with such fruit. ‘Golden Delicious’ blushed fruit are sought after and fetch the highest price in South Tyrol, Italy (Martin Thalheimer, personal communication). Therefore, exposing consumers to this product may lead to higher preference. Though the taste of sunburnt fruit was preferred, it is yet to be established if consumers would prefer the appearance of this fruit after being exposed to it. Unfortunately, sunburnt fruit may store poorly (Arndt, 1992) and further research may be required to determine the storability of these fruit (Schrader et al., 2009).

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Table 1. The effect of canopy position (inner canopy versus outer canopy fruit) on the background colour, sunburn intensity and hue angles of outer and inner canopy ‘Golden Delicious’, ‘Starking’ and ‘Granny Smith’ fruit harvested in 2011 at Vastrap Farm in Ceres, Western Cape, South Africa; measured after approximately one month storage at -0.5 ^{0}C.

	Background colour	**Hue angles (◦)**
Golden Delicious		
Inside Canopy	1.7 b^{z}	112.2 a
Outside Canopy	1.8 b	94.9 b
Outside Canopy: Sunburnt	2.2 a	110.2 a
P value	*0.0002*	*<0.0001*
Granny Smith		
Inside Canopy	1.5 ^{NS}	114.2 a
Outside Canopy	1.5	89.8 b
P value	*0.8619*	*<0.0001*
Starking		
Inside Canopy	2.0 b	58.1 a
Outside Canopy	2.8 a	21.3 b
P value	*<0.0001*	*<0.0001*

^{NS} Non-significant

^{z} Means with different letters differ significantly at P<0.05

Table 2. The effect of canopy position on firmness, titratable acidity (TA), total soluble solids (TSS), TSS:TA ratio and percentage dry matter concentration (DMC) for 'Golden Delicious', 'Granny Smith' and 'Starking' harvested in 2011 at Vastrap Farm in Ceres, Western Cape, South Africa measured after approximately one month storage at -0.5 ^{0}C.

	TSS (ºBrix)	TA (%Malic acid)	TSS:TA	Firmness (N)	DMC (%)
Golden Delicious					
Inside Canopy	11.2 b[z]	0.42 a	26.9 c	73.5 b	13.0 c
Outside Canopy	13.4 a	0.42 a	31.8 b	79.4 a	15.7 b
Outside Canopy: Sunburnt	13.7 a	0.31 b	45.0 a	78.4 a	17.2 a
P value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0003*	*<0.0001*
Granny Smith					
Inside Canopy	11.5 b	0.68 [NS]	17.0 b	79.4 b	13.7 b
Outside Canopy	12.9 a	0.71	18.3 a	86.2 a	15.7 a
P value	*<0.0001*	*0.2339*	*0.0226*	*<0.0001*	*<0.0001*
Starking					
Inside Canopy	10.4 b	0.29 [NS]	36.5 b	82.3 [NS]	13.8 b
Outside Canopy	13.0 a	0.27	48.5 a	82.3	16.0 a
P value	*<0.0001*	*0.0616*	*<0.0001*	*0.7992*	*0.0007*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05.

Table 3. The effect of canopy position (inner canopy versus outer canopy fruit) on the overall means of sensory characteristics of 'Golden Delicious', 'Granny Smith' and 'Starking' apple cultivars apples harvested at Vastrap Farm in Ceres, Western Cape, South Africa; measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2011.

Treatment	Apple flavour	Sweet Taste	Sour Taste	Crispness	Crunchiness	Hardness	Juiciness
Golden Delicious							
Inside Canopy	56.1 b[z]	51.0 c	45.3 a	57.3 a	56.5 a	53.8 b	58.0 a
Outside Canopy	60.8 a	57.4 b	41.2 a	59.5 a	58.7 a	56.5 a	59.3 a
Outside Canopy: Sunburnt	51.2 c	62.3 a	27.3 b	51.3 b	50.7 b	51.4 b	50.2 b
P value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Granny Smith							
Inside Canopy	58.1 b	54.3 b	58.1 a	64.5 [NS]	62.8 b	59.0 b	63.0 [NS]
Outside Canopy	59.8 a	57.0 a	53.9 b	64.4	64.5 a	61.3 a	62.7
P value	*0.0317*	*0.0009*	*<0.0001*	*0.8560*	*0.0085*	*0.0005*	*0.7703*
Starking							
Inside Canopy	47.2 b	48.8 b	36.2 a	60.0 b	59.3 b	54.5 [NS]	59.1 b
Outside Canopy	57.8 a	65.0 a	29.5 b	61.6 a	61.3 a	54.6	64.9 a
P value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0139*	*0.0031*	*0.9083*	*<0.0001*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05.

Table 4. Demographic table showing of the number of people in each age groups and gender of the consumers that took part in the tasting of apples from Ceres and Stellenbosch. Stellenbosch1 consumers tasted 'Granny Smith' and Stellenbosch2 consumers tasted 'Golden Delicious' and 'Starking'.

	Ceres (%)	Stellenbosch1(%)	Stellenbosch2 (%)
Age groups			
18-22	15	34	46
23-31	32	34	38
32-41	26	18	10
Above 41	27	14	6
Gender			
Male	81	30	29
Female	19	70	71
	***N*=117**	***N*=94**	***N*=100**

Table 5. The effect of canopy position on the preference for taste of Stellenbosch and Ceres consumers for 'Golden Delicious' apples.

Taste Liking		
Ceres		
In	5.5	c [z]
Out	6.6	ab
Sunburn	6.9	a
Stellenbosch		
In	6.3	b
Out	6.6	ab
Sunburn	6.7	ab
P value		
Canopy Position	*<0.0001*	
Location	*0.1823*	
Location x Position	*0.0335*	

[z] Means with different letters differ significantly at $P<0.05$.

Table 6. The effect of canopy position on the preference for appearance of Stellenbosch and Ceres consumers for 'Golden Delicious' apples.

Appearance liking		
Canopy Position		
Inside Canopy	6.9	a [z]
Outside Canopy	6.2	b
Outside Canopy: Sunburnt	5.1	c
Location		
Ceres	6.1	NS
Stellenbosch	6.1	
P value		
Canopy Position	*<0.0001*	
Location	*0.3020*	
Location x Position	*0.8348*	

NS Non-significant

z Means with different letters differ significantly at P<0.05.

Table 7. The effect of canopy position on the preference for appearance and taste of Stellenbosch and Ceres consumers for 'Granny Smith' apples.

	Taste liking		Appearance liking	
Canopy Position				
Inside Canopy	5.2	NS	6.5	a
Outside Canopy	5.4		5.9	b
Location				
Ceres	4.2	b	5.8	b
Stellenbosch	6.6	a	6.6	a
P value				
Canopy Position	*0.2586*		*0.0080*	
Location	*<0.0001*		*0.0003*	
Location x Position	*0.6765*		*0.4800*	

NS Non-significant

z Means with different letters differ significantly at P<0.05.

Table 8. The effect of canopy position on the preference for appearance and taste of Stellenbosch and Ceres consumers for 'Starking' apples.

	Taste liking	Appearance liking
Ceres		
Inner canopy	5.4 c [z]	5.8 c
Outer canopy	7.2 a	8.2 a
Stellenbosch		
Inner canopy	5.5 c	6.3 c
Outer canopy	6.4 b	7.6 b
P value		
Canopy Position	*<0.0001*	*<0.0001*
Location	*0.1449*	*0.7108*
Location x Position	*0.0228*	*0.0071*

[z] Means with different letters differ significantly at P<0.05.

Table 9. Consumers' opinions data for Ceres and Stellenbosch consumers on the degree of liking for various apple sensory characteristics that are considered most important for consumers.

Sensory characteristics	**Ceres**	**Stellenbosch**
Hard apples	5.0 c [z]	7.0 b
Juicy apples	8.2 a	7.1 ab
Sweet tasting apples	7.2 b	6.5 c
Apple flavour	8.2 a	7.3 a
Sour tasting apples	2.9 d	4.8 d
Mealy apples	3.0 d	2.1 e
P value	*<0.0001*	*<0.0001*

[z] Means with different letters differ significantly at P<0.05.

Table 10. Consumers' opinions data for Ceres and Stellenbosch on the degree of liking for apple peel appearance for cultivars evaluated in this research as well as the general appearance characteristics in apples.

Apple peel appearance	**Ceres**		**Stellenbosch**	
Golden Delicious	8.1	a [z]	6.7	a
Blush apples	6.2	c	6.5	ab
Red apple	7.9	a	6.2	bc
Starking	7.2	b	6.1	c
Green apples	5.0	d	6.5	ab
Granny Smith	5.5	d	6.2	bc
P value	*<0.0001*		*0.0084*	

[z] Means with different letters differ significantly at $P<0.05$.

Table 11. Consumers' opinions data for 2010 and 2011 on the degree of liking for apple peel appearance for cultivars evaluated in this research as well as the general appearance characteristics in apples.

Apple peel appearance	**Ceres**		**Stellenbosch**	
Colour	8.2	a [z]	7.8	a
Price	7.2	c	6.3	b
Shape	7.5	bc	6.2	b
Size	7.9	ab	6.5	b
P value	*0.0020*		*<0.0001*	

[z] Means with different letters differ significantly at $P<0.05$.

Table 12. Results of cluster analysis for 'Golden Delicious' appearance liking.

A. Stellenbosch consumer descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**
		N [y] =45 (48%)	N=34 (37%)	N=14 (15%)
Ethnic group	W	43	29	13
	B	2	5	1
Gender	Male	16	9	3
	Females	29	25	11
Age Group (years)	18-22	16	12	3
	22-31	16	9	7
	31-41	8	7	2
	+41	5	6	2
Canopy Position	In	7.2 [NS]	7.5 a [z]	6.3 a
	Out	6.8	6.5 b	3.6 b
	Sunburnt	6.6	3.8 c	2.7 b
	P value	*0.1457*	*<0.0001*	*0.0002*

B. Ceres consumers descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**
		N [y] =46 (40%)	N=40 (35%)	N=29 (25%)
Ethnic group	C	13	21	11
	B	33	19	18
Gender	Male	34	33	26
	Females	12	7	3
Age Group (years)	18-22	7	5	5
	22-31	12	12	11
	31-41	17	8	6
	+41	10	15	7
Canopy Position	In	2.9 c [z]	7.9 a	6.4 a
	Out	4.9 b	6.5 b	7.1 a
	Sunburnt	8.2 a	7.2 a	3.9 b
	P value	*<0.0001*	*0.0007*	*<0.0001*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05.

[y] where N= number of consumers in the cluster, W = white, C= coloured, B= black.

Table 13. Results of cluster analysis for ‘Golden Delicious’ taste liking.

A. Stellenbosch consumer descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**
		N [y] =42 (45%)	N=24 (26%)	N=28 (30%)
Ethnic group	W	36	24	21
	B	6		7
Gender	Male	12	6	10
	Females	30	18	18
Age Group (years)	18-22	11	10	11
	22-31	16	9	7
	31-41	9	2	6
	+41	6	3	4
Canopy Position	In	7.3 b [z]	7.0 a	4.2 b
	Out	7.6 ab	6.9 a	4.9 b
	Sunburnt	7.8 a	5.0 b	6.6 a
	P value	*0.0330*	*<0.0001*	*<0.0001*

B. Ceres consumer descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**
		N [y] =63 (54%)	N=21 (18%)	N=32 (28%)
Ethnic group	C	23	8	13
	B	40	13	19
Gender	Male	51	17	27
	Females	12	4	5
Age Group (years)	18-22	6	3	8
	22-31	21	6	9
	31-41	17	6	8
	+41	19	6	7
Canopy Position	In	7.2 [NS]	2.6 b [z]	3.1 c
	Out	7.0	6.3 a	6.9 b
	Sunburnt	7.4	3.3 b	8.1 a
	P value	*0.6026*	*<0.0001*	*<0.0001*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05.

[y] where N= number of consumers in the cluster, W = white, C= coloured, B= black.

Table 14. Results of cluster analysis for 'Granny Smith' appearance liking.

A. Stellenbosch consumer descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
		N [y]=39 (39%)	N=17 (17%)	N=12 (12%)	N=32 (32%)
Ethnic group	W	32	17	10	27
	B	7		2	5
Gender	Male	12	6	2	8
	Females	27	11	10	24
Age Group (years)	18-22	19	4	6	17
	22-31	15	6	5	12
	31-41	4	3	0	3
	+41	1	4	1	0
Canopy Position	In	8.5 a [z]	7.7 a	5.9 a	7.2 a
	Out	6.9 b	6.4 b	3.0 b	4.8 b
	P value	*<0.0001*	*0.0003*	*0.0170*	*<0.0001*

B. Ceres consumer descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**
		N [y] =37 (32%)	N=50 (44%)	N=28 (24%)
Ethnic group	C	20	19	6
	B	17	31	22
Gender	Male	26	45	22
	Females	11	5	6
Age Group (years)	18-22	6	8	3
	22-31	10	12	13
	31-41	12	13	6
	+41	9	17	6
Canopy Position	In	8.1 a	7.6 [NS]	1.3 b
	Out	3.1 b	7.2	5.1 a
	P value	*<0.0001*	*0.1408*	*<0.0001*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05

[y] where N= number of consumers in the cluster, W = white, C= coloured, B= black.

Table 15. Results of cluster analysis for 'Granny Smith' taste liking.

A. Stellenbosch consumer descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**
		N [y] =72 (72%)	N=6 (6%)	N=22 (22%)
Ethnic group	W	62	5	19
	B	10	1	3
Gender	Male	21	0	8
	Females	51	6	14
Age Group (years)	18-22	30	3	13
	22-31	29	2	7
	31-41	8	1	1
	+41	5		1
Canopy Position	In	7.4 NS	3.1 NS	4.5 NS
	Out	7.4	7.6	3.8
	P value	*0.9998*	*0.0812*	*0.1053*

B. Ceres consumer descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**
		N [y] =21 (18%)	N=34 (29%)	N=61 (53%)
Ethnic group	C	7	13	25
	B	14	21	36
Gender	Male	18	31	45
	Females	3	3	16
Age Group (years)	18-22	5	6	6
	22-31	4	9	22
	31-41	8	8	15
	+41	4	11	18
Canopy Position	In	2.1 b [z]	7.5 NS	2.9 a
	Out	7.3 a	7.1	1.9 b
	P value	*<0.0001*	*0.3105*	*0.0004*

[NS] Non-significant

[z] Means with different letters differ significantly at $P<0.05$

[y] where N= number of consumers in the cluster, W = white, C= coloured, B= black.

Table 16. Results of cluster analysis for 'Starking' appearance liking.

A. Stellenbosch consumer descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**
		N [y] =50 (53%)	N=33 (35%)	N=11 (12%)
Ethnic group	W	46	26	10
	B	4	7	1
Gender	Male	13	14	1
	Females	37	19	10
Age Group (years)	18-22	13	13	6
	22-31	21	8	3
	31-41	10	5	2
	+41	6	7	
Canopy Position	In	7.4 b [z]	4.9 b	5.3 [NS]
	Out	8.2 a	7.8 a	4.5
	P value	*0.0001*	*<0.0001*	*0.7776*

B. Ceres consumer descriptors		**Cluster 1**	**Cluster 2**	**Cluster 3**
		N [y] =14 (12%)	N=33 (29%)	N=68 (59%)
Ethnic group	C	4	14	27
	B	10	19	41
Gender	Male	12	27	54
	Females	2	6	14
Age Group (years)	18-22	2	5	10
	22-31	4	12	19
	31-41	6	10	15
	+41	2	6	24
Canopy Position	In	6.6 a	3.1 b	7.0 b
	Out	4.0 b	8.7 a	8.8 a
	P value	*0.0079*	*<0.0001*	*<0.0001*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05.

[y] where N= number of consumers in the cluster, W = white, C= coloured, B= black.

Table 17. Results of cluster analysis for 'Starking' taste liking.

A. Stellenbosch consumer descriptors		Cluster 1	Cluster 2	Cluster 3
		N [y] =43 (46%)	N=17 (18%)	N=34 (36%)
Ethnic group	W	37	17	28
	B	6		6
Gender	Male	11	1	16
	Females	32	16	18
Age Group (years)	18-22	12	10	10
	22-31	18	5	9
	31-41	8	2	7
	+41	5		8
Canopy Position	In	7.5 [NS]	3.4 [NS]	4.2 b [z]
	Out	7.7	2.5	6.7 a
	P value	*0.2333*	*0.0725*	*<0.0001*

B. Ceres consumer descriptors		Cluster 1	Cluster 2	Cluster 3
		N [y] =40 (35%)	N=49 (43%)	N=26 (22%)
Ethnic group	C	11	19	15
	B	29	30	11
Gender	Male	33	37	23
	Females	7	12	3
Age Group (years)	18-22	5	6	6
	22-31	12	14	9
	31-41	14	11	6
	+41	9	18	5
Canopy Position	In	2.6 b	7.9 b	4.9 a
	Out	7.9 a	8.5 a	3.6 b
	P value	*0.0001*	*0.0083*	*0.0191*

[NS] Non-significant

[z] Means with different letters differ significantly at P<0.05.

[y] where N= number of consumers in the cluster, W = white, C= coloured, B= black.

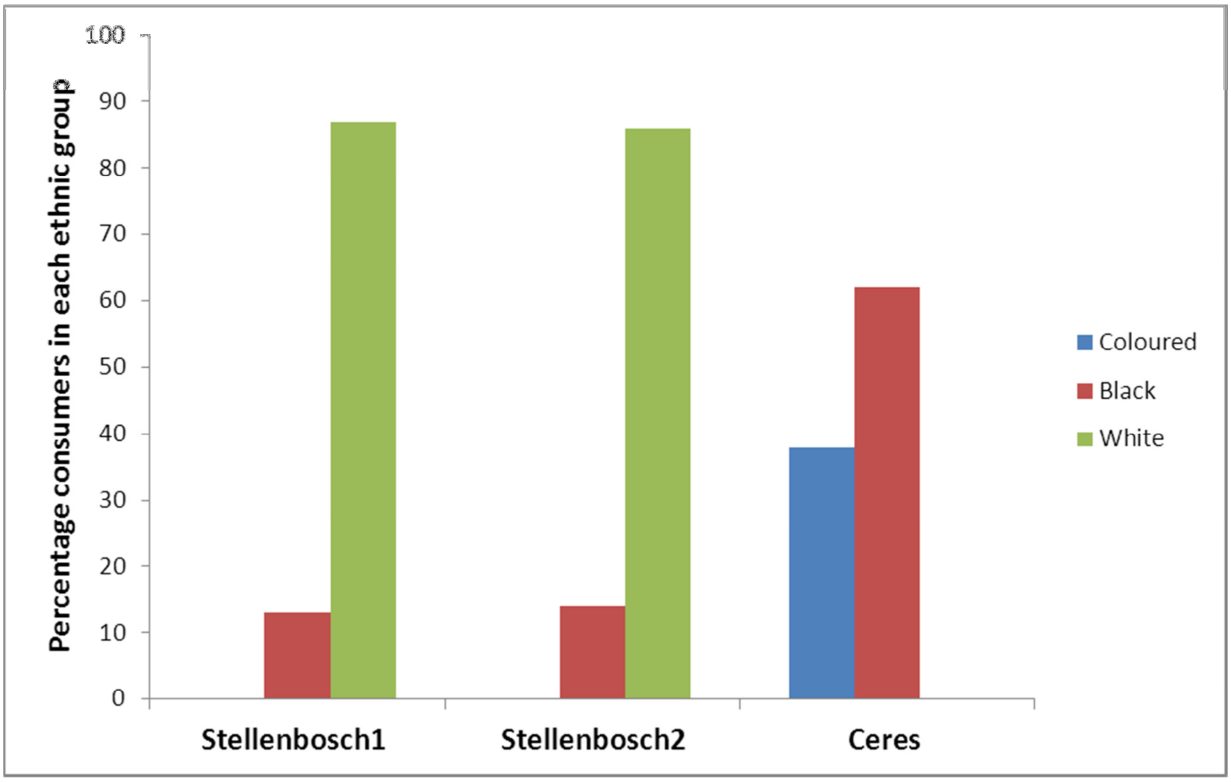

Fig. 1. The demographics of the ethnic groups (based on skin colour) of consumers from Stellenbosch and Ceres. Stellenbosch1 consumers tasted ‘Granny Smith’ and Stellenbosch2 consumers tasted ‘Golden Delicious’ and ‘Starking’.

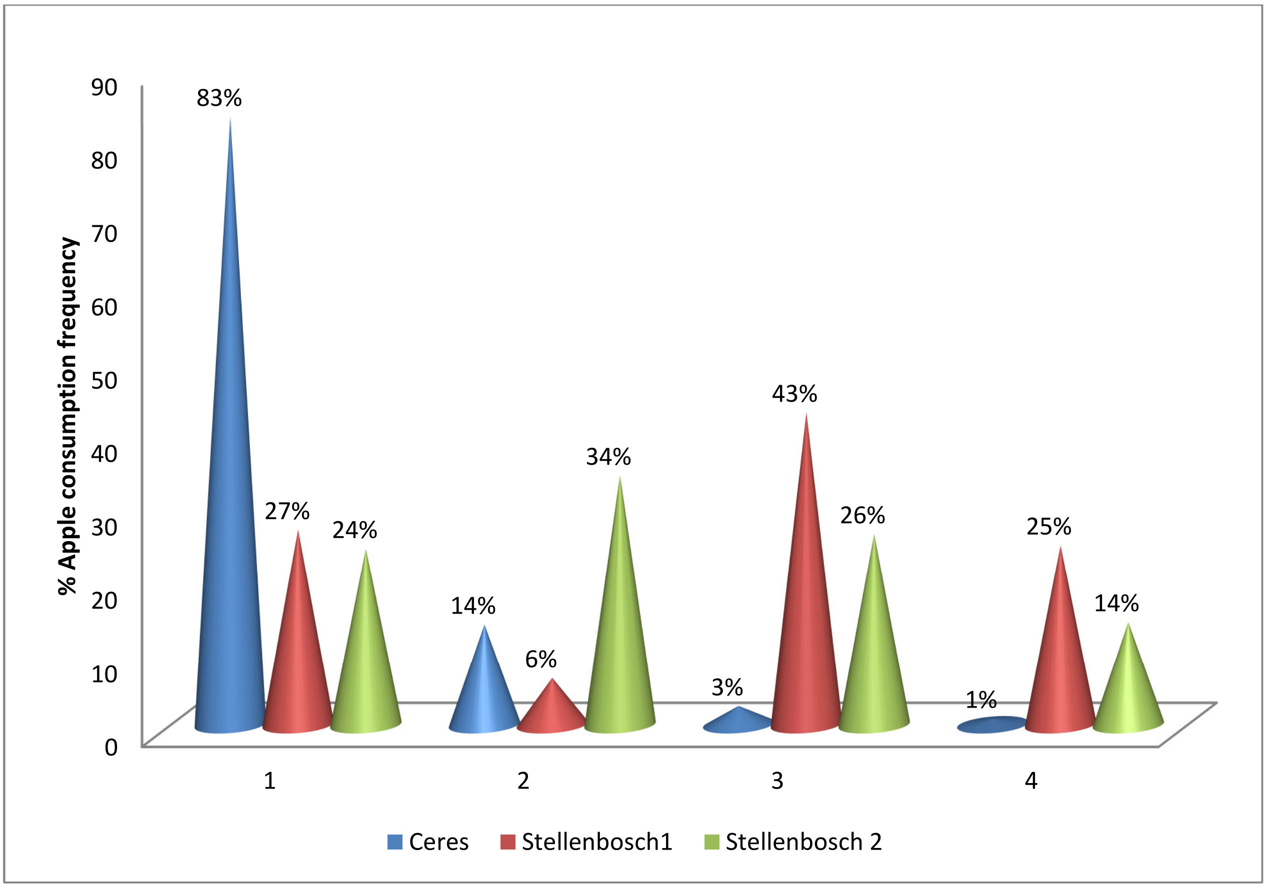

Fig. 2. The figure illustrates the apple consumption frequency of the Ceres and Stellenbosch consumers. Consumption frequency 1= consumes apples 5 to 7 times per week; 2= consumes apples 3 to 4 times per week; 3= consumes apples at least once per week; 4= consumes apples at least twice a month.

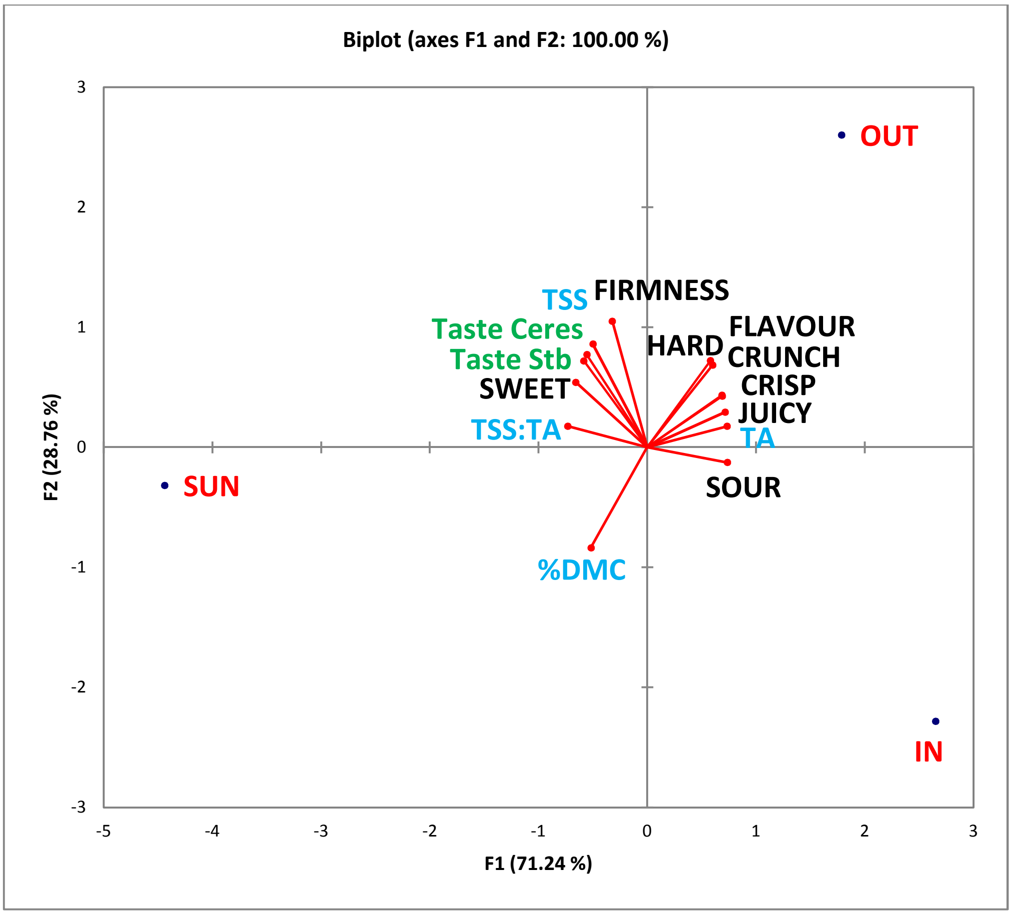

Fig. 3. Principal Component Analysis (PCA) bi-plot indicating the position of consumer preference for taste liking for Ceres (Taste Ceres) and Stellenbosch (Taste Stb) in relation to the sensory attributes (black) and chemical composition (blue) of inside canopy, outside canopy and outside canopy sunburnt 'Golden Delicious' apple fruit (red).

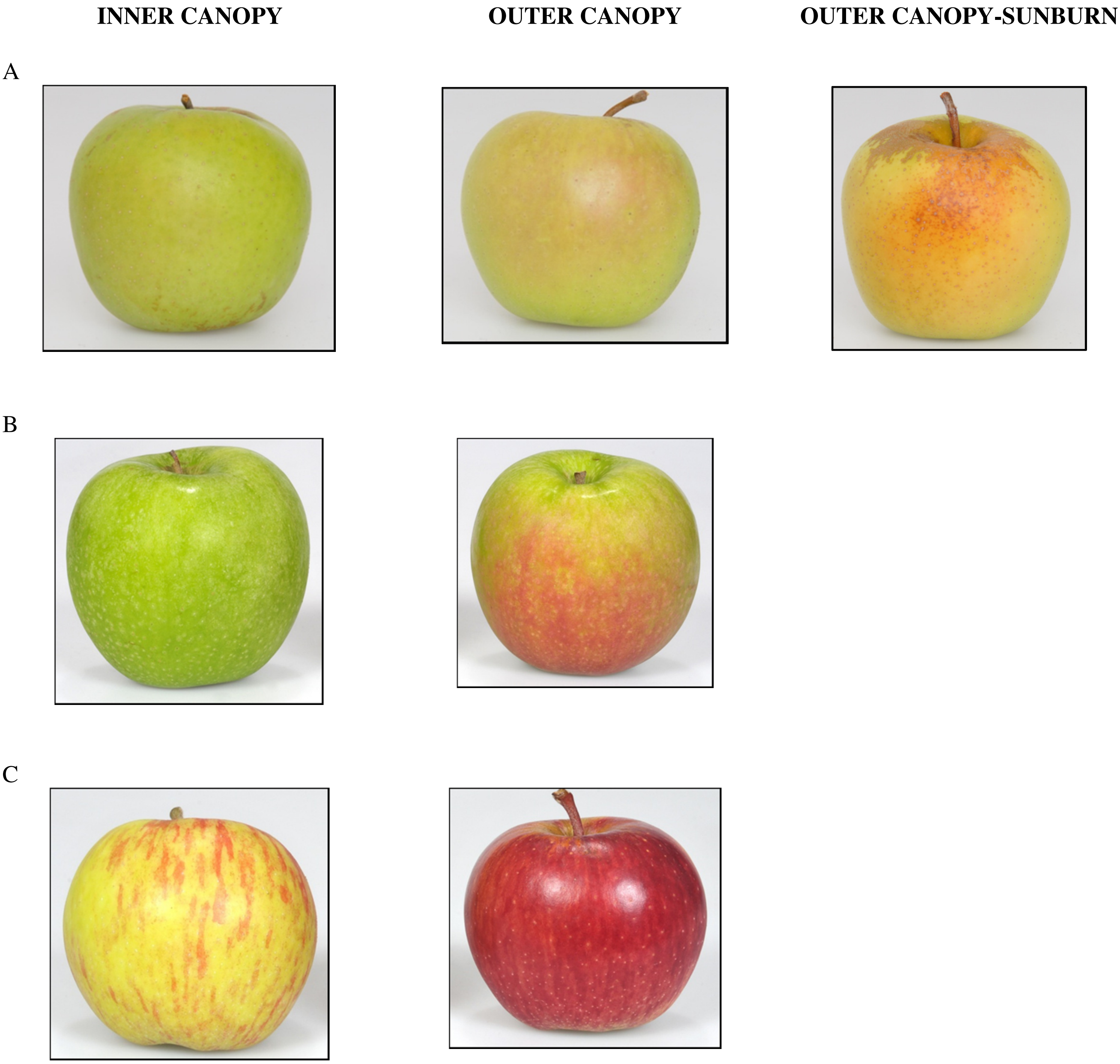

Fig. 4. Images of inner and outer canopy fruit of ‘Golden Delicious’ (A), ‘Granny Smith’ (B) and ‘Starking' (C) harvested from Ceres.

GENERAL DISCUSSION AND CONCLUSION

We set out to determine how the microclimatic variations brought about by canopy position influence apple fruit quality characteristics and ultimately the consumer preference of apple fruit. Differences in fruit quality and consumer preference for inner and outer canopy fruit may justify harvesting and marketing them separately. We also wanted to determine if red colour in apple peel is a reliable indicator of fruit quality to consumers and whether there might be a niche market for fruit with sunburn browning and blushed fruit of green cultivars. In order to achieve these objectives, quality and consumer assessments were made for ‘Golden Delicious’, ‘Granny Smith’ and ‘Starking’ fruit harvested from the innermost and outermost portions of the canopy. Ecophysiological measurements confirmed that outer canopy fruit are exposed to higher irradiance and are heated to high temperatures (Paper1). Differences in the composition of inner and outer canopy fruit resulted in differences in their appearance and taste that affected consumer preference for these fruit.

Fruit quality

In all three cultivars, peel from outer canopy fruit was higher in ascorbic acid, phenolic compounds (measured via the FC method) and antioxidant capacity. These compounds play a photoprotective role in apple peel and light is an important regulatory factor in their synthesis (Demmig-Adams and Adams III, 1992; Ma and Cheng, 2003). Apple flesh from outer canopy fruit was also higher in antioxidant capacity and phenolic compounds (measured via FC method). Ascorbic acid was only higher in the flesh of outer canopy ‘Granny Smith’ fruit. The higher concentrations of phenolics in apple flesh require further research as literature is not consistent regarding the effect of light and temperature on the pathways that regulate phenolic levels in apple flesh (Drogoudi and Pantelidis, 2011; Hagen et al., 2007). Outer canopy ‘Golden Delicious’ and ‘Granny Smith’ fruit developed a red blush, while outer canopy ‘Starking’ fruit had a more intense red colouration due to greater light-induced anthocyanin synthesis (Steyn et al., 2005).

In a survey, consumers revealed that one of the reasons they eat apples is because of their perception that apples are good for health and promote a long life (Jaeger and MacFie, 2001). Anthocyanins, phenolics and ascorbic acid have high antioxidant activities and may provide protection against chronic diseases (Dragsted et al., 1993; Lila, 2004; Moyer et al., 2002;).

Hence, outer canopy fruit having higher concentrations of these beneficial compounds in the peel and, in some instances also in the flesh, may be perceived as a healthier product.

Outer canopy fruit may also be more nutritious and tastier than inner canopy fruit due to their consistently higher concentration of reducing sugars, TSS and percentage dry matter concentration (DMC) over the two seasons of the study. Outer canopy leaves and fruit intercept much more light resulting in enhanced synthesis of photoassimilates (Johnson and Lakso, 1986), resulting in more carbohydrates accumulating in outer canopy fruit (Robinson et al., 1983). Outer canopy fruit harvested in 2010 were lower in TA while no differences between inner and outer canopy fruit were observed in 2011. Variation in fruit composition brought about by seasonal differences was greater than that brought about by canopy microclimate. Seasonal differences in apple fruit quality have been observed in previous research (Nilsson and Gustavsson, 2007).

Consumer preference

Consumer preference is influenced by a number of factors including colour (Thybo et al., 2004), taste (Daillant-Spinnler et al., 1996; Harker, 2001) and non-quality related factors such as familiarity and previous exposure (Pollard et al., 2002). This research was able to assess how these factors influence consumer preference of inner and outer canopy fruit.

Consumers preferred the taste of the outer canopy fruit in all three cultivars. As expected from the differences in carbohydrate and acid content, outer canopy fruit were sweeter than inner canopy fruit in both years of our study. Inner canopy fruit were sourer in 2010. In 2011, ‘Granny Smith’ and ‘Starking’ inner canopy fruit were also perceived to be sourer. Results for apple flavour were not consistent for ‘Granny Smith’, whereas ‘Golden Delicious’ and ‘Starking’ were perceived to be higher in apple flavour in both years. Although apple flavour is influenced by several pre-harvest factors (Yahia, 1994), the influence of canopy position on apple flavour requires more research. Differences in textural attributes were not consistent. Outer canopy fruit tended to score higher for textural attributes in instances where differences were significant.

The consistency of the canopy position effect on consumer preference was evaluated by harvesting ‘Golden Delicious’ from five different orchards. Quality differences between inner and outer canopy fruit and the preference of consumers for the fruit were largely dependent on the orchard system used (Hampson et al., 2002; Wagenmakers, 1991). The smaller canopies of trees at higher planting densities reduced the differences between inner and outer canopy fruit, most likely due to greater light distribution into the smaller canopies. This result does not support our original consideration that separating inner and outer canopy 'Golden Delicious' fruit at harvest would improve product consistency and increase consumer satisfaction with the product.

Peel colour was a reliable indicator of fruit quality characteristics. Generally, the presence of a red blush in a green cultivar or increasing redness in a red cultivar indicates a sweeter taste and sometimes a better texture. In Starking, increasing redness signals increasing sweetness, which is the taste attribute associated with this cultivar. Similarly, in Golden Delicious, which also is a sweet cultivar, the presence of a red blush signals a sweeter and more preferred taste. Conversely, 'Granny Smith' fruit have a characteristic tart taste and are preferred by consumers for this attribute. Hence, the higher preference for the appearance of inner canopy 'Granny Smith' fruit could relate to consumers associating the dark green 'Granny Smith' with the higher acidity (Daillant-Spinnler et al., 1996).

The appearance of blushed 'Golden Delicious' and 'Granny Smith' as well as sunburnt 'Golden Delicious' outer canopy fruit was shunned by consumers. The basis for culling blushed outer canopy fruit of green cultivars is purely aesthetic considering that these fruit were of superior eating quality and were preferred for taste. We attribute the lower preference for sunburnt 'Golden Delicious' and blushed 'Golden Delicious' and 'Granny Smith' fruit to the negative perception or unfamiliarity of consumers with these products, which are either uncommon on the market (blushed 'Golden Delicious'), downgraded and sold at a lower price or processed). In contrast, redder outer canopy 'Starking' fruit were preferred by consumers. Increasing red colouration results in higher consumer preference for typically red products, such as cherries (Crisosto et al., 2002). The same principle may apply for 'Starking'. Consumers had a high preference for the bright red blush of outer canopy 'Golden Delicious' fruit from one of five farms, but the blushed fruit of the other four farms received low liking scores (Paper 3). This is agreement with the high preference for blushed 'Golden Delicious' apples in South Tyrol (Martin Thalheimer, personal communication). Although blushed 'Golden Delicious' fruit can be a successful commercial product, the challenge seems to lie in consistently producing enough fruit with the "right amount" of blush. This may prove difficult under South African conditions.

To further explore how canopy position affects consumer preference, Paper 4 compared two consumer groups, viz. "inexperienced" Stellenbosch consumers who obtain apples on the commercial market, and "experienced" Ceres consumers who as farm labourers are exposed to all the apples on the tree and also eat apples more frequently during the harvesting season. We hypothesised that the "experienced" consumers would score the blushed appearance of outer canopy 'Golden Delicious' and 'Granny Smith' fruit higher than Stellenbosch consumers since they are familiar with these fruit and also know from experience that they prefer the taste of these fruit. We included sunburnt 'Golden Delicious' fruit in the assessment, considering that the same argument would apply for these fruit that generally are higher in TSS, firmer and lower in TA than other fruit on the tree (Makeredza, 2011; Schrader et al., 2009). Our data confirmed that sunburnt fruit was lower in TA and higher in TSS:TA ratio and percentage DMC than outer canopy fruit without sunburn. Although no difference was observed for TSS, sunburnt fruit were sweeter, but lower in apple flavour and in all the textural attributes. Consumers from both locations preferred the taste and appearance of outer canopy 'Starking' fruit. Stellenbosch consumers showed the lowest preference for the appearance of sunburnt and outer canopy 'Golden Delicious' and 'Granny Smith' fruit. However, some of these very consumers preferred that taste of blushed and sunburnt fruit. Cluster analysis indicated that a significant group of Ceres consumers preferred the appearance of blushed and sunburnt 'Golden Delicious' fruit. We attribute this difference between Stellenbosch and Ceres consumers to differences in their familiarity with the taste and appearance of the blushed and sunburnt apples. Certainly familiarity and exposure play an important role in consumer preference of apples (Paper 4, Pollard et al., 2002). However, learned associations can also be misleading to consumers as illustrated by the lower preference for the appearance of outer canopy 'Golden Delicious' and 'Granny Smith' fruit despite their superior quality and taste preference (Paper 2). Similarly 'Jonagold', a tart apple, was mistaken for a sweet apple due to its red peel colour (Schechter, 2010). Apart from familiarity, ethnicity also played a role in these results, as the consumers from Ceres who were black and coloured are biased towards sweet tasting apples (Anreza Van der Merwe, unpublished data).

Conclusions and recommendations

Based on our research, there is no need to separately harvest and market inner and outer canopy fruit of green cultivars. Although consumers could discern taste differences between inner and outer canopy fruit from large canopies, fruit from smaller canopies were much more uniform in taste. However, we do not know how long term storage affects the taste and consumer preference of inner and outer canopy fruit.

There certainly is marketing potential for blushed outer canopy ‘Golden Delicious’ fruit. This has already been explored in South Tyrol in Italy where blushed ‘Golden Delicious’ fruit fetch higher prices (Martin Thalheimer, personal communication). Familiarizing consumers with this product through marketing would be beneficial. ‘Golden Delicious’ fruit with sunburn browning might have a niche on the local market where they can be sold with no or minimal storage. Although sweeter tasting, sunburnt fruit have poor textural qualities and may not have good storability (Arndt, 1992). It may be more difficult to develop a market for blushed outer canopy ‘Granny Smith’ fruit, because consumers like the sour taste of this apple, most probably associate the dark green colour of inner canopy fruit with higher acidity.

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