# EFFECT OF CANOPY POSITION ON FRUIT QUALITY AND CONSUMER PREFERENCE FOR THE APPEARANCE AND TASTE OF PEARS

By

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# DECLARATION

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# SUMMARY

We aimed to determine how canopy position influences fruit quality and consumer preference for the eating quality and appearance of 'Forelle', 'Bon Chrétien' and 'Bon Rouge' pears. Our hypothesis was that consumer preference would be higher for the appearance and eating quality of outer canopy fruit.

Our first trial investigated the effect of canopy position and cold storage duration on quality attributes and consumer preference for 'Forelle' pears. Mealiness was much more prevalent in outer canopy fruit in 2012 and after 9 and 12 weeks cold storage in 2011. In 2011, consumers preferred the eating quality of inner canopy pears that had been subjected to 12 and 16 weeks of cold storage while inner canopy pears were generally preferred in 2012. This study provides support for the mandatory 12 weeks cold storage of 'Forelle' pears.

Our second trial investigated the effect of canopy position and harvest maturity within the commercial picking window on the quality attributes and consumer preferences for 'Forelle' pears. Inner canopy pears of harvest 1 (23 February) and harvest 2 (27 February) were significantly preferred in terms of eating quality. The general dislike for harvest 3 (13 March) pears and outer canopy fruit seemed to relate to an incidence of mealiness. Our results suggest that harvesting 'Forelle' pears at a firmness ≈6.2 kg will ensure that both inner and outer canopy pears have acceptable eating quality.

In our third trial, fruit were harvested at commercial firmness from two orchards in each of Elgin and Ceres to assess the effect of orchard site on quality attributes of 'Forelle' pears. Total soluble solids (TSS) were higher in Elgin while flavour attributes were more pronounced in Ceres. In both areas, outer canopy pears were higher in TSS and lower in titratable acidity (TA) but canopy position had no effect on sweet and sour taste. Mealiness incidence was high in outer canopy fruit from Elgin, as well as in one Ceres orchard. Further research over consecutive seasons is needed to determine the reasons for orchard differences in mealiness incidence.

Our fourth trial investigated the effect of canopy position on quality attributes and consumer preference for 'Bon Chrétien' and 'Bon Rouge' pears. Despite a higher TSS:TA ratio in outer canopy 'Bon Rouge' pears and a higher TSS and dry matter concentration in outer canopy 'Bon Chrétien' pears, canopy position did not affect sensory eating quality attributes. Seen overall, results indicate that canopy position has a minor effect on consumer preference for 'Bon Chrétien' and 'Bon Rouge' eating quality.

No significant differences in colour and consumer preference for appearance were found between outer and inner canopy 'Bon Chrétien' pears.  Consumers slightly preferred the redder outer canopy 'Bon Rouge' pears over the less red inner canopy fruit.  Although consumers preferred the red blush colour of outer canopy 'Forelle' pears, inner canopy pears also received high scores. Inner canopy 'Forelle' pears should not be viewed as inferior to outer canopy fruit with regard to both eating quality and appearance.

# OPSOMMING

Ons het gepoog om die effek van boomposisie op vrugkwaliteit en verbruikersvoorkeur vir die eetkwaliteit en voorkoms van 'Forelle', 'Bon Chrétien' en 'Bon Rouge' pere te ondersoek. Ons hipotese was dat verbruikersvoorkeur hoër sou wees vir die voorkoms en eetkwaliteit van pere van die buitekant van die boom se blaredak.

Ons eerste proef se doelstelling was om die effek van boomposisie en koelopberging op die kwaliteitseienskappe en verbruikersvoorkeur vir 'Forelle' pere te bepaal. Melerigheid was beduidend meer aanwesig in buitevrugte in 2012 asook na 9 en 12 weke koelopberging in 2011. Verbruikersvoorkeur vir eetkwaliteit was die hoogste vir binnevrugte na 12 en 16 weke koelopberging in 2011 terwyl binnevrugte in die algemeen voorkeur geniet het in 2012. Hierdie studie steun die bevindinge van vorige studies dat 'Forelle' pere vir ten minste 12 weke koelopgeberg moet word.

Die doel van ons tweede proef was om te bepaal of 'Forelle' pere wat by verskillende ryphede binne die kommersiële oesperiode geoes is, verskille toon in kwaliteitseienskappe en of hierdie verskille, indien enige, verband hou met verbruikersvoorkeur vir eetkwaliteit. Die eetkwaliteit van binnevrugte van oes 1 (23 Februarie) en oes 2 (27 Februarie) is verkies bo buitevrugte. Die algemene afkeur vir oes 3 (13 Maart) en buitevrugte kan moontlik toegeskryf word aan die hoë voorkoms van melerigheid. Ons resultate dui aan dat beide binne- en buitevrugte aanvaarbare eetkwaliteit behoort te hê indien 'Forelle' pere by 'n fermheid van ≈6.2 kg geoes word.

Vir ons derde proef is 'Forelle' pere geoes by kommersiële fermheid (≈6.4 kg) vanaf twee boorde in elk van Elgin en Ceres. Totale opgeloste vastestowwe (TOV) was hoër in Elgin pere terwyl geur-eienskappe meer prominent was in Ceres pere. In beide areas het buitevrugte hoër TSS en laer titreerbare sure (TS) gehad, maar boomposisie het egter geen effek op soet en suur smaak gehad nie. Die voorkoms van melerigheid was hoog in buitevrugte van die Elgin boorde, sowel as in een van die Ceres boorde. Verdere navorsing oor opeenvolgende seisoene word benodig om redes vir die verskille in die voorkoms van melerigheid tussen boorde te ondersoek.

Die doelstelling van ons vierde proef was om die effek van boomposisie op die kwaliteitseienskappe en verbruikersvoorkeur vir 'Bon Chrétien' en 'Bon Rouge' pere te ondersoek. Ondanks 'n hoër TOV:TS ratio in 'Bon Rouge' buitevrugte en 'n hoër TOV en droë massa konsentrasie in 'Bon Chrétien' buitevrugte, het boomposisie 'n minimale impak gehad op sensoriese eetkwaliteitseinskappe en verbruikervoorkeur vir die pere.

Boomposisie het geen effek op die kleur en verbruikersvoorkeur vir die voorkoms van 'Bon Chrétien' pere gehad nie. Verbruikers het 'n effense hoër voorkeur getoon vir die rooier 'Bon Rouge' buitevrugte. Alhoewel verbruikers die aantreklike rooi bloskleur van 'Forelle' buitevrugte verkies het, het die groen tot geel binnevrugte ook hoë voorkeurpunte behaal. Rakende voorkoms en eetkwaliteit, is 'Forelle' binnevrugte glad nie minderwaardig teenoor buitevrugte nie.

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**"And we know that in all things God works for the good of those who love him, who have been called according to his purpose."**

[Romans 8:28]

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# GENERAL INTRODUCTION

Fruit are produced throughout the canopy and are therefore exposed to varying irradiance and ambient temperatures that may affect postharvest fruit quality characteristics and influence consumer preference regarding eating quality and appearance (Bramlage, 1993; Frick, 1995; Fouché *et al*., 2010). A study on the irradiance levels within 'Granny Smith' apple trees in the Southern Hemisphere showed that outer canopy fruit on the northern side of the tree were exposed to 53% of full sunlight while inner canopy fruit near the trunk received only 2% of full sunlight (Fouché *et al*., 2010). Exposed fruit on the northern side of the row had the highest peel temperature throughout the season, approximately 5°C higher on average than the average ambient air temperature (24°C). In contrast, the inner canopy fruit did not differ from the ambient air temperature.

A recent study on the effect of 'canopy position on fruit quality and consumer preference of apples' found that outer canopy fruit was sweeter, had a higher TSS concentration, lower TA and had higher antioxidant capacities (Hamadziripi, 2012). This is probably due to greater access to photo-assimilates produced by outer canopy leaves. The colour of fruit is influenced by the concentration and distribution of anthocyanins, carotenoids and chlorophylls (Steyn, 2012). The synthesis of anthocyanins, responsible for red peel color in pears, requires light (Steyn, 2005). Therefore, the light exposure of pear peel determines the amount of red blush.

'Forelle' (*Pyrus communis* L.), a late season red blush pear, is South Africa's second most planted pear cultivar and occupies 26% of the area under pear production (Hortgro Services, 2011). 'Forelle' pears cultivated in South Africa are prone to be astringent or develop mealiness if they are not stored at -0.5°C for at least 12 weeks (De Vries & Hurndall, 1993; Martin, 2002; Crouch *et al*,. 2005; Crouch & Bergman, 2010; Carmichael, 2011). Mealiness, a dry textural disorder, is associated with a floury sensation in the mouth, with loss of juiciness, crispness and hardness (Barreiro *et al*., 1998). A ripened pear with good eating quality will have a juicy, buttery melting texture accompanied by a characteristic pear flavour (Zerbini, 2002).

The degree of maturity at harvest has a direct influence on the period for which pears can be stored without losing quality (Kvale, 1990; Kader, 1999) and it also affects the ripening potential (Kader, 1999; Crouch *et al*., 2005). Previous experience with climacteric fruit has proven that immature fruit will not ripen adequately after removal from cold storage and that these fruit will have poor sensory quality (Peirs *et al*., 2001). Fruit that are harvested at an advanced stage of maturity will have a short cold storage life where after they will quickly soften during ripening and become mealy (Peirs *et al*., 2001). Therefore, it is of the utmost importance that optimum harvest maturity must be well defined to reduce postharvest losses and maintain good eating quality after storage (Hansen & Mellenthin, 1979).

Previous research has indicated that mealiness was influenced by geographic and seasonal differences (Carmichael, 2011). In South Africa, 'Forelle' pears are mainly produced in the Western Cape where the growing areas have varying climatic factors which might influence harvest maturity and ripening potential of fruit (Wand *et al*., 2008). Seasons that experienced high total heat units were associated with mealiness incidence of 53% to 70% in pears (Hansen, 1961). Another study by Mellenthin and Wang (1976) found that 'd' Anjou' pears exposed to high temperatures six weeks before harvest had a high incidence of mealiness. Carmichael (2011) found that 'Forelle' pears from warmer production areas such as the Warm Bokkeveld and Elgin were more prone to mealiness compared to cooler areas such as the Koue Bokkeveld. On average, the Koue Bokkeveld region accumulates 1477 daily positive chill units (DPCU) annually and is cooler than the Warm Bokkeveld (1007 DPCU) and the Elgin region (768 DPCU) (Carmichael, 2011).

The ultimate objective of this research study was to determine how canopy position influences pear eating quality and consumer preference for 'Forelle', 'Bon Chretien' and 'Bon Rouge' pears. The aim of our first trial carried out over two seasons (2011/ 2012) was to determine whether outer and inner canopy 'Forelle' pears harvested at commercial maturity (≈6.4 kg) and subjected to different cold storage durations (9, 12 and 16 weeks) differ in quality attributes and how these differences, if any, relate to consumer preference for the eating quality of the pears (Chapter 2). In Chapter 3 we endeavored to investigate whether outer and inner canopy 'Forelle' pears harvested at different maturity stages differed in quality attributes and how these differences, if any, related to consumer preference for the appearance and eating quality of the pears. The aim of Chapter 4 was to determine whether inner and outer canopy pears from diverse climatic production areas differed in their physicochemical and sensory profiles. We especially focussed on the incidence of mealiness in all the chapters where 'Forelle' pears were studied. The objective of our fourth trial was to determine whether outer and inner canopy 'Bon Chretien' and 'Bon Rouge' pears differ in quality attributes and how these differences, if any, relate to consumer preference for pear eating quality and appearance (Chapter 5). The research chapters of the study were underpinned by a literature review (Chapter 1) on the effect of differential light exposure of fruit within the tree canopy on postharvest fruit quality and consumer preference.

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# CHAPTER 1 LITERATURE REVIEW

## THE EFFECT OF CANOPY ENVIRONMENT ON FRUIT QUALITY

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# 1. INTRODUCTION

The "Farm to Fork" approach is often used to explain the importance of every aspect of the production process on fruit quality (Crisosto *et al*., 1995). Both pre- and postharvest factors affect fruit quality. Pre-harvest factors include harvest maturity, climate, soil, nutrient levels, water status as well as applied chemicals (Thompson, 2003). In general, fruit quality cannot be improved after harvest, only maintained. Therefore, it is necessary to understand the important effects that pre-harvest factors may have on postharvest quality and the potential shelf-life of fruit (Bramlage, 1993). Environmental and tree cultivation management practices significantly influence the external and internal characteristics of fruit. Harvesting at the optimum maturity and the handling of fruit during and after harvest is also a major concern as mechanical damage and deterioration of fruit quality must be prevented. The correct cold storage conditions and duration is of the utmost importance to provide premium quality fruits that satisfy consumer needs (Frick, 1995).

Fruit quality is a multi-criteria concept that is not easily defined since it is a combination of physical and chemical attributes, both internal and external of the fruit (Kader, 1999). It can also mean different things to different people; it all depends on where they are positioned in the food value chain. To farmers, a commodity must be easy to harvest, have a high yield and good appearance, and must have good storage potential to be shipped to different markets. Good appearance, firmness and a long shelf-life are important for wholesale and retail marketers. Consumers judge fresh fruits on the basis of appearance, freshness and firmness at the point of initial purchase. Subsequent purchases depend upon the consumer's satisfaction in terms of sensory eating quality of the product. Safety and nutritional value are two aspects that are of growing importance to consumers (Crisosto *et al*., 1995; Kader, 1999). The sensory eating quality together with the appearance of the fruit, are two of the most important factors that influence consumer acceptance (Zerbini, 2002). Fruit quality, however, is an evolving variable that changes over time as consumers' expectations change (Harker *et al*., 2003).

Climatic variables, specifically light (Bramlage, 1993) and temperature (Frick, 1995) prevailing during fruit growth have a fundamental effect on the post-harvest quality of pome fruit. Fruit are produced throughout the canopy and are therefore exposed to varying irradiance, ambient temperatures, water and nutrient flow as well as endogenous supply of hormones (Kingston, 1994; Tomala, 1999). The developing fruit is a living system that consists of various biochemical pathways that may be influenced by several environmental factors (Wills *et al.*, 2007). It is therefore almost impossible to consider environmental factors in isolation. Fruit that are constantly exposed to sunlight may differ in quality from shaded fruit and may subsequently have different postharvest attributes (Thompson, 2003). This review will focus on the effect of differential light exposure of fruit within the tree canopy on postharvest fruit quality and consumer preference.

## 2. LIGHT INTERCEPTION AND DISTRIBUTION

Light responses are dependent on both the quantity and quality of light (Shahak *et al*., 2004). Light energy is absorbed by chlorophyll in order to drive photosynthesis, which affects the soluble solid concentration in fruit (Lambers *et al*., 1998). Light interception (LI) is the proportion of light available at the orchard level that falls onto leaves. LI determines the yield potential; therefore good light interception is necessary to obtain a high yield (Palmer, 1989). There are three factors that influence the yield of apples: the amount of light energy that the orchard system can intercept, the proportion of the absorbed light energy that is converted into available carbohydrates and lastly the amount of assimilates allocated into fruits (Wünsche & Lakso, 2000). Light exposure has the potential to influence the following processes in fruit: biosynthesis of pigments, fruit carbohydrate utilization, amino acid metabolism as well as acid metabolism (Rudell *et al*., 2008). The amount of light intercepted by an orchard system depends on orchard design factors like the training system, the spacing of the trees, tree shape, height of the trees, alley width as well as row orientation (Wünsche & Lakso, 2000). Increased light interception is usually found at higher tree densities that offer a greater leaf area and more even distribution of light (Palmer, 1989). At light interception of less than 50%, the yield is linearly related to the total amount of light that is intercepted by the orchard. These orchards usually have taller trees (Wagenmakers & Callesen, 1995) with open and well-exposed canopies (Palmer, 1989) which produces fruit with more colour (Wagenmakers & Callesen, 1995). It was found that fruit yields varied greatly at light interception levels above 50%, thus other factors such as light distribution becomes limiting. The distribution of light within the tree canopy also affects yield (Wünsche & Lakso, 2000) and fruit quality attributes such as fruit size, fruit colour (Wagenmakers & Callesen, 1995), total soluble solids (TSS) concentration and titratable acidity (TA) concentration (Lewallen, 2000). As a result of the negative effects of canopy shading (smaller fruits and less red colour), good apple yields were obtained at 70% light interception (Wagenmakers & Callesen, 1995). Fouché *et al*. (2010) found that outer canopy fruit in a 'Granny Smith' orchard were exposed to 54% (962 μmol $m^{-2}$ $s^{-1}$) of full sun in contrast to the inner canopy fruit that received only 2% (33 μmol $m^{-2}$ $s^{-1}$) of full sunlight during the course of an average day during the 2007/2008 season. Row direction also affects the percentage exposure to full sun. In the Southern Hemisphere, apples on the northern side of rows with an east west orientation received a higher percentage of sunlight than fruit on the southern side of the rows (Fouché *et al*., 2010).

## 3. THE EFFECT OF THE CANOPY LIGHT ENVIRONMENT ON FRUIT QUALITY

### 3.1 Maturity

Maturity can be defined as the completeness of development, while ripeness is defined as ready to eat (Wills *et al*., 2007). Maturity must take place while the fruit is still on the tree while ripening of climacteric fruit like apples and pears can occur on or off the tree. In order to ensure edible quality, the fruit need to be physiologically mature when harvested (Haller, 1952). The following attributes might be affected during ripening: fruit colour, respiration rate, ethylene production, tissue permeability, cellular structure, texture, organic acid concentration, protein concentration as well as the development of a specific aroma due to the production of volatiles (Wills *et al*., 2007). During fruit ripening, carbohydrate polymers are broken down and starch is converted to sugars. This impacts the taste (the increase in sugars makes the fruit much sweeter) and texture of the fruit. At a certain stage during the growth and development of fruit, the produce will have an optimum eating condition, after which the irreversible event of senescence will occur. Firmness, starch breakdown, ground colour, acid, sugars, ethylene and carbon dioxide production are maturity variables that are used to define fruit quality traits that can predict harvest maturity for optimum sensory eating quality (Watkins, 2003). The rate of change of these maturity variables is dependent on the biochemical and physiological changes that occur during maturation and ripening, in which temperature (Wang *et al*., 1971) and light (Kappel & Neilsen, 1994) are key factors. Low pre-harvest temperatures have a positive effect on the hydrolysis of starch to sugars in apples while high temperatures in contrast are inhibitory to this conversion (Smith *et al*., 1979). In addition, Wang *et al*. (1971) found that low temperatures that occurred four to five weeks prior to harvest caused premature ripening in ‘Bartlett’ pears.

Astringency in apples and pears is viewed as a maturity rather than a storage problem (Zerbini & Spada, 1993; Young *et al*., 1999; Mielke & Drake, 2005). The possible reason for this is the high levels of tannins in less mature fruit (Ramin & Tabatabaie, 2003). Farhoomand *et al*. (1977) found that upper and outer canopy ‘Delicious’ apples that ripened on the tree were more mature than inner and lower canopy fruit, even though inner and lower canopy fruit are more physiologically advanced with a higher ethylene production. In contrast, Jackson *et al*. (1977) found that outer canopy ‘Cox’s Orange Pippin’ apples had a higher respiration rate and ethylene production than shaded fruit. Krishnaprakash *et al*. (1983) reported that apples in the lower canopy matured earlier than the middle and upper canopy fruit.

Fruit maturity at harvest has a direct effect on the fruit storage period with regards to optimum quality (Kader, 1999) in that it will determine their susceptibility to mechanical injuries, their postharvest performance, their potential postharvest life and finally the sensory fruit quality (Kader, 1999; Murray *et al*., 2005). Differences among cultivars are expected, but maturity indices also differ among fruit from a single tree. It is believed that variability of maturity and quality at harvest and following the storage period is strongly affected by the canopy light environment during fruit development (Mowat & Chee, 1990; Murray *et al*., 2005). Lawes (1989) mentioned that fruit under poor light conditions takes longer to reach commercial harvest maturity; they are usually smaller in size, lower in firmness, has a low carbohydrate content, less red colour development as well as poor sensory attributes. Larger pear fruit have been found to have a lower firmness (Lötze & Bergh, 2005; Bai *et al.*, 2009). Murray *et al*. (2005) found that shaded 'Laetitia' plums (≤70% PPFD) were less mature at harvest, smaller in size, firmer, had poor red colour development and a lower soluble solids concentration. However, it was found that the ripening processes during postharvest cold storage proceeded more rapidly in shaded plums. The result was that the shelf-life of the shaded fruit was not inferior to the fruit that developed in exposed conditions. However, red colour development is lower at pre-harvest light exposure of less than 70%. Thus it was advised in this particular study that the light exposure should be at least 70% in all the different bearing positions, which will subsequently lead to more uniform maturity at harvest as well as better postharvest quality of plums. Other studies on plums show that lower canopy fruit are more mature than upper canopy fruit (Taylor *et al*., 1993).

Marini and Trout (1984) found that differences in maturity among peaches on the same tree accounted for more than half the variation in maturity even when fruit were harvested with the same ground colour. The shading of peach trees delays harvest and increases pre-harvest drop (Marini & Trout, 1984). Stone fruit that are harvested at an advanced maturity will not be able to withstand postharvest handling, have a short shelf-life and may develop unwanted overripe flavours and a mealy texture (Crisosto *et al*., 1995; Day *et al*., 1995; Kader, 1999). On the contrary, fruit that are harvested immature will not ripen to their optimum flavour and texture qualities, will lose water faster and may be prone to internal breakdown (Crisosto *et al*., 1995; Kader, 1999). Mangoes from the upper canopy ripened faster (Léchaudel & Joas, 2007) while sun-exposed avocados took longer to ripen at 20°C and were firmer than shaded fruit (Woolf *et al*., 1999). Taking into account all the above information, we infer that there does not seem to be any consistency regarding the effect of fruit canopy position, fruit maturity and ripening within a specific fruit cultivar.

## 3.2. Appearance

### ***3.2.1 Fruit colour***

Fruit colour is determined by pigment composition, which from a quality signalling and aesthetic perspective plays an important role in consumer acceptability (Steyn, 2012). Fruit colour in pome fruit results from the interaction between chlorophylls, carotenoids and anthocyanins present in the peel (Lancaster *et al*., 1994). Changes in peel colour of apples occur when fruit approaches maturity as a result of chlorophyll degradation in conjunction with the biosynthesis of anthocyanins and carotenoids (Saure, 1990; Honda *et al*., 2002). Even though carotenoids are synthesized during the growing stage, they are masked by the presence of chlorophyll. Carotenoids are stable compounds and therefore stay intact in the tissue even when senescence occurs (Wills *et al*., 2007). However, some apple and pear cultivars stay green, with just a slight change to a light green or yellow during ripening (Saure, 1990; Honda *et al*., 2002). Light is a prerequisite for anthocyanin synthesis in many fruit, including apple and pear (Steyn, 2009) and consequently for the external red colour of these fruit (Steyn, 2012). Awad *et al*. (2000) found that the sun-exposed apple peel had much higher anthocyanin and quercetin 3-glycoside levels than shaded peel. The anthocyanin, quercetin 3-glycoside and total flavonoid concentration were the highest in fruit from the top of trees, followed by outer canopy fruit, and lastly inner canopy fruit (Jackson *et al*., 1977; Dever *et al*., 1995; Awad *et al*., 2000).

Solar radiation in combination with cool temperatures at night promotes anthocyanin synthesis in apples and at least some pear cultivars (Saure, 1990; Honda *et al*., 2002; Steyn, 2009). In contrast to most other fruit, the highest anthocyanin concentrations are found in immature pears (Saure, 1990; Steyn, 2009). As a result of this pigmentation pattern, the degradation of anthocyanins at high temperatures may cause red colour loss towards harvest. Thus, light has two opposing effects in pears; it is prerequisite for anthocyanin synthesis, but also increases the loss of red colour through degradation of anthocyanins (Saure, 1990; Steyn *et al*., 2005). Carbohydrate accumulation and anthocyanin synthesis respond to the same environmental stimuli. Anthocyanin synthesis is sugar inducible, therefore poor fruit colour can be related to lower TSS levels (Roberts & Steyn, 2008). Poor red colour in apples at harvest is due to insufficient anthocyanin synthesis during the growing period and can therefore be linked to environmental factors such as low light levels within the tree canopy as well as high temperatures (Saure, 1990; Steyn *et al*., 2005).

Mangoes (Léchaudel & Joas, 2007), 'Bartlett' pears (Ramos *et al.* 1993) and apples (Tustin *et al*. 1988; Nilsson & Gustavsson, 2007) from the inner canopy have a greener peel colour than outer canopy fruit. Marini *et al*. (1991) found that shaded peaches developed a yellow ground colour later than fruit in high light conditions. Upper canopy peaches were intense purple, less orange-red, less firm, had higher total soluble solids content, lower citric acid content and a higher pH than fruit from the lower parts of the canopy (Génard & Bruchou, 1992; Laubscher, 2006). Syvertsen *et al*. (2003) found that the peel of shaded navel oranges was more orange than the peel of sun-exposed fruit. This is contradictory to all the other fruit examples that were discussed.

On some apple and pear cultivars, russet occurs naturally due to the appearance of dead and corked cells that originate from the secondary cambium or phellogen (Yuri & Castelli, 1998). The combination of low temperatures and free water on fruit during the vulnerable period (10-15 days after petal fall) have the potential to induce russet on pears, which is desirable in cultivars such as 'Conference' for the Spanish market (Asín *et al*., 2011). Asín *et al*. (2011) found that micro-sprinkler irrigation significantly increased russet on pears.

#### ***3.2.2 Fruit size and shape***

Inner canopy star-fruit were larger than exposed fruits (Zabedah *et al.*, 2007). The possible reason for this phenomenon is that high irradiance may affect the transpiration rate and the supply of assimilates to the developing star-fruit. Similar results were found in peaches (Loreti *et al*., 1993), mangoes and citrus fruit (Sites & Reitz, 1950) where fruit that received lower irradiance had a higher fresh weight. In contrast, pears (Ramos *et al*., 1993; Benitez & Duprat, 1998), kiwifruit (Tombezi *et al*., 1993) and apples (Tahir *et al*., 2007) that were exposed to more light were larger. The possible reason for this is that there is a higher percentage of intercellular airspace in larger fruit which consequently leads to softer fruit (Volz *et al*., 2004). Results from a comparison study on adjacent persimmon fruit from a canopy showed that even localized shading in the canopy can have a huge impact on fruit weight and quality (Mowat & Chee, 1990). Overall shading of trees during early development of fruit resulted in a reduction of fruit retention that led to a decrease in fruit size and crop load. Fruit temperature may have an effect on fruit weight as is the case for persimmons where fruit weight will be higher at 20°C, which is the optimum temperature for persimmon growth, in contrast to persimmons developing at 15°C or 30°C (Mowat & Chee, 1990). Avocado fruit that develop in cooler conditions are more rounded compared to fruit in warmer conditions which are more elongate (Arpaia *et al*., 2004). Westwood and Burkhart (1968) found that apples that were exposed to high day temperatures and cool night temperatures were more conic-elongate compared to those grown in hot days and warm nights. High temperatures increased cucumber fruit curvature (Kanahama, 1989).

### 3.3 Eating Quality

#### ***3.3.1 Flavour***

The olfactory sensations caused by volatile substances that are released in the mouth (aroma), gustatory senses (taste) as well as other chemical mouth-feel factors like astringency all contribute to flavour (Meilgaard *et al*., 1987). The eating quality of fruit depends on the composition of organic acids and sugars and the delicate balance between them (Ulrich, 1970; Laubscher, 2006). During the process of ripening, starch is converted to simple sugars that contribute to sweetness (Hubbard *et al*., 1990; Wills *et al*., 2007). There is a concomitant decrease in organic acids and phenolics thereby respectively decreasing sourness and astringency (Wills *et al*., 2007) while volatiles increase to produce the characteristic fruit aroma (Pantastico, 1975; Wills *et al*., 2007).

Pre-harvest light exposure influences the TSS concentration. Higher TSS was observed in light-exposed peaches (Marini *et al*., 1991; Lewallen & Marini, 2003), mangoes (Lechaudel & Joas, 2007), pears (Ramos *et al*., 1993), kiwifruit (Tombezi *et al*. 1993) and apples (Nilsson & Gustavsson, 2007; Hamadziripi, 2012) while TA was negatively correlated to the amount of light (Marini *et al*., 1991; Ramos *et al*., 1993; Kingston, 1994; Nilsson & Gustavsson, 2007). Outer canopy apple fruit have higher concentrations of dry matter and soluble solids; therefore it is safe to say that there is a close relationship between the level of light within the tree canopy and the amount of carbohydrates stored within the fruit at harvest (Jackson *et al*., 1977; Seeley *et al*., 1980; Tustin *et al*., 1988; Nilsson & Gustavsson, 2007; Hamadziripi, 2012). Fruit with a low TSS are likely to have poor sensory quality and low aroma intensity after storage and ripening as is the case for peaches (Harman, 1981; Mitchell, 1990).

Mellenthin and Wang (1976) found that the quality and the ripening of 'd' Anjou' pears after long storage periods was influenced by the daily-hourly average temperatures six weeks before harvest. Pears that grew at 13.9°C and 17.2°C had higher TA and TSS concentrations while pears that developed at 20°C and 11.7°C were of low quality and did not ripen adequately. As a result of high photosynthetic rates and reserves of carbohydrates, TSS concentrations were higher in pears that were cultivated in an environment with higher heat unit accumulation (Lötze & Bergh, 2005).

In most cases, fruit at the top of the tree will be of better quality than lower shaded canopy fruit (Day *et al*., 1992). Peaches (Génard & Bruchou, 1992; Marini *et al*., 1991) that grew at the top part of the canopy (well-exposed fruits) were less firm, had a higher sucrose content and lower citric acid, but overall a good sweet-sour balance compared to peaches in the bottom canopy. Krishnaprakash *et al*. (1983) found that apple fruit at the top of the canopy had better texture compared to apples at the bottom of the canopy, but lower mean values for juiciness, taste, aroma and soluble solids while there were no significant differences with regards to acidity. Tustin *et al*. (1988) worked with 'Granny Smith' apples and found that the inner canopy fruit had lower TSS concentrations. Dever *et al*. (1995) found that the non-blushed side of apples was crisper, less sweet, had lower pH values and soluble solids concentrations than the blushed side, independent of apple cultivar. The TSS concentration of kiwifruit increased with approximately 1°Brix for each metre of canopy above the ground and in addition fruit from the northern side of the vine (southern hemisphere) had a higher TSS (Smith *et al*., 1994).

Phenolic compounds are secondary plant metabolites that play an important role in the flavour of fruit (Spanos & Wrolstad, 1992) and are also known for their potential health benefits (Stoibiecki *et al*., 2002). Phenolic compounds act as UV-absorbing pigments in all plant organs and are influenced by environmental conditions, especially light irradiance and light quality (Burchard *et al*., 2000; Kolb *et al*., 2003; Andreotti *et al.*, 2006). The cultivar, stage of ripeness as well as conditions during storage can also influence the content of plant phenolics (Drewnowski & Gomez-Carneros, 2000). Phenolic compounds are responsible for bitterness and astringency in fruits (Drewnowski & Gomez-Carneros, 2000). The most common bitter compound in immature apples and other fruit is quercetin (Drewnowski & Gomez-Carneros, 2000). McDonald *et al*. (2000) found that outer canopy grapefruit contained a higher concentration of total phenols, including flavanols and coumarins when compared with inner canopy fruit.

Light is important in the biosynthesis of ascorbic acid, another important antioxidant and indicator of nutritional value (Ma & Cheng, 2004). Exposed star fruit (Zabedah *et al*., 2007) and apples (Hamadziripi, 2012) had higher ascorbic acid levels than inner canopy fruit.

### ***3.3.2 Texture***

The texture of food can be related to a group of physical characteristics that is associated with the deformation, disintegration and the flow of food under the application of a force (Bourne, 1980). Texture can be determined in a subjective way through direct human evaluation as well as objective (quantitative instruments) such as pressure test methods. Fruit texture is affected by attributes like cellular organelles, biochemical constituents, water content or turgor, as well as the composition of cell walls. Time of harvesting; conditions and duration of storage as well as the conditions of post-storage ripening are all factors that can modify the texture of fruit (Sams, 1999; Zerbini, 2002). Texture attributes are very important in determining consumer acceptability; however, it is important to always keep in mind that fruit texture is linked to individual consumer preference (Sams, 1999).

The temperature during fruit growth indirectly affects the cellular structure which relates to fruit texture and may cause damage to fruit (Sams, 1999). The maturity stage of fruit at harvest directly affects the texture of the fruit to be consumed (Knee & Smith, 1989). Thus, the measurement of flesh firmness is a good indicator of fruit maturity (Hansen & Mellenthin, 1979; Chen & Mellenthin, 1981). A decrease in flesh firmness is probably the most noticeable change that occurs during fruit ripening and is closely related to the texture of the fruit as well as the overall fruit quality (Wills *et al*., 1989; Zerbini, 2002). Firmer apple fruit are usually less ripe and consequently have a more acidic taste and have a volatile profile based on aldehydes that creates a grassy / stalky aroma and flavour (Harker *et al*., 2003). Softer apple fruit have a volatile profile containing esters that creates a fruity aroma and flavour. 'Cresthaven' peaches (Lewallen, 2000) and kiwifruit (Tombezi *et al*., 1993) that were exposed to high-light environments were firmer than the fruit that grew in shaded or low light environments. However, opposing results were obtained in 'Norman' peaches where the outer canopy fruit had a lower firmness (Lewallen, 2000). Blanpied *et al*. (1978) found that shaded inner canopy apples were less firm than outer canopy apples. Ramos *et al*. (1993) found that the firmness of 'Bartlett' pears was not influenced by canopy position. Thus, canopy position or the light environment does not have a consistent effect on the flesh firmness of fruit (Lewallen, 2000).

Mealiness is an umbrella term for fruit flesh developing a coarse, floury, soft and dry texture (Harker & Hallet, 1992; Barreiro *et al*., 1998; Andani *et al*., 2001). Mealy apples have a stale flavour and a floury and granular texture with very little juice (Jaeger *et al*., 1998) that is associated with the separation of cells from each other during mastication (Lapsley *et al*., 1992; Harker & Sutherland, 1993). A mealy pear tastes dry because the juice is not released from within the cells as a result of cell separation after the degradation of the middle lamella (Harker & Hallet, 1992; Crouch, 2011). Due to the separation, cells slide past each other instead of breaking, preventing the juice from being released. Mealiness, also known as low extractable juice content, is the key internal quality disorder associated with the sensory quality of ‘Forelle’ pears in South Africa (Martin, 2002; DFPT Technical Services, 2008; Carmichael, 2011).

Geographic and seasonal fluctuations influence the sensory quality related disorders, especially mealiness. Mealiness incidences of 70% were observed in a particular growing season where high temperatures were experienced (Hansen, 1961). In agreement, exposure of ‘d’ Anjou’ pears to high daily temperatures from about six weeks before harvest resulted in uneven ripening and a higher incidence of mealiness (Mellenthin & Wang, 1976). Carmichael (2011) indicated that fruit from the Warm Bokkeveld as well as Elgin, which are warmer areas than the Koue Bokkeveld, tended to be more prone to mealiness. Very little research has been done regarding the link between canopy position and the incidence of mealiness. Crisosto *et al*. (1997) found that mealiness and flesh browning in peaches were associated with fruit from the inner canopy.

### 3.4. Temperature and light-induced disorders

#### ***3.4.1 Pre-harvest induced disorders***

Air temperatures that exceed 30°C may cause peel temperatures to rise above 45°C, which in turn may result in sunburn in the presence of light (Schrader *et al*., 2003). Three types of sunburn have been identified, viz. photo-oxidative sunburn, sunburn necrosis and sunburn browning. Sunburn necrosis is heat-induced; when the fruit surface temperature of an apple reaches 52°C for only 10 minutes, thermal death of the cells in the peel occurs which leads to a dark spot that appears later (Schrader *et al*., 2003). Sunburn browning is the most common type of sunburn and results in a dark tan spot on the sun-exposed side of the apple. Apples with sunburn browning have been exposed to high solar irradiance and air temperatures that increase the fruit surface temperature (FST) to at least 46°C for one hour or more (Schrader *et al*., 2008). Photo-oxidative sunburn is a light-induced disorder where the fruit develops sunburn when it is suddenly exposed to full sunlight. For instance, when pruning takes place some apples that were exposed to shaded conditions are now suddenly exposed to light (Schrader *et al*., 2003). Apples with sunburn necrosis are not suitable for the fresh market as cell death occurs in outer layers of the peel. Apples with slight sunburn browning are often packed and marketed. High light in combination with high temperatures causes photooxidation and photodestruction of chlorophyll in apple peel even though the xanthophylls cycle (carotenoids) and antioxidant systems are up-regulated (Chen *et al*., 2008; Rudell *et al*., 2008).

The intensity of radiation and the circulation of air influences fruit temperature (Bergh *et al*., 1980). Smart and Sinclair (1976) found that intense sunlight and low wind velocity can result in the temperature of grape berries to rise 10-15°C above air temperature. Fouché *et al*. (2010) found that outer canopy 'Granny Smith' fruit on the northern side of east west rows in the Southern Hemisphere had the highest peel temperature throughout the season, approximately 5°C higher on average than the average ambient air temperature of 24°C. Outer canopy fruit on the southern side of rows and fruit from intermediate positions on the northern side of rows had slightly higher peel temperatures (25°C) than the ambient. Fruit from the inner canopy and intermediate positions on the southern side of rows did not differ in temperature from the ambient air temperature. Nearly 50% of the 'Granny Smith' apple crop is culled in the orchard as a result of sunburn (Fouché *et al*., 2010). Exposed fruit from the northern side of east-west rows received fruit surface temperatures 5°C higher than ambient air temperature (Fouché *et al*., 2010).

Sunburnt fruit has been found to be higher in TSS (Schrader *et al*., 2009; Makeredza, 2011, Hamadziripi, 2012), dry matter concentration (Hamadziripi, 2012) and firmness (Makeredza, 2011) compared to fruit without the disorder. Higher flesh firmness and TSS, lower relative water concentration and TA have been recorded on the sun-exposed side of apples (Schrader *et al*., 2009). An increase in firmness might slow down softening during storage (Makeredza, 2011). Apples with sunburn browning tend to be more mature (Schrader *et al*., 2009). The increased TSS may affect the taste acceptability (Schrader *et al*., 2009) in that the fruit are perceived as sweeter. Hamadziripi (2012) found that many consumers preferred the taste of sunburnt 'Golden Delicious' apples. Sunburnt fruit may have a shorter storage life as a result of the reduction in TA (Schrader *et al*., 2009), which consequently affects taste acceptability (Harker *et al*., 2003).

Sunburn is known to be one of the factors that cause shrivelling in vineyards (Krasnow *et al*., 2010). Grapes (Krasnow *et al*., 2010) and walnuts (Lampinen *et al*., 2009) can be damaged by sunburn, which is caused by a combination of high temperatures and ultraviolet radiation (Krasnow *et al*., 2010). Sunburn damages the epidermal tissues of berries and consequently causes berries to crack. Extreme cases of sunburn have caused the complete desiccation of berries and the formation of raisins (Krasnow *et al*., 2010).

Abnormal pre-harvest and postharvest conditions, microbial decay as well as mineral imbalances during the growth period may cause the development of physiological disorders such as bitterpit, chilling injury, superficial scald, watercore etc (Wills *et al*., 2007). The development of physiological disorders during postharvest ripening and storage of fruit is influenced by pre-harvest factors brought about by the positional effect that may reflect cropping and pollination effects as well as differences in the flow of minerals and water into the developing fruit (Ferguson *et al*., 1999).

The relationship between fruit position and nutrition as well as the responses of fruit to temperature changes or extremes play an important role in fruit development (Ferguson *et al*., 1999). High temperatures experienced pre-harvest by apples and avocados can influence the response of those fruit to high and low temperatures postharvest. Calcium is often associated with postharvest disorders such as bitter pit in apples. However, maturity is the only exception where calcium nutrition does not play a role in bitter pit development. Ferguson and Watkins (1989) found that the incidence of bitter pit was higher in less mature fruit, although the reason was unclear. In contradiction, observations with increased bitter pit were seen in 'Jonagold' apples that were exposed to high temperatures and water stress as they neared maturity (Seeley *et al*., 1980). Low mesocarp calcium concentrations in papayas have been linked with premature fruit softening (Qiu *et al*., 1995).

Watercore is a physiological disorder associated with dysfunction in carbohydrate physiology of apples. This disorder is found on the tree and can decrease during storage and ripening (Marlow & Loescher, 1984) but in some cultivars the affected fruit may then develop internal breakdown (Perring, 1971). Watercore incidence is associated with an increase in sorbitol in the extracellular spaces of the fruit. Two types of watercore have been identified. The first type is associated with late harvest and advanced maturity (Yamada *et al*., 1994). Low temperature during fruit maturation can exacerbate this type of watercore. The second type of watercore can be related to exposure of fruit to high temperature on the tree, before fruit maturation (Faust *et al.*, 1969). Translucence found in pineapples is similar to watercore as it is related to high radiation, temperatures and rainfall during growth (Solar, 1994). Translucence is more common in large fruit, a finding which suggests that it is related to fruit growth rates and the supply of carbohydrates (Soler, 1994).

### ***3.4.2 Storage-induced disorders that are modified by pre-harvest factors***

The ideal postharvest temperature for good quality maintenance of horticultural produce is just above its freezing point, where the metabolism is slow and the produce is above its chilling injury threshold temperature (Wills *et al*., 2007). Chilling injury (CI), also called internal breakdown (IB), dry fruit or woolliness appears during prolonged cold storage and/or after ripening after cold storage at room temperature. Subtropical and tropical commodities are extremely prone to CI with thresholds of around 13°C. CI symptoms in general include skin pitting, rind spotting, failure to ripen, de-greening, increased incidence and severity of rots and the development of off-flavours or odours (Wilkinson, 1970). CI is a limiting factor for the long-term storage and the export of susceptible cultivars for distant markets (Claypool, 1977; Saenz, 1991). Although moisture loss is a primary factor in the development of chilling injury, differences in light exposure within the canopy during fruit development could also influence the susceptibility to chilling injury. 'Honey Dew' melons that matured in sunlight were less prone to chilling injury (Lipton & Aharoni, 1979). The prevalence of chilling injury in tomatoes (King *et al*., 1982) and avocados can be reduced by heat treatments applied directly after harvest (Woolf *et al*., 1999). Therefore, exposure to high temperature on the tree close to harvest may induce tolerance to low temperature in postharvest storage. Sun-exposed avocado fruit had lower levels of chilling injury than fruit from the shaded parts of the tree when they were stored at 0˚C. However, a specific commodity that is grown in different areas may behave differently after it has been exposed to the same temperatures (Wills *et al*., 2007).

Crisosto *et al*. (1995) found that shaded peach fruit showed a greater incidence of internal breakdown than fruit from the outer canopy. On the contrary, Ferguson *et al*. (1999) found that citrus fruits that developed in shaded conditions were less susceptible to chilling injury. Inner canopy and shaded grapefruit are less susceptible to chilling injury compared to outer canopy fruit that was extremely susceptible to develop chilling injury (Purvis, 1984). Chilling injury symptoms have been described as occurring all over the fruit surface (Purvis, 1980), however, the sun-exposed side of outer canopy fruit showed more chilling injury than the shaded side of the same fruit (Purvis, 1984). The sun-exposed surface of outer canopy fruit had lower resistances and was more susceptible to chilling injury than the shaded side of the same fruit. Moisture loss during low temperature storage of grapefruit is a contributing factor to the development of chilling injury (Purvis, 1984). The reduced susceptibility of chilling injury in grapefruit had been positively correlated with higher levels of reducing sugars and proline in the peel (Purvis *et al*., 1979; Purvis, 1981; Purvis & Grierson, 1982).

Some apple cultivars are prone to develop various scalds during storage. Superficial scald is a physiological disorder linked to autoxidation of α-farnesene to conjugated trienes that only develops after long-term cold storage and has been defined as a chilling injury which manifests as brown or black patches on apple and pear peel after removal from cold storage (Watkins *et al*., 1995; Lurie & Watkins, 2012). Shaded parts of apple fruit cultivated in warmer, dry climates have been found to be more susceptible to superficial scald while low night temperatures leading up to harvest decreases the incidence of scald (Ferguson *et al*., 1999; Rudell *et al*., 2008; Lurie & Watkins, 2012;). This suggests a link between temperature, irradiation level and scald development. In contrast to superficial scalds, sunscald entails the gradual darkening of yellow sunlight-induced blemishes on the sun exposed sides of apples during storage (Lurie *et al*., 1991).

## 4. MANIPULATION OF THE LIGHT ENVIRONMENT

Shading with nets is widely used in parts of the world where high temperatures and intense solar radiation exists (Iglesias & Alegre, 2006). The effect of shade-nets on fruit quality is similar to effects observed for inner and lower canopy fruit where TSS and fruit weight of apples is negatively influenced by shading (Seeley *et al*., 1980). Fruit size distribution, fruit weight and fruit firmness were not significantly affected by the use of nets (Iglesias & Alegre, 2006). The lower light interception experienced under shade nets (Jackson, 1980) may cause a reduction in fruit peel colour, may have a detrimental effect on the flavour and may contribute to the variation in fruit quality at harvest (Génard & Bruchou, 1992).

Fruit grown under hail nets experiences problems with reduced quality, lack of red colouration, insufficient fruit firmness, problems with storability as well as reduced TSS levels (Blanke, 2008). Reflective mulches can overcome these shortcomings by improving the utilisation of light in an orchard. Extenday®, a reflective polymer white woven ground mulch, increased $CO_2$ assimilation and resulted in an increase in fruit growth, weight, diameter as well as TSS (Costa *et al*., 2003).

The “bagging” of individual fruit is a specialized production system, widely practiced in Japan, that shades only the fruit but not the leaves (Bound, 2005). The bags create a physical barrier that reduces damage from fungal and insect pathogens, sunburn, sprays and russet. Reduced titratable acidity, TSS and firmness at harvest and during storage are some of the physiological effects of fruit bagging.

## 5. CANOPY POSITION AND CONSUMER PREFERENCE

Consumers use fruit appearance to predict the eating experience they will have. Associations between the appearance of a certain apple cultivar and the eating experience are firmly established in the psyche of regular apple consumers (Cliff *et al*., 1999; Harker *et al*., 2003). High consumer acceptance has been associated with high TSS, but there are many other factors involved such as acidity, TSS:TA ratio as well as phenolics (Kader, 1999). The absence of diseases and disorders can be used to define a good quality fruit, however, for good eating quality an appropriate texture is crucial, with a good balance between sweet and sour taste, as well as the development of the typical flavour of the specific fruit (Zerbini, 2002).

The fruit industry (dependent on a specific country) has developed grading systems where numerical limits have been set for all quality parameters including fruit colour (Oraguzie *et al*., 2009). Appearance provides the first impression of the fruit that will either attract or repel the consumer (Kays, 1998). Colour changes in ripening fruit are associated with sweetening (Wills *et al*., 2007). Predominantly, outer and inner canopy 'Forelle' pears are marketed separately. Inner canopy 'Forelle' pears are marketed under the 'Vermont Beauty' label as a result of their lack of blush colouring (De Vries & Hurndall, 1993). Red blushed outer canopy 'Forelle' pears receive higher premium prices on the export market.

Research on consumer preferences for the appearance and eating quality of apples has mostly focused on the differences between cultivars (Daillant-Spinnler *et al*., 1996; Jaeger, 2000; Iglesias *et al*., 2008). Few studies have been conducted on the effect of apple fruit canopy position on consumer preference (Jaeger *et al*., 1998; Casals *et al*., 2005). A study by Hamadziripi (2012) on the relationship between canopy position and fruit quality as it pertains to consumer liking found that consumers preferred the taste of outer canopy 'Starking', 'Golden Delicious' and 'Granny Smith' apples due to a higher TSS, and TSS:TA ratio. The outer canopy fruit were sweeter and had a more prominent apple flavour when compared to the inner canopy fruit. With regards to consumer preference for appearance, the more intense red colour of the outer canopy 'Starking' apples was preferred. On the contrary, inner canopy 'Granny Smith' and 'Golden Delicious' apples received a higher degree of liking with regards to appearance. Outer canopy 'Granny Smith' apples that contain a yellow, orange or red blush are downgraded because consumers prefer the green coloured inner canopy fruit (Hirst *et al.,* 1990).

## 6. CONCLUSION

It is evident from this literature review that pre-harvest factors play a significant role in final fruit quality. Final fruit quality at the consumer level does not only depend on the maturity level at harvest and the postharvest conditions during storage and marketing, but on the environmental conditions during the cultivation period as well. Therefore it is of the utmost importance for growers to understand the impact of the environment on final fruit quality. There must be a good understanding regarding the effect of the light environment and canopy position on the potential shelf-life and final sensory fruit quality as well as the physiological effects that may arise post-harvest. Outer canopy fruit are exposed to much higher irradiance and temperatures compared to shaded fruit. Outer canopy fruit accumulate more carbohydrates and are higher in dry matter content and TSS. The latter fruit are generally perceived as sweeter and this may influence the consumer preference for these fruit. On the down side, the light-exposed fruit are more prone to develop irradiance-induced defects such as sunburn. Anthocyanins, responsible for the red peel colour, are dependent on light and therefore the outer canopy fruit have better red colour development. Although a recent apple study showed that consumers preferred the eating quality of outer canopy apples, the consumer preference may be different for other types of fruit. More studies are needed to investigate how canopy position affects fruit quality and how this relates to consumer preferences for appearance and eating quality.

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# CHAPTER 2

# EFFECT OF CANOPY POSITION AND COLD STORAGE DURATION ON CONSUMER PREFERENCE FOR THE APPEARANCE AND EATING QUALITY OF 'FORELLE' PEARS

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# 1. ABSTRACT

The position of fruit within the canopy of a pear fruit tree may affect the fruit quality characteristics due to microclimatic differences in temperature and irradiance. The first objective of this study carried out over two seasons (2011/ 2012) was to determine whether outer and inner canopy pears differ in quality attributes and how these differences, if any, relate to consumer preference for the appearance and eating quality of the pears. Mealiness, a soft, dry textural disorder, is often associated with 'Forelle' pears that did not receive adequate cold storage resulting in uneven ripening. Since previous studies indicated that mealiness decreases with cold storage duration, the second objective was to investigate the effect of cold storage duration (9, 12 and 16 weeks) on the eating quality of inner and outer canopy 'Forelle' pears. 'Forelle' pears were harvested from the inner and outer canopy in two consecutive seasons and stored under regular atmosphere at -0.5°C. Thereafter, fruit were ripened at room temperature (20°C) for seven days prior to experimental analyses. Fruit firmness, size, colour, total soluble solids concentration (TSS), titratable acidity (TA), ethylene, dry matter concentration (DMC) as well as the incidence of mealiness were determined after each cold storage period and subsequent ripening. In 2011, cell wall analyses were conducted to establish the role of $Ca^{2+}$ in mealiness development. A trained panel of eight judges assessed the flavour and texture of the pear samples during descriptive sensory analysis. Consumer preference assessments for 'Forelle' eating quality and appearance were held after each cold storage period (ca. 120 consumers per event). Consumers were able to discern eating quality differences between inner and outer canopy 'Forelle' pears. Significant differences in fruit quality between the seasons were observed. In 2011, inner canopy pears that were cold stored for 12 and 16 weeks were preferred for eating quality. Mealiness was generally low in inner canopy pears and significantly lower than in outer canopy pears, except after 16 weeks cold storage when mealiness was also much less in outer canopy pears. $Ca^{2+}$ did not play a role in the development of mealiness differences in inner and outer canopy fruit during 2011. More $Ca^{2+}$ became bound to the cell wall at 12 weeks of cold storage and this might explain the reduction in the incidence of mealiness as observed in 2011. While the preference for inner canopy pears after 12 weeks storage may relate to the lower incidence of mealiness, reasons for the preference after 16 weeks cold storage are uncertain. In 2012, the incidence of mealiness in outer canopy pears was double that of inner canopy pears, which may explain the general consumer preference for inner canopy pears. Mealiness levels decreased from 9 and 12 weeks cold storage to 16 weeks cold storage in 2012. Consumer preferences for eating quality were closely associated with juiciness in 2012 while a combination of factors was involved in 2011. There was a slight preference for the red blushed appearance of the outer canopy 'Forelle' pears in 2011 while no significant preference difference was evident in 2012. In light of the above, inner canopy 'Forelle' pears should not be viewed as inferior to outer canopy pears. Furthermore, this study supports the mandatory 12 weeks cold storage period for 'Forelle' pears to ensure optimum eating quality. The

consistent differences in mealiness incidence between inner and outer canopy ‘Forelle’ pears opens up a new avenue for investigating mealiness development.

## 2. INTRODUCTION

Forelle (*Pyrus communis* L), a late season red blush pear, is South Africa's second most planted pear cultivar and occupies 26% of the area under pear production (Hortgro Services, 2011). 'Forelle' pears are prone to mealiness, a dry textural disorder that is associated with a floury sensation in the mouth, with loss of juiciness, crispness and hardness (Barreiro *et al*., 1998). Mealiness seems to peak during 6 to 12 weeks of cold storage, but when storage is extended longer than 12 weeks at -0.5°C, mealiness seems to decrease (Martin, 2002; Carmichael, 2011). Consequently, South African 'Forelle' pears have a mandatory 12 week cold storage period at -0.5°C for fruit to ripen to an acceptable eating quality and to minimize the incidence of mealiness.

The industry aims to have a continuous market supply of premium quality SA bicolour pear cultivars, but the mandatory 12 weeks cold storage requirement for 'Forelle' causes a market gap after the supply of Rosemarie and Flamingo (Crouch & Bergman, 2010). This prevents South African 'Forelle' pears from accessing earlier markets that offer premium prices (De Vries & Hurndall, 1993) and may result in potential consumers buying earlier packed fruit from South America, a switch that often remains permanent, even when South African 'Forelle' pears enter the market. Hence, South African 'Forelle' pears with good eating quality should be available in Europe from week 15 (Crouch *et al*., 2013). Research projects have examined the possibility of shortening the mandatory cold storage period, but none with great success (Crouch & Bergman, 2010; Carmichael, 2011; Du Toit *et al*., 2001). Export reports also indicated a high incidence of astringency in 'Forelle' pears that were cold stored for less than 12 weeks (Martin, 2002; Crouch & Bergman, 2010).

Eating quality of pears varies between fruit of the same cultivar (Predieri *et al*., 2005). Differences in eating quality may relate to the effect of canopy position on internal fruit quality attributes. Irradiance and temperature are two factors that differ highly in the tree canopy (Fouché *et al*., 2010). Outer canopy fruit are exposed to higher irradiance, which leads to higher assimilate levels in outer canopy fruit (Hamadziripi, 2012). This increase in sugars is likely to show in the measurement of TSS and TSS:TA as well as the sensory flavour profile with an increase in sweetness and apple flavour. Hamadziripi (2012) found that outer canopy apples were sweeter, had a higher TSS concentration, lower TA and had higher antioxidant capacities than inner canopy apples. Canopy position also affects the external quality of fruit. Awad *et al*. (2000) found that sun-exposed apple peel had much higher anthocyanin levels compared to shaded peel. Anthocyanin synthesis is light-dependent, therefore the position of fruit in the tree canopy influences the extent of red colouration (Steyn *et al*., 2005). Hamadziripi (2012) found that consumers preferred the appearance of the redder outer canopy 'Starking' apples. Appearance provides the first impression of the fruit that will either attract or repel the consumer (Kays, 1998).

'Forelle' pears may be predisposed to develop mealiness due to poor formation of the middle lamella (De Smedt *et al*., 1998) or an insufficient $Ca^{2+}$ concentration needed for cell adhesion (Crouch, 2011). The cell wall contains the biggest pool of $Ca^{2+}$ in fruit tissue and small changes in the ability of the cell wall to bind $Ca^{2+}$ may cause a large variation in the amount of $Ca^{2+}$ available for other cellular functions (De Freitas *et al*., 2010). $Ca^{2+}$ in the cell wall is in a constant state of flux moving in and out of the cell wall during cold storage.

At present, outer and inner canopy 'Forelle' pears are marketed separately. Inner canopy 'Forelle' pears are marketed under the 'Vermont Beauty' label as a result of their lack of blush colouring. Red blushed outer canopy 'Forelle' pears receive higher prices on the export market (E.M. Crouch, Department of Horticulture, Stellenbosch University, Stellenbosch, South Africa, 2013, personal communication).

In light of the above; the objective of this study carried out over two seasons (2011/ 2012) was to determine the effect of canopy position (inner canopy versus outer canopy) and cold storage duration (9, 12 and 16 weeks) on the physicochemical and sensory (flavour and textural) attributes of 'Forelle' pears. Special attention was directed to the incidence of mealiness in inner and outer canopy fruit that were subjected to different cold storage periods. The import role that calcium play in determining the texture of the fruit led to a preliminary study in which the aim was to see whether cell wall $Ca^{2+}$ availability differed between inside and outside fruit. Moreover, we studied the relationship between canopy position and consumer preference for the eating quality and appearance of the pears.

## 3. MATERIALS AND METHODS

### 3.1 Plant material

'Forelle' pears were harvested on 24 February 2011 at Glen Fruin farm in Elgin (latitude: 34°10' S, longitude: 19°03' E). The orchard was planted in 1970 at a spacing of 4.28 m x 2.65 m in a N-E row orientation and trained to a central leader training system. Inner and outer canopy pears were harvested at an average flesh firmness of 7.9 kg and 7.8 kg, respectively. In the second season (2012), 'Forelle' pears were harvested on 2 March 2012 at an average flesh firmness 6.3 kg and 6.4 kg for inner and outer canopy pears, respectively. The outer canopy pears were harvested from the top and outer parts of the canopy while the inner canopy pears were harvested from the shaded inner parts of the canopy.

## 3.2 Experimental design

A total of 450 inner canopy fruit as well as 450 outer canopy fruit were harvested for each season (2011 & 2012) with 10 replicates of 15 fruit for each of the three storage periods. The original study was laid out as a complete randomised design with ten replications. Two fruit per replication (i.e., 20 fruit in total) were randomly selected for a firmness test immediately after harvest in order to determine whether the inner and outer canopy fruit had the same maturity. The intention of this particular study was to use inside and outside canopy fruit of comparable maturity; therefore, a further harvest would have been scheduled if the pears had differed in maturity.

In 2011, inner and outer canopy pear replicates were packed in separate boxes. Each box was seen as a randomized repetition of the storage period and canopy position combination. In 2012, inner and outer canopy pears of the same replication were packed in the same box, thereby giving rise to a split plot design with storage duration as the main factor and canopy position as the subplot factor. Fruit were placed on pear pulp trays and then packed into cartons lined with a polyethylene bag (37.5 µm), which was folded over to cover the fruit completely. 'Forelle' pears were stored at -0.5°C for 9, 12 and 16 weeks and then ripened at room temperature (20ºC) for seven days before commencement of physicochemical analysis, sensory descriptive analysis and consumer preference assessment. Of the fourteen remaining pears, five were used for physicochemical analyses, four pears for descriptive sensory analysis and five pears to assess consumer preference.

## 3.3 Physicochemical analyses

The five pears from the same replicate were viewed as composite samples. All the physical and chemical measurements were taken from the same set of 'Forelle' pears after each of the cold storage periods.

Due to time constraints and to compare measurements with previous research, it was decided to combine the fruit of two replicates to obtain 5 replications of 10 pears each for ethylene assessment. Each composite sample was placed into 5 L air tight plastic jars and left at room temperature for 30 minutes. After 30 minutes, gas samples were taken using gas tight 10 mL syringes, which were then injected into a gas chromatograph (Model N6980, Agilent technologies, Wilmington, U.S.A.) with a PorapakQ and Molsieve packed column and flame ionization and thermal conductivity detectors. The total fruit mass and volume of free space in the jar were used to calculate the ethylene production rates.

The fruit mass and diameter of each individual pear was measured using an electronic balance and a set of digital Mitutoyo callipers (Mitutoyo, Japan). The external colour of the pears was measured with a chromameter (Model CR-400; Minolta Co., Ltd., Tokyo, Japan), where lightness

(L), chroma (C) and hue angle (H) was recorded. The chromameter measurements were taken on the reddest position of each fruit. The lightness coefficient (L*) ranges from black=0 to white=100 with a lower number representing a darker colour. According to Thai and Shewfelt (1990), a good measure of fruit peel colour can be obtained from the calculation of hue angle and chroma as they relate better to human colour perception. Hue angle (H) quantifies colour, where $0^{o}$= red/purple, $90^{o}$= yellow and $180^{o}$= bluish/ green (McGuire, 1992). Chroma (C) is the degree of departure from gray or white towards the pure hue colour and is a measure of colour saturation. Background colour refers to the change from green to a yellow ground colour and was assessed using the Colour Charts for Apples and Pears (Unifruco Research Services [Pty] Ltd.) with a scale of 0.5 to 5 (where 0.5=dark green, and 5=deep yellow).

Fruit firmness (kg) was determined as the maximum force required to push an 8 mm diameter probe with a convex tip into the flesh after peeling two equatorial sites, approximately halfway between the calyx and the stem, of each pear using a motorized penetrometer (Fruit Texture Analyzer, Güss Manufacturing, Strand, South Africa).

The incidence of mealiness was tested after each cold storage period followed by seven days of ripening at room temperature (20°C). Longitudinal wedges (± $1/6^{th}$ of fruit) were cut from each of the 'Forelle' pears on the evaluation dates. The wedges were sensorially assessed for mealiness as well as squeezed to assess free juice. Fruit that were dry with a coarse, floury texture were classified as mealy. The same evaluator assessed mealiness for the duration of the study.

Percentage dry matter concentration (DMC) was determined by weighing a fresh pear sample and oven drying the pear sample over a period of 72 hours at 45°C. The pear sample was weighed, returned to the oven for another 24 hours and re-weighed to ensure that all the moisture had evaporated. The percentage DMC was calculated as dry weight as a percentage of fresh weight.

A composite flesh sample of five pears from each replicate was placed in a juice extractor and the juice was used to determine the TSS concentration (°Brix) with a calibrated hand held refractometer (PR32; Model N1, Atago, Tokyo, Japan). TA was determined using an automated titrator (Tritino 719S and Sample Changer 674, Metrohm Ltd., Herisau, Switzerland) to titrate 10.0 g of juice from each composite pear sample with 0.1 N NaOH to a pH of 8.2. TA is expressed as percentage malic acid.

Cell wall (CW) analyses were conducted only in the 2011 season. Inner and outer canopy pear samples were peeled, diced, flash-frozen, milled in liquid nitrogen and stored at -80ºC. A total of eight fruit were used per canopy position and storage period to perform the analyses. Frozen milled samples were weighed (±20 g) and boiled for 20 min in 80 mL 96% (v/v) ethanol to ensure inactivation of wall-modifying enzymes. Samples were cooled and homogenized by Ultra Turrax, filtered through a glass microfiber filter (Whatman Schleicher & Schuell, GF/C) and washed with 96% (v/v) ethanol (4 x 25 mL) and then with 100% acetone (2 x 25 mL) to dry the cell wall sample sufficiently. The cell wall yield, expressed as the percentage alcohol insoluble residue (% AIR), was then carefully scraped off from the paper. The AIR, which is supposed to retain all but oligosaccharides less than a degree of polymerization of about five (Martin-Cabrejas *et al*., 1994), was then dried to a constant weight at 20°C. The ethanol/ acetone filtrate was dried to 5 mL in the savant and analyzed at a later stage to indicate the free calcium in the tissues. AIR samples were extracted in 25 mL of de-ionized water at room temperature (20°C) on a shaker (Janke & Kunkel, GMBH & CO.KG, KS500, Staufen, Germany) for 16 h where-after the sample was centrifuged ($500g_n$ for 10 min at 4°C), the supernatant collected and the pellet re-suspended in another 25 mL of water and extracted for another 8 h at room temperature whilst mechanically shaken before it was centrifuged again ($500g_n$ for 10 min at 4°C). The second supernatant was combined with the supernatant collected from the first extraction. This was used as the CW water-soluble fraction and used to measure cell wall water soluble calcium. The water-insoluble pellet was washed with 96% (v/v) ethanol (4 x 25 mL) and then with 100% acetone (2 x 25 mL), collected, dried at 25°C and weighed. This pellet was used to determine the cell wall bound calcium.

### 3.4 Descriptive sensory analysis

Descriptive sensory analysis (DSA) was carried out in the sensory laboratory of the Food Science Department, University of Stellenbosch by a panel of eight panellists who had prior experience in DSA and were familiar with the sensory attributes of the fresh pear product. The same panel of judges were used after each of the cold storage periods. The panel of judges received extensive training using the consensus method to develop and define descriptors (Lawless & Heymann, 2010). The definitions used for the sensory attributes (Table 1) were similar to those used by Daillant-Spinnler *et al*. (1996). After each cold storage period, two training sessions were held; approximately 40 min per session. During each training session the panel members were exposed to 5 inner canopy and 5 outer canopy ‘Forelle’ pear samples. Product-specific scaling was used to rate attribute intensities. The 100 mm unstructured line scale, where the left side of the scale corresponds to the lowest intensity and the right hand side corresponds to the highest intensity, was used to rate each attribute (Lawless & Heymann, 2010).

Panellists were seated individually at sensory booths that were light and temperature controlled (21°C) and fitted with the data capturing software programme Compusense *five* (Compusense®, Guelph, Canada). For the descriptive sensory analysis of the samples, a complete randomized design was used where each judge received 20 pear samples; 10 inner canopy samples and 10 outer canopy samples. Each judge received an unpeeled pear slice from the same pear; hence the sample size was an eighth of a pear. Each pear sample was coded with a three-digit random code and presented on petri dishes in a completely randomized order so that judges could evaluate samples per replication. A total of ten replications were evaluated over two sessions. There were mealy pears amongst the test samples in both seasons. The judges were asked to peel the pears and for this purpose a sharp knife was provided. Distilled water and unsalted fat free biscuits were provided as a palette cleanser between the samples.

### 3.5 Consumer preference

Consumer preference analyses were conducted after each cold storage period on approximately one-hundred and twenty recruited South African pear consumers living in the Stellenbosch area. Consumers were presented with a questionnaire that consisted of four sections. Part one of the questionnaire was used to classify consumers in different categories regarding socio-demographical information and the frequency of their pear consumption. In the second section, the consumers had to taste the samples and give an indication of their degree of liking for the overall eating quality of the pears. A visual assessment of their degree of liking for pear appearance (primarily peel colour) comprised the third section. A subset of general questions regarding general fruit purchasing information completed the questionnaire.

On each consumer evaluation date each consumer received two samples (inner and outer canopy of ‘Forelle’ pears). Each pear sample was coded with a three-digit random code and presented on petri dishes in a completely randomized order. Each sample consisted of a quarter of a peeled pear, presented on a petri dish on a white tray at room temperature (21°C). Water was used by the consumers to cleanse their palette between the two samples.

The nine-point hedonic scale was used by the consumers to compare the overall degree of liking for the eating quality of the two pear samples. In this test, the consumer was asked to indicate which term best describe his/her attitude towards the products being tasted using the scale with the following nine categories: *9=Like extremely; 8=Like very much; 7=Like moderately; 6=Like slightly; 5=Neither like nor dislike; 4=Dislike slightly; 3=Dislike moderately; 2=Dislike very much and 1=Dislike extremely* (Lawless & Heymann, 2010). An important question was whether or not mealy pears should have been included in the consumer preference test. Previous studies showed that mealiness is the main reason for consumer dislike in apples (Jaeger *et al*., 1998; Andani *et al*., 2001) and pears (Manning, 2009). After 9 weeks of cold storage in 2011, a very high percentage of ‘Forelle’ pears were mealy. At the beginning we tried to exclude mealy samples from the consumer analyses, but it became impossible as we only had a limited number of ripened ‘Forelle’ pear samples and historically mealiness has been the main driver for longer storage of ‘Forelle’ in South Africa (Martin, 2002; Carmichael, 2011; Crouch, 2011) and a component of ‘Forelle’ eating quality that should not be omitted.

Photographs of whole 'Forelle' fruit taken after cold storage and ripening for 5 days at room temperature (20°C) was presented to the consumers for assessment (Fig. 1). Four photo-sets of canopy position, presented in a randomized order, were used in the study. A photo of the inner as well as the outer canopy 'Forelle' pears was provided as part of the questionnaire in order for the consumers to assess the appearance using the nine point hedonic scale. In 2012, a few changes were made to the questionnaire in that the degree of liking for appearance, texture, flavour, as well as overall eating quality was investigated.

### 3.6 Statistical procedures

Four sets of data were collected, viz. physicochemical measurements, descriptive sensory data, consumer preference data as well as CW analyses data. In 2011, the experimental design was a complete randomized design with ten replications for each storage period and in 2012 a split plot design was used.

Physicochemical analysis data were subjected to analysis of variance (ANOVA) by general linear models (GLM) using SAS version 9.2 (SAS Institute Inc., 2008, Cary, North Carolina, USA). The Shapiro-Wilk test was performed on the residuals to test for non-normality (Shapiro & Wilk, 1965). If non-normality was significant ($P \leq 0.05$) and caused by scewness, the outliers were identified and removed until the data were normally or symmetrically distributed. The final analysis of variance (ANOVA) was performed after the pre-processing procedures had taken place. Student's t-least significant difference (LSD) was calculated at the 5% significance level to compare treatment means.

CW data were analyzed using the GLM (General Linear Means) procedure in the SAS Enterprise Guide 3.0 programme (SAS Institute Inc., Cary, NC, USA, 2004). ANOVA-generated *P*-values and the significant differences between parameters were determined using Fisher's protected least significant difference test with a 95% confidence interval.

For the descriptive sensory analysis of the samples a complete randomized design was used where each judge received 20 samples; 10 inner canopy samples and 10 outer canopy samples, i.e. one sample from each replicate. The data were subjected to test-retest analysis of variance (ANOVA) by general linear models (GLM) to test for reliability as temporal stability between judge and replication and internal consistency between judge and treatment using SAS version 9.2 (SAS Institute Inc., 2008, Cary, North Carolina, USA). The Shapiro-Wilk test was performed on the residuals to test for non-normality (Shapiro & Wilk, 1965). If non-normality was significant ($P \leq 0.05$) and caused by scewness, the outliers were identified and removed until the data were normally or symmetrically distributed (Glass *et al*., 1972). The final analysis of variance (ANOVA) according to the design of the experiment was performed after the pre-processing procedures had taken place.

Student's t-least significant difference (LSD) was calculated at the 5% significance level to compare treatment means.

For consumer preference data, a complete randomized design was used, with each consumer tasting both samples. ANOVA was performed on the consumer data to establish if there was a difference in the consumer preference for inner and outer canopy pears with regard to eating quality and appearance.

Multivariate statistical analysis was employed (XLStat, Addinsoft, France) to investigate the possible relationships between physicochemical data, descriptive sensory data and consumer preference data, e.g. Principal Component Analysis (PCA). PCA is a projection method that assists one to visualize all the information in a data table; it provides a tool to find patterns and relationships between samples and several variables simultaneously. The possibility exist that attribute groupings may arise from a general tendency of attributes to change in a similar manner over a large group of samples (Wolters & Alchurch, 1994). Therefore it is useful to examine the correlation coefficients. XLStat software (Addinsoft, France) was used to perform Pearson's correlation between sensory and physicochemical measurements.

# 4. RESULTS

## 4.1 Physicochemical measurements

Outer canopy pears were significantly larger in both seasons with an average weight of 186 g in 2011 and 179 g in 2012 compared to the inner canopy pears that were 158 g in 2011 and 164 g in 2012.

The blushed sides of outer canopy pears displayed red pigmentation in both seasons while the sun-exposed sides of inner canopy pears tended to have little to none red pigmentation overlying the yellow ground colour (Table 2; Fig. 1). Canopy position did not affect the ground colour in either season (Table 2). The ground colour of fruit after 9 weeks cold storage in 2011 was significantly more yellow compared to fruit after 12 and 16 weeks cold storage. Pears that were stored for 12 weeks had the greenest ground colour. In 2012, storage duration did not affect the ground colour (Table 2). The chroma of the red blush of outer canopy pears increased with storage period, which means that the red blush of the outer canopy pears became a more intense red colour (Table 3). The chroma of inner canopy pears was more stable during storage.

Interaction between canopy position and storage duration was significant for flesh firmness in both 2011 and 2012 (Table 4). In 2011, firmness was lower after 12 weeks compared to 9 and 16 weeks of cold storage (Table 4). Inner canopy fruit were firmer after 16 weeks than after 9 weeks of cold storage while outer canopy fruit did not differ in firmness after these storage durations. In 2012, firmness seemed to increase with storage duration resulting in firmness being highest after 16 weeks cold storage (Table 4). Inner canopy pears were slightly firmer than outer canopy pears after 12 weeks storage.

Outer canopy pears were slightly but significantly higher in TSS and significantly higher in TSS:TA, but lower in TA in 2011 (Table 5). TSS was higher after 12 weeks cold storage compared to storage for 9 and 16 weeks. TA was higher after 12 weeks compared to 9 and 16 weeks cold storage and also higher after 9 weeks compared to 16 weeks cold storage. TSS:TA ratio was higher after 16 weeks compared to 9 and 12 weeks cold storage. Outer canopy pears were slightly but significantly higher in TSS in 2012 and TSS was lower after 16 weeks compared to 9 and 12 weeks cold storage (Table 5). Outer canopy pears stored for 9 weeks and inner canopy pears stored for 12 weeks had significantly higher TA compared to pears stored for 16 weeks and outer canopy pears stored for 12 weeks (Table 6). TA for 2012 after 9 and 12 weeks storage was higher than after 16 weeks of storage regardless of position. Inner canopy pears had higher TA than outer canopy fruit after 12 and 16 weeks storage. TSS:TA ratio was significantly higher in outer canopy pears stored for 16 weeks compared to all other treatment combinations (Table 6). Inner canopy pears stored for 12 weeks had the lowest TSS:TA ratio.

The incidence of mealiness in the 2011 season was much greater (78%) in outer canopy pears stored for 9 weeks compared to all other treatment combinations (Table 6). Outer canopy pears that were stored for 12 weeks were also higher in mealiness (32%) compared to inner canopy pears of all storage durations and outer canopy pears stored for 16 weeks (10-16%). In 2012, the outer canopy pears were significantly and more than double higher in mealiness compared to the inner canopy pears (Table 7). The incidence of mealiness was lowest (11%) after 16 weeks of cold storage while mealiness was much higher after 9 and 12 weeks of cold storage.

Inner and outer canopy 'Forelle' pears stored for 9 and 12 weeks in 2011 had lower ethylene levels than pears stored for 16 weeks (Table 6). Inner and outer canopy pears had similar ethylene production after 9 and 12 weeks cold storage. Outer canopy pears stored for 16 weeks had higher ethylene levels than inner canopy pears stored for 16 weeks. Inner and outer canopy pears had similar ethylene levels in 2012 (Table 7). Ethylene levels in 2012 were higher after 16 weeks cold storage than after 9 and 12 weeks cold storage.

Canopy position had no effect on DMC in either season (Table 7). In 2011, DMC was significantly higher for pears that were stored for 9 and 16 weeks compared to pears that were stored for 12 weeks. In 2012, DMC was significantly higher for pears stored for 9 weeks compared to pears stored for 12 and 16 weeks (Table 7).

The AIR percentage in 2011 was significantly higher after 9 weeks of cold storage at -0.5°C compared to longer storage durations (Table 8). Outer canopy pears had a significantly higher AIR percentage compared to inner canopy pears after 9 weeks of storage at -0.5°C. No canopy or storage duration effect on AIR percentage was apparent after storage for longer than 9 weeks.

Inner canopy fruit had more ethanol-acetone soluble $Ca^{2+}$ compared to outer canopy fruit after 9 weeks cold storage at -0.5°C and $Ca^{2+}$ was lower in fruit stored for 12 and 16 weeks (Table 8). Ethanol-acetone soluble $Ca^{2+}$ was lower after 12 compared to 16 weeks cold storage. No canopy position effect was apparent for longer storage durations.

Canopy position had no effect on CW water-soluble $Ca^{2+}$ and CW bound $Ca^{2+}$ in the 2011 season (Table 9). After 12 and 16 weeks of cold storage the CW water soluble $Ca^{2+}$ and the CW bound $Ca^{2+}$ were significantly higher compared to the values at 9 weeks. Canopy position had no effect on the percentage $Ca^{2+}$ per fraction of the total $Ca^{2+}$ (Table 10). The percentage $Ca^{2+}$ bound to the cell wall and the percentage CW water-soluble $Ca^{2+}$ were higher after 12 and 16 weeks compared to 9 weeks cold storage while the opposite was true for the percentage $Ca^{2+}$ that was soluble in ethanol-acetone.

## 4.2 Sensory attributes

Canopy position had no effect on pear flavour and the sweetness of 'Forelle' pears in both seasons (Table 11). In 2011, inner canopy pears were slightly but significantly higher in sourness while no significant difference was found in 2012 (Table 11). In 2011, after 16 weeks of cold storage, pear flavour and sweet taste were significantly higher in comparison to after 9 and 12 weeks cold storage. Pear flavour was also significantly higher after 12 weeks compared to 9 weeks cold storage. Pears were significantly higher in sour taste after 16 weeks cold storage in both seasons. In 2012, the sour taste was significantly lower after 12 compared to 9 weeks cold storage.

In 2011, canopy position had no significant effect on melt character, mealiness and grittiness while inner canopy pears were slightly juicier than outer canopy pears (Table 12). Juiciness increased while mealiness decreased from one cold storage duration to the next (Table 12). Melt character was significantly higher after 16 weeks than after 9 and 12 weeks cold storage (Table 12). Grittiness did not respond to cold storage duration (Table 12). Hardness was higher for outer compared to inner canopy pears after 16 weeks cold storage (Table 13).

In 2012, canopy position had no effect on melt character and grittiness (Table 14). Inner canopy pears were slightly but significantly harder and juicier while outer canopy pears were significantly higher in mealiness. Pears were harder and considerably less mealy after 16 weeks of cold storage. Juiciness was higher after 12 and 16 weeks cold storage. Melt character was slightly but significantly higher and grittiness lower after 12 weeks cold storage compared to 9 and 16 weeks cold storage. Mean scores for astringency and bitterness were extremely low in both seasons (data not presented).

## 4.3 Consumer preference

### *4.3.1 Consumer socio-demographic information*

In 2011, inner and outer canopy 'Forelle' pears were tasted by 341 consumers (78% females). Fifty nine per cent of the consumers were between the ages of 18 and 30. With regard to ethnicity, 61% of consumers were white, 26% coloured and 13% black. Of these consumers, 10% indicated that they consume pears daily, 37% indicated that they consume pears two or more times a week, another 37% indicated that they consume pears approximately two times per month and another 16% of consumers, four times per year.

In 2012, a total of 348 consumers partook in the consumer evaluations of which 74% were female. Fifty six per cent of consumers were between the ages of 18 and 30. With regard to ethnicity, 54% of the consumers were white, 32% coloured and 14% black. Of these consumers, 10% indicated that they consume pears daily, 34% indicated that they consume pears two or more times a week, another 30% indicated that they consume pears approximately two times per month and another 26% of consumers, four times per year.

### *4.3.2 Consumer preference for pear eating quality and appearance*

In 2011, consumers significantly preferred the eating quality of inner canopy pears stored for 12 and 16 weeks compared to inner canopy pears stored for 9 weeks, as well as the outer canopy pears from all three cold storage periods (Table 15). Inner and outer canopy pears stored for 9 weeks, as well as outer canopy pears stored for 12 weeks received similar and slightly lower hedonic scores. Storage duration did not affect the preference for outer canopy pears.

In 2012, the consumers were asked to score the texture and flavour of the pears in addition to eating quality. Canopy position had no effect on texture liking (Table 16). Inner canopy pears were scored slightly but significantly higher for flavour and eating quality. Hedonic scores for texture, flavour and eating quality after 9 weeks cold storage were significantly lower compared to scores after 12 and 16 weeks cold storage.

Consumers preferred the appearance of outer canopy pears after 16 weeks storage in 2011 to all other treatment combinations except for outer canopy pears stored for 12 weeks while inner canopy pears stored for 16 weeks received the lowest score (Table 15). As the storage period increased in 2011, the difference in hedonic scores for inner and outer canopy pears became greater. Hedonic scores for inner canopy pears after 9 weeks cold storage, as well as inner and outer canopy pears stored for 12 weeks received similar scores. There was no significant difference between appearance scores for inner and outer canopy 'Forelle' pears in 2012 (Table 16). There was a slight preference for pear appearance after 12 weeks compared to 9 weeks of cold storage.

Without tasting the products, consumers were asked their opinions on certain pear attributes using a nine point hedonic scale. In the first year of the study, pear flavour was considered most important followed by sweetness and juiciness (Table 17). Least in the line of importance were crispness and hardness. In the second year of study, more attributes were added on the questionnaire, some of them negative. Consumers indicated their preference for pears that are high in sweetness, juiciness and pear flavour. In addition, consumers indicated that they like crisp pears. Melt character and hardness received intermediate hedonic scores. Mealiness and bitterness were the most undesired attributes. Sourness, astringency, internal browning and blandness were further attributes that received very low hedonic scores.

### 4.4 Multivariate analyses

The Principal Component Analysis (PCA) bi-plot for the 2011 season explains ca. 82% of the variation in the bi-plot considering the first two principal components (Fig. 2). The first (F1 or PC1) and second components (F2 or PC2) explained 58% and 24% of the total variability in the data, respectively. Pear flavour, sweet and sour taste, hardness, melt character, juiciness, sensory mealiness, grittiness as well as measured firmness are indicated on PC1. Eating quality liking, TA, TSS:TA and DMC are indicated on PC2. TSS contributed to variability on the third and mealiness incidence on the fourth principal component (results not shown). The wide distribution of the pear samples in every quadrant of the bi-plot portrays the sensory and physicochemical differences between them. The bi-plot shows that the inner and outer canopy pears stored for 9 and 12 weeks are separated from the pears that were stored for 16 weeks along the horizontal axis, which explains most (58%) of the variation. A division between inner and outer canopy pears is clearly visible on the bi-plot by the separation along the vertical axis which explains 24% of variation. Outer canopy pears stored for 9 and 12 weeks are closely associated with mealiness incidence and sensory mealiness. Inner canopy pears cold stored for 16 weeks are situated in the bottom right half of the PCA together with sensory attributes like sourness and juiciness while outer canopy pears stored for 16 weeks are situated at the top right half of the PCA and associate with hardness and sweetness.

It is important to note that although certain attributes seem to be strongly associated on a PCA bi-plot, they are not necessarily strongly correlated. It is for this reason that it is useful to also examine correlation coefficients. Unfortunately, none of the sensory or physicochemical measurements correlated significantly with consumer preference for eating quality in 2011. However, the consumer preference for eating quality is more associated with the inner canopy pears that were subjected to cold storage for 12 weeks. The latter pears were also associated with a high TA. Some significant correlations between attributes were found. Pear flavour had significant positive correlations with sweet taste (r = 0.97), sour taste (r = 0.95), melt character (r = 0.97) and juiciness (r = 0.99). Equally important, sweet taste had significant positive correlations with juiciness (r = 0.96) and melt character (r = 0.97). Sensory mealiness was inversely correlated with juiciness (r = -0.97) and melt character (r = -0.91); the higher the level of mealiness the lower the pears were scored in terms of juiciness and melt character. Flesh firmness measured with a penetrometer correlated significantly with sensory hardness (r = 0.88). Firmness and sensory hardness were associated with outer canopy pears that were stored for 16 weeks.

The PCA bi-plot for the 2012 season explains 85% of the variation in the data (Fig. 3). PC1 and PC2 explained 59% and 26% of the total variability in the data, respectively. Eating quality, sweet taste, sour taste, sensory hardness, juiciness and sensory mealiness, as well as physicochemical measurements of firmness, mealiness incidence, TSS, TA, TSS:TA and DMC are indicated on PC1. Pear flavour, melt character and grittiness distinguished between the pear samples on PC2. Differences between inner and outer canopy pears became smaller as storage duration increased from 9 to 16 weeks. Inner and outer canopy pears stored for 9 and 12 weeks are separated from the pears that were stored for 16 weeks along the horizontal axis, which explains most of the variation (59%). Outer canopy pears stored for 9 weeks are associated with sensory mealiness while outer canopy pears stored for 12 weeks are associated with mealiness incidence. Consumer preference for eating quality is situated between 12 and 16 weeks cold storage. Pears that were stored for 12 weeks are associated with pear flavour and melt character while pears that were in cold storage for 16 weeks, were associated with hardness, firmness, sweet, sour taste and TSS:TA. Juiciness was a positive driver of liking for consumer preference of eating quality (r=0.99) while sensory mealiness and DMC were negative drivers of liking for eating quality (r= -0.83 and -0.84, respectively). Sensory mealiness correlated negatively with hardness (r=-0.96), firmness (r=-0.97) and juiciness (r=-0.87). Moreover, the sensory perception of mealiness correlated strongly with mealiness incidence (r=0.88). Flesh firmness measured with a penetrometer strongly correlated with sensory hardness (r=0.93).

# 5. DISCUSSION

### 5.1 The effect of cold storage duration and canopy position on 'Forelle' texture

Cold storage duration had a significant effect on the physicochemical and sensory attributes of 'Forelle' pears. South African 'Forelle' pears undergo a mandatory 12 week cold storage period at -0.5°C for fruit to ripen evenly to an acceptable eating quality (Martin, 2002). This low temperature treatment prior to ripening of winter pears is needed to stimulate ACC-*synthase* and ACC-*oxidase* necessary for ACC (1-aminocyclopropane-1-carboxylic acid) accumulation, the precursor of ethylene (Wang *et al*., 1985), to the stage where ripening resistance is reduced and the expression of autocatalytic ethylene results in normal and even ripening when fruit is removed from cold storage (Mellenthin & Wang, 1976). Several research projects have examined the possibility of shortening the mandatory cold storage period; with varying levels of success (Du Toit *et al*., 2001; Crouch & Bergman, 2010; Carmichael, 2011; Crouch, 2011). The ability of pears to ripen can occur before 12 weeks of cold storage (even as soon as four to six weeks) but the eating quality improves with longer storage due to mealiness and astringency reduction and probably also the pear flavour and TSS:TA levels that improve after prolonged storage (Carmichael, 2011; Crouch, 2011). Results from the 'Forelle' Early Market Access (FEMA) Programme suggest the possibility of shortening the 12 week mandatory cold storage period (Crouch *et al*., 2013). In this programme, pears were allowed to mature on the trees until they reached a flesh firmness of between 6.0 and 5.5 kg, and a TSS of at least 14%. Directly after harvest, fruit were subjected to the ripening inhibitor SmartFresh$^{SM}$ (1-methylcyclopropene), then immediately packed into 20 μm low density polyethylene (LDPE) bags, and shipped to reach offshore markets by week 15. SmartFresh$^{SM}$ retarded fruit ripening, thereby eliminating mealiness and resulting in a crispy, sweet pear. More recent research found that later harvested 'Forelle' can be marketed as "Crisp and Sweet" within 4 to 6 weeks of harvest if SmartFresh$^{SM}$ application is used at harvest (Crouch *et al*., 2013).

Mealiness is an umbrella term for fruit flesh developing a coarse, floury, soft and dry texture (Harker & Hallet, 1992; Barreiro *et al*., 1998; Andani *et al*., 2001). Mealy apples have a stale flavour and a floury and granular texture with very little juice (Jaeger *et al*., 1998) that is associated with the separation of cells from each other during mastication (Lapsley *et al*., 1992; Harker & Sutherland, 1993). In contrast to 'd' Anjou' (Chen *et al*., 1983), 'La France' and 'Marguerite Marillat' pears (Murayama *et al*., 2002) where mealiness develops after long storage durations, mealiness in 'Forelle' decreases with prolonged cold storage at -0.5°C. Mealiness in 'Forelle' seems to peak during 6 to 12 weeks of cold storage at -0.5°C, but then decreases with storage beyond 12 weeks (Martin, 2002; Carmichael, 2011, Crouch, 2011). In agreement with these studies, the 'Forelle' pears in our research showed the lowest incidence of mealiness after 16 weeks of cold storage in both seasons. Mealiness in outer canopy fruit seemed to decrease with storage time in 2011, whereas only after 16 weeks of cold storage did mealiness decline in 2012. Outer canopy 'Forelle' pears showed a significantly higher incidence of mealiness in both seasons (41% vs. 13% in 2011; 53% vs. 25% in 2012) suggesting that canopy microclimate or an unidentified tree factor influences the tendency for 'Forelle' pears to become mealy. It is however possible that the outer canopy pears were slightly riper and peaked in mealiness earlier during the shelf-life period at the time (7 days) when we conducted our assessments. To investigate this possibility, future studies comparing inner and outer canopy 'Forelle' fruit should assess the incidence of mealiness at intervals during the shelf- life period.

Very little research has been done to determine the effect of canopy position on mealiness. The results of our study are contradictory to research by Crisosto *et al*. (1997) where mealiness was associated with inner canopy peaches. There are, however, differences between fruits in the mechanism of mealiness development. Mealiness in peaches, for example, results from chilling injury (Brummel *et al*., 2004). Two main mechanisms are involved in mealiness development. Firstly, a decrease in intercellular adhesion may reduce cell breakage during mastication, thereby preventing cell contents to be released (Ben-Arie *et al*., 1979; Harker & Hallet, 1992; Harker *et al*., 1997). Secondly, cell fluids may form $Ca^{2+}$-pectate gel complexes with high molecular weight pectins in the middle lamella (Ben-Arie & Lavee, 1971). In apple mealiness, the first mechanism seems to be involved since the dissolution of the middle lamella is observed, with no cell breakage (Ben-Arie *et al*., 1979; Harker & Hallet, 1992; Harker *et al*., 1997). The latter mechanism seems to be involved in plums where $Ca^{2+}$-pectate gel complexes will result in cell separation not occurring and water-soluble pectins that have a higher viscosity in gel breakdown (Taylor *et al*., 1994). In peach, a combination of these two mechanisms seems to be involved (Brummel *et al*., 2004). Pear mealiness seems to resemble apple mealiness in that maturity makes it worse due to ripening causing cells to separate (Crouch, 2011). Contrary to apples, with longer storage of pears there may be a chilling induced inhibition of enzymes that separate cells during ripening and therefore tissues are firmer (Crouch, 2011).

Previous research by Martin (2002) and Carmichael (2011) found that the levels of mealiness differed between seasons. Our results are consistent with these findings. After 12 weeks cold storage, the incidence of mealiness in outer canopy pears was 32% and 72% in 2011 and 2012, respectively. Many factors, viz. pre-harvest climate, harvest maturity, conditions and duration of the storage period as well as post-storage ripening affect pear texture (Crouch *et al*., 2005). In agreement with Martin (2002), it seems that the mandatory 12 weeks cold storage period does not completely absolve the problem of mealiness in 'Forelle', however, the longer the storage at -0.5°C the less likely mealiness will be present (Carmichael, 2011; Crouch, 2011), regardless of harvest maturity (Carmichael, 2011). Storage duration may influence the middle lamella degrading enzymes; the longer the storage the more suppressed they may become (Crouch, 2011).

At cellular level, texture is dependent on a number of factors including mechanical properties of cell walls, biochemical constituents, turgor, bond strength between neighbouring cells and the area of cell-to-cell contact (Harker *et al*., 1997; Sams, 1999). A mealy pear tastes dry because the juice is not released from within the cells as a result of cell separation after the degradation of the middle lamella (Harker & Hallet, 1992; Crouch, 2011). Due to the separation, cells slide past each other instead of breaking, preventing the juice from being released. Sensory mealiness in our research had significant negative correlations with juiciness (r = -0.97 and -0.87 in 2011 and 2012). 'Forelle' pears may be predisposed to develop mealiness due to poor formation of the middle lamella (De Smedt *et al*., 1998) or an insufficient $Ca^{2+}$ concentration needed for cell adhesion (Crouch, 2011). The cell wall contains the biggest pool of $Ca^{2+}$ in fruit tissue and small changes in the ability of the cell wall to bind $Ca^{2+}$ may cause a large variation in the amount of $Ca^{2+}$ available for other cellular functions (De Freitas *et al*., 2010). $Ca^{2+}$ in the cell wall is in a constant state of flux moving in and out of the cell wall during cold storage. The fact that canopy position had no effect on cell wall water-soluble $Ca^{2+}$ and cell wall bound $Ca^{2+}$ suggests that $Ca^{2+}$ did not play a role in the difference in mealiness incidence between inner and outer canopy fruit. As previously mentioned; mealiness decreases with prolonged cold storage duration (Martin, 2002; Carmichael, 2011; Crouch, 2011). The lower incidence of mealiness after 12 and 16 weeks cold storage may be due to the greater amount of $Ca^{2+}$ that became bound to the cell wall during prolonged cold storage (>12 weeks) with a resultant decrease in the total tissue ethanol-acetone soluble $Ca^{2+}$. Thus, the longer the cold storage period, the more $Ca^{2+}$ is bound to the cell wall, which may contribute to a reduction in the incidence of mealiness.

Crouch (2011) found no difference in the CW yield as expressed as percentage alcohol insoluble residue (AIR) between non-mealy and mealy fruit. Our results may correspond with this finding in that no difference in AIR for inner and outer canopy pears were found after 12 weeks cold storage while the mealiness incidence was higher in outer canopy fruit after 12 weeks cold storage in 2011. In contrast to this result, AIR was higher in outer canopy pears after 9 weeks cold storage in 2011.

Application of mechanical force to an apple results in the breaking of cells in non-mealy flesh while failure occurs between cells in mealy flesh (Lapsley *et al*., 1992). Due to this difference, mealiness may decrease flesh firmness (Harker & Hallet, 1992). Although sensory hardness and fruit firmness increased in both seasons as mealiness incidence decreased with storage duration, the firmness of mealy and non-mealy fruit did not differ significantly and no dramatic differences were experienced in sensory hardness between inner and outer canopy fruit despite considerable differences in mealiness incidence. Although the latter finding is in accordance with Carmichael (2011), the fruit used for our study was very ripe (<2.9 kg) and differences are normally seen between 4.7 and 3 kg when one is fortunate enough to observe mealiness at the latter firmness (Crouch, 2011). Firmness measurements do not always discriminate between non-mealy and mealy apple fruit while changes in firmness do not readily predict the onset of mealiness during storage (Iwanami *et al*., 2005). Firmness measurements made in the centre of the blushed portion of apples did not represent the texture of the majority of the apple flesh (Harker *et al*., 2002a). The development of mealiness in 'Forelle' pears starts at the 'neck' of the fruit and then moves downward and spreads out to the sides of the fruit (E.M. Crouch, Department of Horticulture, Stellenbosch University, Stellenbosch, South Africa, 2013, personal communication). Firmness measurements were taken halfway between the calyx and the stem of each pear on two equatorial sites that were peeled. It could be that mealiness development had not progressed to the point where it could influence firmness readings.

Carmichael (2011) also reported an increase in flesh firmness of 'Forelle' with an increase in cold storage duration and suggested that the prolonged storage of 'Forelle' pears at -0.5°C might decrease the activity of cell wall degradation enzymes during fruit ripening. This could cause cell walls to break instead of slide during the mastication process. Crouch (2011) also found that fruit stored for 6 weeks at -0.5°C and then ripened for 7 days at 15°C had the ability to ripen to a lower firmness compared to fruit stored for longer periods at -0.5°C. The molecular size of uronic acid pectins from fruit stored for 9 weeks at -0.5°C and 7 days at 15°C, also was not as degraded as that from fruit stored for 6 weeks at -0.5°C and ripened for 11 days at 15°C. It therefore seems that the rate at which the cell wall degrades would decrease with an increase in cold storage duration, which would correspond with the apparent counterintuitive phenomenon of firmness increasing with prolonged cold storage.

Sensory mealiness and mealiness incidence levels did not correspond, possibly because the sensory panel assessed the level of mealiness for each sample and not the incidence of mealiness as was done in the physicochemical assessment. Only 20 samples were analysed during the sensory assessment of mealiness while 100 samples were evaluated during physicochemical mealiness. While a 100 mm unstructured line scale was used to rate the level of mealiness, a pear was either classified mealy or non-mealy for the assessment of mealiness incidence.

## 5.2 The effect of cold storage duration and canopy position on 'Forelle' flavour and mouthfeel attributes

The incidence of astringency in pears (Mielke & Drake, 2005), apples (Young *et al*., 1999) and persimmons (Ramin & Tabatabaie, 2003) is related to the degree of maturity of the fruit with immature being more astringent due to higher tannin levels. The ripening process leads to the loss of astringency and the development of flavour, texture, aroma, which subsequently contribute to optimum sensory eating quality (Wills *et al*., 2007). The sensory panel of judges in our research did not detect astringency in any of the pear samples. This absence of astringency probably relates to the adequate ripening of the 'Forelle' pears at room temperature (20°C) for 7 days after each cold storage period. Carmichael (2011) proposed that the optimum edible firmness for 'Forelle' pears should be 3.5 kg; however, the pears in our research were at a later stage of ripeness as they had a lower mean firmness, which was more towards the optimum consumption firmness (≈1.5 kg) for pears that was proposed by Vayasse *et al.* (2005). The low firmness values

(<3.5 kg) and similar ethylene levels also suggest that inner and outer canopy pears were equally ripe. Moreover, ethylene levels were significantly higher after 16 weeks of cold storage in both seasons compared to 9 and 12 weeks storage. Crouch (2011) and Carmichael (2011) made similar observations.

In the fruit industry titratable acidity (TA) and total soluble solids (TSS) are regarded as primary indicators of overall sensory quality (Mattheis & Fellman, 1999). According to Visser *et al*. (1968), acidity and sweetness in both pears and apples inherit independently and can thus be analysed as separate entities during sensory analysis, but less accurately in pears than in apples because the acidity in pears is considerably lower than in apples. Generally, light-exposed fruit are higher in TSS and lower in TA (Kingston, 1994; Nilsson & Gustavsson, 2007; Hamadziripi, 2012) and will subsequently be perceived as being sweeter (Hoehn *et al*., 2003; Dussi *et al*., 2005; Hamadziripi, 2012). Outer canopy 'Forelle' pears were significantly higher in TSS in both seasons, but the differences were less than 1 °Brix. Harker *et al*. (2002b) stated that a difference in sweetness in apples could only be detected by a trained panel if TSS differed by more than 1 °Brix, which probably explains why canopy position had no effect on the sensory scores for sweetness. In a study by Hoehn *et al.* (2003) it came to light that TSS did not link with sweetness although the same fruit were used to perform both analyses. Instruments do not necessarily measure the same combination of attributes that humans tend to integrate when analysing fruit quality (Abbott *et al*., 2004). Visser *et al*. (1968) stated that a poor correlation between sweet taste and TSS could be ascribed to the influence of the acid level on sweet taste that is over- or underestimated in the presence of a low and high sour taste, respectively. Another example where this phenomenon was observed was in a study by Van der Merwe (2012) where apples tasted sweeter (intensity score >50) due to their low TA values although they had a lower TSS (<10 °Brix) compared to other apples with a higher TSS. This suggests that panellists perceive sweetness as a lack of sourness, and *vice versa*. The dominance of fructose with its high relative sweetness in the sugar profile of pears may result in an increase in sweetness perception compared to physicochemical measurements of TSS (Visser *et al*. 1968). Harker *et al*. (2002b) stated that fruit maturity (starch content) is not represented in TSS measurements and may affect the perception of sweetness and contribute to poor correlations between sweetness and TSS. The high TSS:TA ratio in outer canopy fruit that were stored for 16 weeks in 2011 corresponds with a high sensory score for sweet taste, sour taste and pear flavour. Visser *et al*. (1968) found that scores for sweetness correlated significantly ($r = 0.47$) with the degree of juiciness. This leads to the assumption that the evaluators perceived fruit as being sweeter when more juicy. Juiciness and sweetness correlated significantly ($r = 0.96$) in 2011, however, this is not necessarily a causal relationship as pears naturally turn sweeter and more juicy during the ripening process.

The best predictor of sour taste is TA (r = 0.86 for the median panellist) and trained judges could detect a difference of 0.08% malic acid in apples (Harker *et al*., 2002b). Inner canopy 'Forelle' pears had a higher TA in 2011 and sour taste was more pronounced compared to outer canopy pears. Inner canopy pears were higher in TA compared to outer canopy pears after 12 and 16 weeks cold storage in 2012, however, no significant difference was found with regard to canopy position and sour taste. In agreement with previous studies by Visser *et al*. (1968), Martin (2002) and Błaszczyk (2010), TA decreased from 9 and 12 to 16 weeks cold storage. Even though significant, the largest difference between TA was never more than 0.04%, especially after the 16 week storage period when TA was the lowest in both seasons.

Dry matter concentration (DMC) is a holistic measure of quality as it includes both soluble solids (sugars and acids) and insoluble solids (structural carbohydrates and starch) and decreases only slightly during postharvest handling (Palmer *et al*., 2010; Crisosto *et al*., 2011). Apple (Harker *et al*., 2009; Palmer *et al*., 2010) and kiwifruit (Crisosto *et al*., 2011) with higher DMC have been found to receive higher consumer preference scores. The higher DMC and TSS in outer canopy apples indicate a close relationship between the light level within the tree canopy and the concentration of carbohydrates stored at harvest (Nilsson & Gustavsson, 2007; Hamadziripi, 2012). Contrary to findings in other fruits, there was a lack of a positional effect on DMC for 'Forelle' pears in both seasons despite significantly higher TSS in outer canopy pears. Also, there was no difference in AIR between inside and outside canopy fruit.

Canopy position had no effect on sensory scores for pear flavour. However, opposing results were obtained in a study on apples where apple flavour was higher in outer canopy 'Golden Delicious' and 'Starking' apples (Hamadziripi, 2012). Pear flavour had significant positive correlations with sweet taste (r = 0.97), sour taste (r = 0.95), juiciness (r = 0.99) and melt character (r = 0.97) in 2011. Pear flavour is normally linked to volatile production and in turn to ethylene production. Our results after 16 weeks cold storage in 2011 confirm this link. No significant correlations were found with pear flavour in 2012.

Dever *et al*. (1995) investigated sources of variation in apple fruit quality and found sensory and analytical differences not only between apples from the same cultivar but also within the same fruit. To minimize variation, we used one pear to train all the judges for sensory analyses; however, even in that single 'Forelle' pear, variation was sometimes evident (the blush side of the pear differed from the non-blushed side). It is important to remember that different 'Forelle' pears were used for the sensory analyses and the physicochemical measurements.

### 5.3 The effect of cold storage duration and canopy position on consumer preference for pear eating quality and appearance

Canopy position and storage duration influenced consumer preference for 'Forelle' eating quality. Inner and outer canopy pears from the different cold storage periods differed from each other and were clearly separated along the vertical axis of the PCA bi-plot in 2011 (Fig. 2). However, in 2012, there was no distinct separation between inner and outer canopy fruit from the different cold storage periods (Fig. 3). As the storage period increased from 9 to 16 weeks in 2012, the inner and outer canopy samples became more similar. It seems as if harvesting at a riper stage reduces the differences between inner and outer canopy pears (Fig. 2 & 3). It is likely that differences between the 2011 and 2012 seasons were brought about by differing harvest maturities, as well as possible seasonal variation. In 2011, inner and outer canopy pears were harvested at an average flesh firmness of 7.9 kg and 7.8 kg, respectively while in 2012, pears were harvested at an average flesh firmness of 6.3 kg and 6.4 kg for inner and outer canopy pears, respectively. The effects of canopy position and harvest maturity on consumer preference for 'Forelle' pears are discussed in more detail in Chapter 3.

Consumers significantly preferred the eating quality of inner canopy pears over outer canopy pears after 12 and 16 weeks cold storage in 2011. The reasons for the higher liking of the latter pears are unclear from the sensory and physicochemical results. To further investigate the matter we used multivariate analyses, i.e. PCA-plots and Pearson's correlations. Unfortunately, none of the sensory or physicochemical measurements correlated significantly with consumer preference for eating quality. It has to be noted that only six pear values were used in the consumer preference study and correlations had to be strong ($r \geq 0.75$) to be significant. However, it does appear that no single factor drove consumer preference for eating quality in 2011 but rather a combination of factors. The combination of factors is most likely inherent to inner canopy fruit as one can see on the PCA-plot where eating quality are associated with inner canopy pears (Fig. 2). Consumer opinions of various pear characteristics in our study indicated that consumers prefer pears that are high in sweetness, juiciness and pear flavour while mealiness and bitterness were two undesired attributes. This is in agreement with similar findings by Jaeger *et al*. (2003) and Manning (2009).

After 9 weeks cold storage and 7 days ripening, 78% of outer canopy pears were mealy in comparison to only 16% of the inner canopy pears that were mealy. Considering this, one would expect a lower consumer preference score for outer canopy pears stored for 9 weeks. However, this was not the case. The inner canopy pears at all three storage periods had a low incidence of mealiness and did not differ in the level of mealiness while the outer canopy pears showed a significant decrease in mealiness as the storage period progressed. The incidence of mealiness was equally low in inner and outer canopy pears after 16 weeks cold storage; however the inner canopy pears received significantly higher preference scores. Outer canopy pears stored for 16 weeks associated with hardness and sweetness on the PCA bi-plot while inner canopy pears stored for 16 weeks associated with juiciness and sourness (Fig. 2). Juiciness is one of the textural attributes that are important to pear consumers (Table 17) (Zerbini, 2002) and this might be the reason why the inner canopy pears stored for 16 weeks are situated more towards consumer preference for eating quality (Fig. 2).

Unlike in 2011, there was no clear separation between inner and outer canopy pears in 2012. However, consumers again showed a higher liking for the eating quality and flavour of inner canopy pears. It was surprising that consumers did not indicate a difference in the liking of texture considering the importance of textural properties of fruit and vegetables as drivers of consumer preference (Harker *et al*., 2008; Corollaro *et al*., 2013). Outer canopy pears had double the mealiness incidence of inner canopy pears when evaluated after 7 days of ripening. Consumer preference for eating quality, texture and flavour increased significantly from 9 to 12 weeks. A decrease in mealiness and an increase in juiciness as detected by the sensory panel could have played a role, however, there was no difference in mealiness incidence at 9 and 12 weeks. Consumer preference for eating quality is situated between 12 and 16 weeks cold storage but, the consumers apparently liked these pears for different reasons (Fig. 3). Pears that were stored for 12 weeks associated with pear flavour and melt character while pears that were in cold storage for 16 weeks associated with TSS:TA, hardness, sweet and sour taste. Juiciness was a positive driver of liking for consumer preference of eating quality ($r = 0.99$).

The attractive red blushed colour of ‘Forelle’ pears might catch the initial attention of the consumer, but if they are continuously disappointed in the eating quality of the fruit, it is unlikely that they will repurchase this specific cultivar. The assessment of preference for pear appearance revealed that the red blush colour of outer canopy pears was slightly preferred in 2011. However, there was no significant difference in preference scores for appearance in 2012. Manning (2009) found that European consumers had the highest preference for the appearance of yellow ‘Bon Chretien’ pears. Bon Chretien is the most produced pear cultivar in South Africa (Hortgro Services, 2011) and we assume that most consumers are familiar with this cultivar. Inner canopy ‘Forelle’ pears are completely green/ yellow (when ripe) in colour and sold under the ‘Vermont Beauty’ label. It is possible that the yellow appearance of inner canopy ‘Forelle’ pears resembled the appearance of ‘Bon Chretien’ pears. Gamble *et al*. (2006) found that Australian and New Zealand consumers responded to fruit colour in terms of familiarity.

## 6. CONCLUSION

This study confirms that the position of ‘Forelle’ pears in the canopy and the cold storage duration they are subjected to may result in differences in physicochemical and sensory characteristics and these differences may affect consumer preference. Consumers generally preferred the eating quality of inner canopy pears after ripening for 7 days. The reasons for the preference for inner canopy pears are not immediately apparent and may relate to, but are not completely explained by the generally higher incidence of mealiness in outer canopy fruit. These findings warrant further research. As expected, preference of eating quality increased with storage duration from 9 to 12 weeks and longer. This study thus provides support for the mandatory 12 weeks cold storage period for 'Forelle' pears. In fact, the percentage of mealy pears will be less if pears are stored for 16 weeks at -0.5°C.

$Ca^{2+}$ did not play a role in the development of mealiness differences in inner and outer canopy fruit during 2011. More $Ca^{2+}$ became bound to the cell wall at 12 weeks of cold storage and this might explain the reduction in the incidence of mealiness as observed in 2011, and perhaps may contribute to a reduction in firmness after longer stored fruit is ripened. Further research is needed to clarify the mechanisms by which canopy position affects mealiness in 'Forelle' pears.

Further important information to take from this research study is that inner canopy 'Forelle' pears should not be seen as inferior to the red blushed outer canopy fruit. Consumers preferred their eating quality and also showed a high preference for their yellow appearance. However, it should be cautioned that our findings apply to the specific conditions under which the experiments were conducted. The preference for eating quality of 'Forelle' pears could be different if the pears were harvested at more advanced maturity and then exposed to a 1-MCP treatment or if the pears were stored for a longer period (e.g. 21 weeks). The likelihood of mealiness will be low when 'Forelle' pears receive these treatments. Mealiness in inner and outer canopy fruit may also peak at different times during the shelf- life period due to differences in ripening.

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**Table 1** Terminology for descriptive sensory analysis (Source: Daillant-Spinnler *et al*., 1996).

| Attributes | Description | Scale |
| --- | --- | --- |
| Overall pear flavour | Aromatics of typical pear | 0= None; 100=Very strong pear flavour |
| Sweet taste | Basic taste on tongue caused by characteristic sugars, e.g. sucrose | 0= None; 100=Prominent sweet taste |
| Sour taste | Basic taste on tongue caused by characteristic acids, e.g. citric acid | 0= None; 100=Prominent sour taste |
| Astringency | The sensation associated with drying of the mouth | 0=None; 100=Prominent dry mouthfeel |
| Crispness | Noise generated when first bite is taken with the front teeth | 0= None; 100=Prominent crispness |
| Crunchiness | Noise generated when chewing with molars | 0= None; 100=Prominent crunchiness |
| Hardness | Force required to compress sample with molars | 0= None; 100=Very hard |
| Melt character | Soft, melting of flesh in the mouth | 0= None; 100=Prominent meltiness |
| Juiciness | Amount of juice released by sample during chewing (first three chews) | 0= None; 100=Very juicy |
| Mealiness | Degree to which the flesh breaks down to very fine dry particles | 0= None; 100=Prominent mealiness |
| Grittiness | Presence of small hard particles in the flesh experienced between front teeth | 0= None; 100=Prominent grittiness |

**Table 2** The effect of canopy position (inner canopy versus outer canopy) on the ground colour and hue angle values of 'Forelle' pears harvested on 24 February 2011 and 2 March 2012 at Glen Fruin, Elgin, Western Cape, South Africa. Hue was measured at the reddest position. Measurements were taken after 9, 12 and 16 weeks of cold storage, respectively, at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Year** | **2011** | | **2012** | |
|---|---|---|---|---|
| | **Ground colour (colour chart)[x]** | **Hue (°)** | **Ground colour (colour chart)[x]** | **Hue (°)** |
| **Canopy position** | | | | |
| Inside | 3.69 [NS] | 95 a | 3.34 [NS] | 99 a |
| Outside | 3.75 | 40 b | 3.40 | 40 b |
| **Weeks** | | | | |
| 9 | 3.95 a[z] | 69 [NS] | 3.32 [NS] | 70 [NS] |
| 12 | 3.48 c | 68 | 3.40 | 69 |
| 16 | 3.74 b | 67 | 3.40 | 69 |
| ***P value*** | | | | |
| **Position** | *0.3792* | *<0.0001* | *0.4643* | *<0.0001* |
| **Week** | *<0.0001* | *0.9226* | *0.6214* | *0.5530* |
| **P*W** | *0.8566* | *0.2585* | *0.9600* | *0.4849* |

[NS] Not significant

[x] Chart values 0.5-5: where 0.5= green; 5= pale green/ yellow

[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) on chroma measurement of 'Forelle' pears harvested on 24 February 2011 and 2 March 2012 at Glen Fruin, Elgin, Western Cape, South Africa. Measurements were taken after 9, 12 and 16 weeks of cold storage, respectively, at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Week** | **Canopy position** | **2011** | **2012** |
|---|---|---|---|
| | | **Chroma** | **Chroma** |
| 9 | Inside | 46.0 a[z] | 47.5 b |
| | Outside | 38.2 d | 36.0 e |
| 12 | Inside | 45.6 ab | 48.9 a |
| | Outside | 41.0 c | 38.4 d |
| 16 | Inside | 46.5 a | 47.0 b |
| | Outside | 44.0 b | 40.8 c |
| ***P-value*** | | | |
| **Position** | | *<0.0001* | *<0.0001* |
| **Week** | | *0.0001* | *0.0001* |
| **P*W** | | *0.0009* | *<0.0001* |

[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) on firmness for 'Forelle' pears harvested on 24 February 2011 and 2 March 2012 at Glen Fruin, Elgin, Western Cape, South Africa. Analysis were performed after 9, 12 and 16 weeks of cold storage, respectively, at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Week** | **Canopy position** | **2011** | **2012** |
|---|---|---|---|
| | | **Firmness (kg)** | **Firmness (kg)** |
| 9 | Inside | 1.84 c[z] | 1.78 d |
| | Outside | 1.92 bc | 1.71 d |
| 12 | Inside | 1.16 d | 2.34 b |
| | Outside | 1.32 d | 2.15 c |
| 16 | Inside | 2.25 a | 2.88 a |
| | Outside | 2.08 ab | 2.91 a |
| ***P-value*** | | | |
| **Position** | | *0.6076* | *0.0130* |
| **Week** | | *<0.0001* | *<0.0001* |
| **P*W** | | *0.0305* | *0.0128* |

[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) on total soluble solids (TSS), titratable acidity (TA) and TSS:TA for 'Forelle' pears harvested on 24 February 2011 and TSS for 'Forelle' pears harvested on 2 March 2012 at Glen Fruin, Elgin, Western Cape, South Africa. Analysis were performed after 9, 12 and 16 weeks of cold storage, respectively, at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Year** | **2011** | | | **2012** |
|---|---|---|---|---|
| **Canopy position** | **TSS (° Brix)** | **TA (% malic acid)** | **TSS:TA** | **TSS (° Brix)** |
| Inside | 15.2 b[z] | 0.19 a | 82 b | 16.38 b[z] |
| Outside | 15.8 a | 0.15 b | 108 a | 17.09 a |
| **Weeks** | | | | |
| 9 | 15.2 b[z] | 0.17 b | 92 b | 16.93 a |
| 12 | 16.5 a | 0.19 a | 92 b | 17.04 a |
| 16 | 14.8 b | 0.15 c | 102 a | 16.24 b |
| ***P-value*** | | | | |
| **Position** | *0.0030* | *<0.0001* | *<0.0001* | *<0.0001* |
| **Week** | *<0.0001* | *<0.0001* | *0.0080* | *<0.0001* |
| **P*W** | *0.6368* | *0.5621* | *0.6681* | *0.7087* |

[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) on titratable acidity (TA) and TSS:TA for 'Forelle' pears harvested on 2 March 2012 and the mealiness incidence and ethylene levels for 'Forelle' pears harvested on 24 February 2011 at Glen Fruin, Elgin, Western Cape, South Africa. Analysis were performed after 9, 12 and 16 weeks of cold storage, respectively, at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| | | 2011 | | 2012 | |
|---|---|---|---|---|---|
| **Week** | **Canopy Position** | **Mealiness incidence (%)** | **Ethylene (µL $kg^{-1}$ $h^{-1}$)** | **TA (% malic acid)** | **TSS:TA** |
| **9** | Inside | 16 bc[z] | 3.6 c | 0.24 ab[z] | 77 b |
| | Outside | 78 a | 4.6 c | 0.25 a | 78 b |
| **12** | Inside | 14 c | 4.6 c | 0.25 a | 66 c |
| | Outside | 32 b | 5.1 c | 0.22 b | 78 b |
| **16** | Inside | 10 c | 12.3 b | 0.20 c | 82 b |
| | Outside | 12 c | 16.6 a | 0.16 d | 105 a |
| ***P-value*** | | | | | |
| **Position** | | *<0.0001* | *0.0002* | *0.0019* | *<0.0001* |
| **Week** | | *<0.0001* | *<0.0001* | *<0.0001* | *<0.0001* |
| **P*W** | | *<0.0001* | *0.0029* | *0.0005* | *0.0043* |

[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) on the dry matter concentration (DMC) for 'Forelle' pears harvested on 24 February 2011 and 2 March 2012 as well as the mealiness incidence and ethylene levels for 'Forelle' pears harvested on 2 March 2012 at Glen Fruin, Elgin, Western Cape, South Africa. Analysis were performed after 9, 12 and 16 weeks of cold storage, respectively, at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Treatment** | **2011** | **2012** | | |
|---|---|---|---|---|
| | **DMC (%)** | **DMC (%)** | **Mealiness incidence (%)** | **Ethylene (μL $kg^{-1}$ $h^{-1}$)** |
| **Canopy position** | | | | |
| Inside | 21 $^{NS}$ | 29 $^{NS}$ | 25 b | 6.7 $^{NS}$ |
| Outside | 20 | 28 | 53 a | 5.9 |
| **Weeks** | | | | |
| 9 | 22 a$^{z}$ | 31 a | 54 a$^{z}$ | 4.9 b |
| 12 | 18 b | 28 b | 53 a | 4.4 b |
| 16 | 21 a | 27 b | 11 b | 9.7 a |
| ***P-value*** | | | | |
| **Position** | *0.3042* | *0.3436* | *<0.0001* | *0.2018* |
| **Week** | *0.0027* | *<0.0001* | *<0.0001* | *<0.0001* |
| **P*W** | *0.2704* | *0.6079* | *0.1307* | *0.0524* |

$^{NS}$ Not significant

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

**Table 8** The effect of canopy position (inner canopy versus outer canopy) on percentage alcohol insoluble residue and $Ca^{2+}$ of fresh tissue soluble in ethanol and acetone for 'Forelle' pears harvested on 24 February 2011 at Glen Fruin, Elgin, Western Cape, South Africa. Samples were taken after 9, 12 and 16 weeks of cold storage, respectively, at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Weeks** | **Canopy position** | **AIR (%)** | **$Ca^{2+}$ soluble in ethanol-acetone (mg $g^{-1}$ fresh weight)** |
|---|---|---|---|
| 9 | Inside | 3.72 b | 7.96 a |
| | Outside | 4.34 a | 6.06 b |
| 12 | Inside | 2.20 c | 4.38 c |
| | Outside | 1.96 c | 4.48 c |
| 16 | Inside | 1.86 c | 5.76 b |
| | Outside | 1.96 c | 5.72 b |
| ***P-value*** | | | |
| **Position** | | *0.1162* | *0.0553* |
| **Week** | | *<.0001* | *<.0001* |
| **P*W** | | *0.0063* | *0.0234* |

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

**Table 9** The effect of canopy position (inner canopy versus outer canopy) on the cell wall water soluble $Ca^{2+}$ and CW bound $Ca^{2+}$ for 'Forelle' pears harvested on 24 February 2011 at Glen Fruin, Elgin, Western Cape, South Africa. Samples were taken after 9, 12 and 16 weeks of cold storage, respectively, at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| | **Water soluble $Ca^{2+}$ (mg $g^{-1}$ dry weight)** | **Water insoluble $Ca^{2+}$ (mg $g^{-1}$ dry weight)** |
|---|---|---|
| **Canopy position** | | |
| Inside | 1.02 $^{NS}$ | 7.03 $^{NS}$ |
| Outside | 0.95 | 6.91 |
| **Weeks** | | |
| 9 | 0.58 b | 4.17 b |
| 12 | 1.16 a | 7.93 a |
| 16 | 1.23 a | 8.81 a |
| ***P-value*** | | |
| **Position** | *0.6442* | *0.8650* |
| **Week** | *0.0033* | *0.0001* |
| **P*W** | *0.1774* | *0.8936* |

$^{NS}$ Not significant

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

**Table 10** The effect of canopy position (inner canopy versus outer canopy) on the percentage $Ca^{2+}$ present in each fraction ($Ca^{2+}$ soluble in ethanol-acetone, water soluble $Ca^{2+}$ and water insoluble $Ca^{2+}$) calculated from the total amount of $Ca^{2+}$. 'Forelle' pears were harvested on 24 February 2011 at Glen Fruin, Elgin, Western Cape, South Africa. Samples were taken after 9, 12 and 16 weeks of cold storage, respectively, at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| | **$Ca^{2+}$ soluble in ethanol-acetone (%)** | **Water soluble $Ca^{2+}$ (%)** | **Water insoluble $Ca^{2+}$ (%)** |
|---|---|---|---|
| **Canopy position** | | | |
| Inside | 43.97 [NS] | 7.24 [NS] | 48.79 [NS] |
| Outside | 42.31 | 7.08 | 50.61 |
| **Weeks** | | | |
| 9 | 59.27 a | 4.96 b | 35.77 b |
| 12 | 33.70 b | 8.86 a | 57.44 a |
| 16 | 36.44 b | 7.66 a | 55.90 a |
| ***P-value*** | | | |
| **Position** | *0.3315* | *0.8661* | *0.4027* |
| **Week** | *<0.0001* | *0.0110* | *<0.0001* |
| **P*W** | *0.5652* | *0.2164* | *0.7244* |

[NS] Not significant

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

**Table 11** The effect of canopy position (inner canopy versus outer canopy) on 'Forelle' sensory flavour attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis. Pears were harvested on 24 February 2011 and 2 March 2012 at Glen Fruin, Elgin, Western Cape, South Africa and subjected to cold storage for 9, 12 and 16 weeks followed by 7 days of ripening at room temperature (20°C).

| **Treatment** | **2011** | | | **2012** | | |
|---|---|---|---|---|---|---|
| | **Pear flavour** | **Sweet taste** | **Sour taste** | **Pear flavour** | **Sweet taste** | **Sour taste** |
| **Canopy position** | | | | | | |
| Inside | 52 [NS] | 49 [NS] | 13 a | 55 [NS] | 52 [NS] | 18 [NS] |
| Outside | 50 | 48 | 11 b | 55 | 52 | 18 |
| **Weeks** | | | | | | |
| 9 | 43 c[z] | 43 b | 9 b | 55 [NS] | 51 [NS] | 19 b |
| 12 | 50 b | 46 b | 10 b | 56 | 52 | 16 c |
| 16 | 60 a | 57 a | 17 a | 54 | 54 | 22 a |
| ***P-value*** | | | | | | |
| **Position** | *0.2242* | *0.8504* | *0.0066* | *0.7158* | *0.5164* | *0.0747* |
| **Week** | *<0.0001* | *<0.0001* | *<0.0001* | *0.5213* | *0.1194* | *<0.0001* |
| **P*W** | *0.6539* | *0.4219* | *0.3045* | *0.6310* | *0.3214* | *0.8886* |

[NS] Not significant

[Z] Means with different letters differ significantly at P≤0.05 in the column

**Table 12** The effect of canopy position (inner canopy versus outer canopy) on 'Forelle' sensory texture attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis. Pears were harvested on 24 February 2011 at Glen Fruin, Elgin, Western Cape, South Africa and subjected to cold storage for 9, 12 and 16 weeks followed by 7 days of ripening at room temperature (20°C).

| | **Juiciness** | **Melt character** | **Mealiness** | **Grittiness** |
|---|---|---|---|---|
| **Canopy position** | | | | |
| Inside | 41 a[z] | 39 [NS] | 13 [NS] | 20 [NS] |
| Outside | 37 b | 36 | 19 | 21 |
| **Weeks** | | | | |
| 9 | 26 c | 27 b | 29 a | 21 [NS] |
| 12 | 36 b | 31 b | 16 b | 21 |
| 16 | 55 a | 54 a | 3.0 c | 19 |
| ***P-value*** | | | | |
| **Position** | *0.0269* | *0.1180* | *0.0613* | *0.0906* |
| **Week** | *<0.0001* | *<0.0001* | *<0.0001* | *0.0894* |
| **P*W** | *0.2460* | *0.2188* | *0.1941* | *0.5964* |

[NS] Not significant

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

**Table 13** The effect of canopy position (inner canopy versus outer canopy) on 'Forelle' sensory texture attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis. Pears were harvested on 24 February 2011 at Glen Fruin, Elgin, Western Cape, South Africa and subjected to cold storage for 9, 12 and 16 weeks followed by 7 days of ripening at room temperature (20°C).

| **Treatment** | | **Hardness** |
|---|---|---|
| **Week** | **Canopy position** | |
| 9 | Inside | 8 c[z] |
| | Outside | 8 c |
| 12 | Inside | 4 d |
| | Outside | 3 d |
| 16 | Inside | 13 b |
| | Outside | 17 a |
| ***P-value*** | | |
| **Position** | | *0.1055* |
| **Week** | | *<0.0001* |
| **P*W** | | *0.0337* |

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

**Table 14** The effect of canopy position (inner canopy versus outer canopy) on 'Forelle' sensory texture attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis. Pears were harvested on 2 March 2012 at Glen Fruin, Elgin, Western Cape, South Africa and subjected to cold storage for 9, 12 and 16 weeks followed by 7 days of ripening at room temperature (20°C).

| Treatment | Hardness | Juiciness | Melt character | Mealiness | Grittiness |
|---|---|---|---|---|---|
| **Canopy position** | | | | | |
| Inside | 15 a[z] | 37 a | 34 [NS] | 18 b | 24 [NS] |
| Outside | 14 b | 34 b | 32 | 24 a | 23 |
| **Weeks** | | | | | |
| 9 | 12 b | 27 b | 29 b | 32 a | 25 a |
| 12 | 13 b | 39 a | 39 a | 22 a | 20 b |
| 16 | 18 a | 41 a | 31 b | 8 b | 24 a |
| ***P-value*** | | | | | |
| **Position** | *0.0029* | *0.0290* | *0.1833* | *0.0055* | *0.2141* |
| **Week** | *<0.0001* | *<0.0001* | *<0.0001* | *<0.0001* | *<0.0001* |
| **P*W** | *0.9338* | *0.8326* | *0.5783* | *0.9202* | *0.3446* |

[NS] Not significant

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

**Table 15** The effect of canopy position (inner canopy versus outer canopy) on the overall degree of liking of 'Forelle' pears with regard to eating quality in 2011. A nine-point hedonic scale was used where 9=Like extremely and 1=Dislike extremely. 'Forelle' pears were harvested on 24 February 2011 at Glen Fruin, Elgin, Western Cape, South Africa and stored at -0.5°C for 9, 12 and 16 weeks cold storage.

| **Treatment** | | **Eating Quality** | **Appearance** |
|---|---|---|---|
| **Week** | **Canopy position** | | |
| 9 | Inside | 7.0 b[z] | 7.2 bc |
| | Outside | 6.7 bc | 7.1 c |
| 12 | Inside | 7.6 a | 7.2 bc |
| | Outside | 6.6 bc | 7.6 ab |
| 16 | Inside | 7.7 a | 6.7 d |
| | Outside | 6.4 c | 7.9 a |
| ***P-value*** | | | |
| **Position** | | *<0.0001* | *<0.0001* |
| **Week** | | *0.2862* | *0.3142* |
| **P*W** | | *0.0061* | *<0.0001* |

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

**Table 16** The effect of canopy position (inner canopy versus outer canopy) on the overall degree of liking of 'Forelle' pears with regard to texture, flavour, eating quality and appearance in 2012. A nine-point hedonic scale was used where 9=Like extremely and 1=Dislike extremely. 'Forelle' pears were harvested on 2 March 2012 at Glen Fruin, Elgin, Western Cape, South Africa and stored at -0.5°C for 9, 12 and 16 weeks cold storage.

| | **Texture** | **Flavour** | **Eating Quality** | **Appearance** |
|---|---|---|---|---|
| **Canopy position** | | | | |
| Inside | 6.9 $^{NS}$ | 7.2 a | 7.0 a | 7.4 $^{NS}$ |
| Outside | 6.7 | 7.0 b | 6.7 b | 7.6 |
| **Week** | | | | |
| 9 | 6.1 b$^{z}$ | 6.6 b | 6.2 b | 7.3 b |
| 12 | 7.1 a | 7.3 a | 7.2 a | 7.6 a |
| 16 | 7.3 a | 7.4 a | 7.2 a | 7.5 ab |
| ***P-value*** | | | | |
| **Position** | *0.1002* | *0.0309* | *0.0123* | *0.0645* |
| **Week** | *<0.0001* | *<.0001* | *<.0001* | *0.0552* |
| **P*W** | *0.8559* | *0.5988* | *0.9942* | *0.2234* |

$^{NS}$ Not significant

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

**Table 17** Consumer opinions data for 2011 and 2012 on the degree of liking for various pear sensory characteristics that influences the overall eating quality of pears.

| **Sensory characteristics** | **2011** | **2012** |
|---|---|---|
| Sweetness | 6.4 b[z] | 7.7 a |
| Juiciness | 6.3 b | 7.6 a |
| Pear flavour | 7.1 a | 7.5 a |
| Crispness | 4.5 d | 6.9 b |
| Melt character | - | 5.5 c |
| Hardness | 5.7 c | 4.4 d |
| Grittiness | - | 3.9 e |
| Overripe pears | - | 3.9 e |
| Sour taste | - | 3.4 f |
| Astringency | - | 2.9 g |
| Internal browning | - | 2.7 g |
| Blandness | - | 2.7 g |
| Mealiness | - | 2.4 h |
| Bitterness | - | 2.0 i |
| ***P-value*** | *<0.0001* | *<0.0001* |

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

| INNER CANOPY | OUTER CANOPY |
| --- | --- |

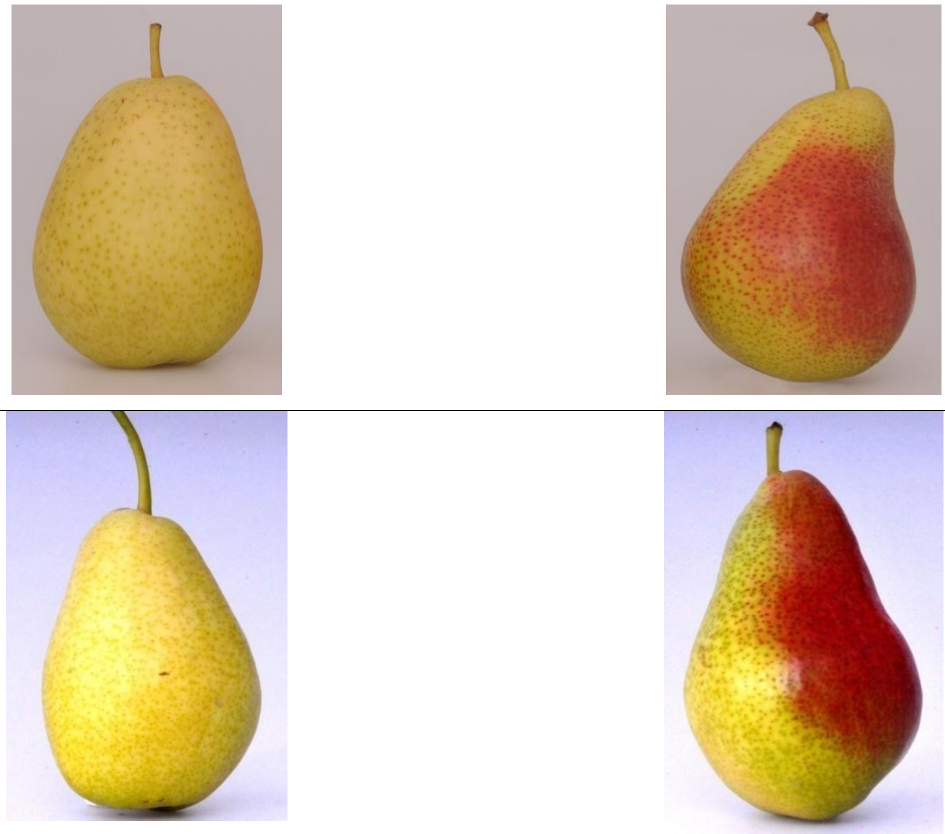

**Figure 1** Images of representative inner and outer canopy 'Forelle' pears harvested on 24 February 2011 and 2 March 2012 from Glen Fruin, Elgin, Western Cape, South Africa. Photographs were taken after cold storage and subsequent ripening at room temperature (20°C) for 5 days.

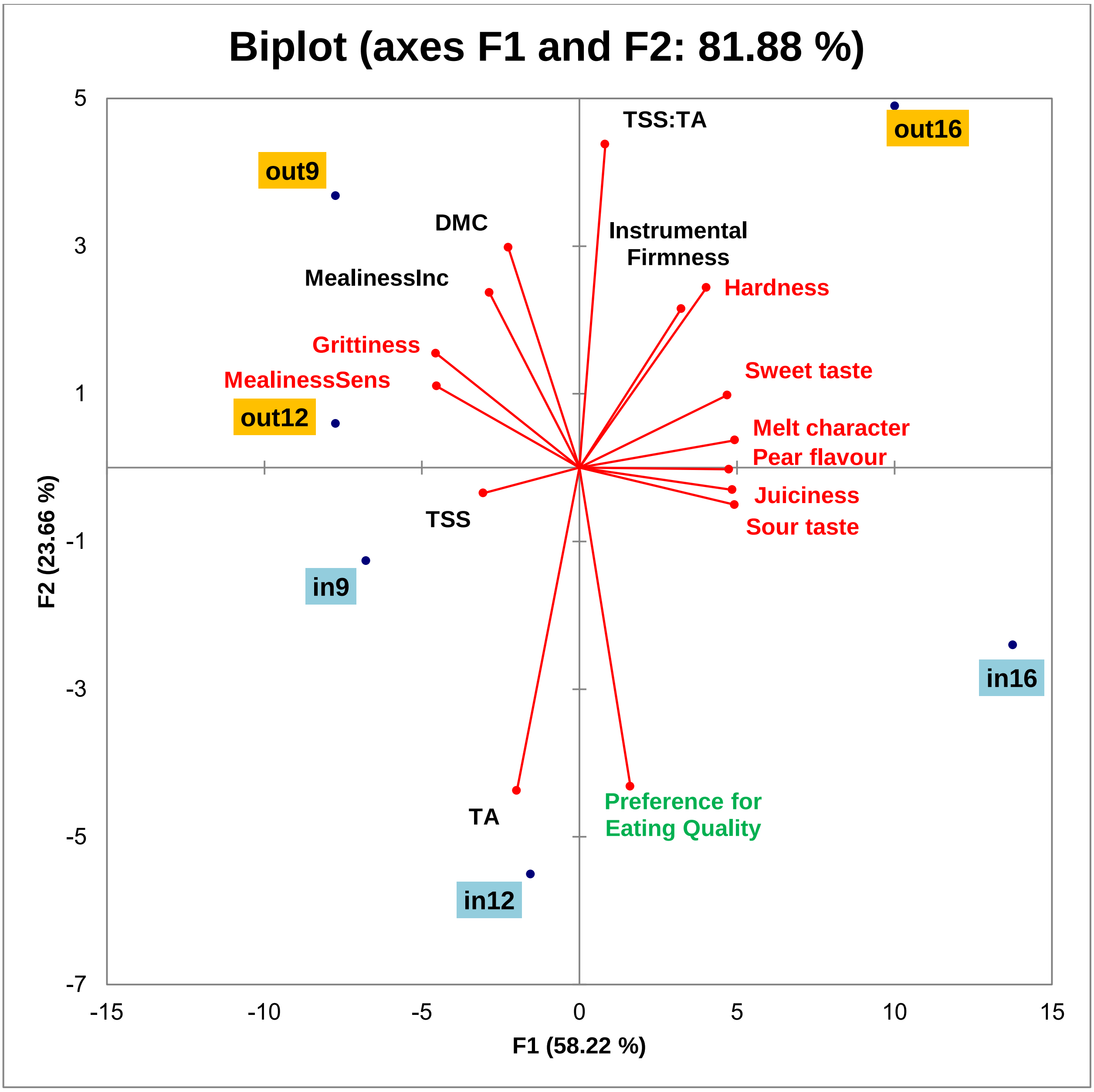


**Figure 2** Principal component analysis bi-plot indicating the position of consumer preference for overall eating quality (green) in relation to sensory attributes (red) and physicochemical measurements (black) of inner and outer canopy ‘Forelle’ pears subjected to cold storage in 2011 for 9, 12 and 16 weeks where TSS - total soluble solids, TA - titratable acidity, DMC - dry matter concentration, MealinessInc - mealiness incidence, MealinessSens - sensory mealiness.

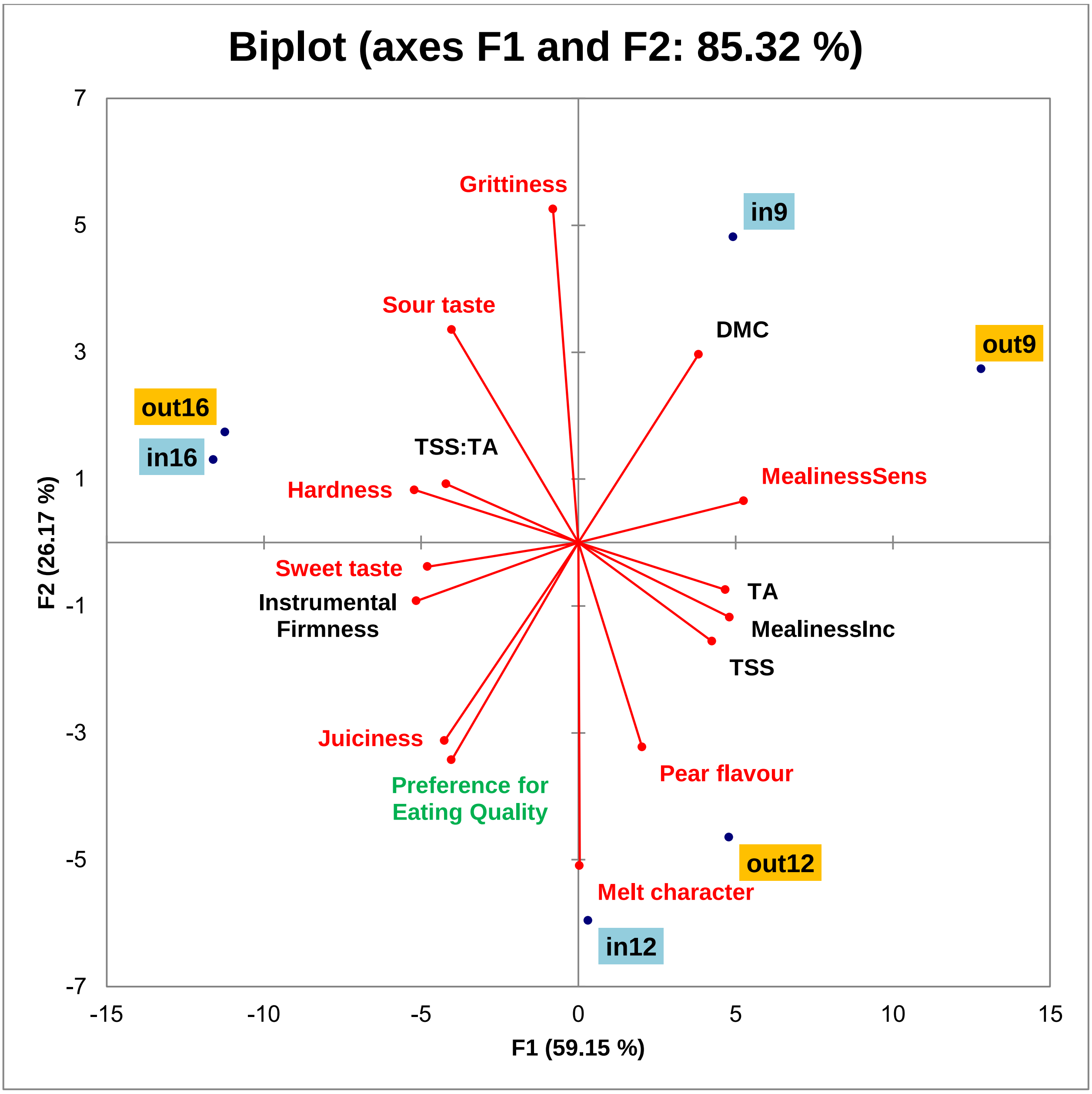


**Figure 3** Principal component analysis bi-plot indicating the position of consumer preference for overall eating quality (green) in relation to sensory attributes (red) and physicochemical measurements (black) of inner and outer canopy ‘Forelle’ pears subjected to cold storage in 2012 for 9, 12 and 16 weeks where TSS - total soluble solids, TA - titratable acidity, DMC - dry matter concentration, MealinessInc - mealiness incidence, MealinessSens - sensory mealiness.

# CHAPTER 3

# EFFECT OF CANOPY POSITION AND HARVEST MATURITY ON CONSUMER PREFERENCE FOR THE APPEARANCE AND EATING QUALITY OF 'FORELLE' PEARS

# 1. ABSTRACT

Inner and outer canopy pears are exposed to different microclimates, particularly with regard to temperature and irradiance. The maturity at harvest may influence the storage period, the ripening potential and subsequently the final sensory eating quality of pears. The ultimate objective of this 2012 study was to determine whether outer and inner canopy 'Forelle' pears harvested at different maturities within the commercial picking window differ in quality attributes and how these differences, if any, relate to consumer preference for the appearance and eating quality of the pears. 'Forelle' pears are prone to mealiness, a dry textural disorder that negatively affects consumer preference. The second objective was therefore to investigate the relationship between mealiness, canopy position and harvest maturity. Flesh firmness is used by the South African deciduous fruit industry to determine harvest maturity of 'Forelle' and ranges from 4.5 kg (over-mature standard) to 6.8 kg (release criterion). 'Forelle' fruit were harvested from the inner and outer canopy in 2012 at three different maturity stages within the commercial harvesting window (start of export picking window or H1≈6.8-6.5 kg; middle of export picking window or H2≈6.4-6.1 kg; lower end of middle export picking window or H3≈6.0-5.5 kg) and stored under regular atmosphere at -0.5°C for 12 weeks and ripened thereafter for seven days at room temperature (20°C). Experimental analyses after ripening included assessment of flesh firmness, peel colour, total soluble solids concentration (TSS), titratable acidity (TA), ethylene and dry matter concentration (DMC). Descriptive sensory analysis was conducted with a trained panel of eight judges where the texture and flavour of the pear samples were evaluated. Consumer preference assessments for eating quality and appearance were conducted after each cold storage period (ca. 120 consumers per event). Consumers preferred the eating quality of H1 and H2 inner canopy 'Forelle' pears. H1 and H3 outer canopy fruit were liked the least. The general dislike for H3 and outer canopy fruit seemed to relate to high incidences of mealiness and maybe even a too low TA which make fruit taste bland. The dislike for H1 outer canopy fruit and the somewhat higher preference for H2 outer canopy fruit may relate to differences in texture and flavour. Inner canopy 'Forelle' pears should not be viewed as inferior as the consumers consistently preferred the eating quality of the inner canopy fruit while the preference for the appearance of outer canopy red blush pears were only slightly higher than the preference for inner canopy pears. Producers should harvest inner and outer canopy 'Forelle' pears at a firmness ~6.2 kg to ensure optimum eating quality, i.e. the greatest consumer preference.

## 2. INTRODUCTION

'Forelle' (*Pyrus communis* L.) is South Africa's most valuable red blushed pear cultivar and accounts for 19.6% of total pear exports (Hortgro Services, 2011). South African 'Forelle' pears have a mandatory 12 week cold storage period at -0.5°C to allow for even ripening and to ensure acceptable eating quality (De Vries & Hurndall, 1993). Past export reports indicated problems with mealiness and astringency in 'Forelle' that were marketed before the minimum 12 week cold storage period (Martin, 2002; Crouch & Bergman, 2010). Conversely, studies have indicated that mealiness decreases with extended storage periods of more than 12 weeks at -0.5°C (Martin, 2002; Carmichael, 2011).

The degree of maturity at harvest has a direct influence on the period for which the pears can be stored without losing quality (Kvale, 1990; Kader, 1999) and it also affects the ripening potential (Kader, 1999; Crouch *et al*., 2005). Maturity in pears is that stage of development when the fruit will ripen adequately following a cold storage period if the cultivar requires it (Stebbins *et al*., 1998). Previous experience with climacteric fruit has proven that immature harvested fruit will not ripen adequately after removal from cold storage and that these fruit will have poor sensory quality (Peirs *et al*., 2001). Astringency in pears and apples may be more related to the stage of maturity at harvest than to cold storage (Zerbini & Spada, 1993; Young *et al*., 1999; Mielke *et al*., 2005). In persimmon, this relates to the higher tannin levels of less mature fruit (Ramin & Tabatabaie, 2003). Apples that are harvested at an advanced stage of maturity will have a short cold storage life where after they will soften quickly during ripening and become mealy (Peirs *et al*., 2001). Carmichael (2011) found that post-optimum harvested 'Forelle' pears were more prone to mealiness with a shorter storage life compared to pre-optimum and optimum harvested fruit or compared to post-optimum harvested fruit stored for longer than 12 weeks. In this particular study pears were harvested bi-weekly from week five (H1), week seven (H2), week nine (H3), week 11 (H4) and week 13 (H5) over a period of three consecutive seasons (2007-2009). The industry norm was implemented per harvest in each season to determine the optimum harvest point for each area based on the assessed maturity (fruit firmness ≤ 6.4 kg; TSS ≥ 14.6%; TA ≤ 0.27% and ground colour index ≥ 2.5). Therefore, it is of the utmost importance that optimum harvest maturity must be well defined to reduce postharvest losses and to maintain good eating quality after storage (Hansen & Mellenthin, 1979).

There are often large differences in texture at harvest between fruit from the same cultivar due to differences in maturity (Sams, 1999). Carmichael (2011) found that the rate of change in firmness together with ground colour is the most reliable variable to determine harvest maturity of 'Forelle' pears. However, maturity indices are greatly influenced by climatic conditions and may differ between seasons (Frick, 1995; Van Rensburg, 1995; Lötze & Bergh, 2005). Inner and outer canopy fruit may also vary in harvest maturity due to exposure to different microclimatic conditions (Predieri *et al*., 2005). The final eating quality of pears is affected by the harvest time, cold storage period, post-storage ripening as well as climatic conditions (Zerbini, 2002). Immature 'd' Anjou' pears did not develop an acceptable flavour after ripening, however, the fruit were more decay-resistant compared to mature pears (Boonyakiat *et al*., 1987). In order to avoid the risk of over-ripening and decay, growers harvest fruit too early; resulting in fruit with poor eating quality (Zerbini & Spada, 1993). Studies have shown that fruit that are harvested later in the picking window develop higher amounts of volatiles (Zerbini & Spada, 1993), are lower in TA and higher in TSS:TA ratio (Mielke *et al*., 2005).

In this paper we investigated the sensory (texture and flavour) differences between inner and outer canopy 'Forelle' pears harvested at different maturity stages. The relationship between the possible positional differences and consumer preference for eating quality and appearance were also determined. We also endeavoured to establish whether there is a link between the development of mealiness and harvest maturity.

# 3. MATERIALS AND METHODS

## 3.1 Plant material

Inner and outer canopy 'Forelle' pears were harvested at different maturity stages within the commercial harvesting window on 23 February 2012 (H1), 27 February 2012 (H2) and 13 March 2012 (H3) at Glen Brae farm in Elgin (latitude: 34°10' S, longitude: 19°03' E), Western Cape, South Africa. The outer canopy pears were harvested from the top and outer parts of the canopy while the inner canopy pears were harvested from the shaded inner parts of the canopy.

## 3.2 Experimental design

A total of 200 inner canopy fruit as well as 200 outer canopy fruit were harvested on each date with 10 replicates of 20 fruit for each of the three harvests, and three post-storage and ripening evaluation dates. The experimental design was a complete randomized design with ten replications. One fruit per replication (i.e., 10 fruit per canopy position) was randomly selected and subjected to a firmness test immediately after harvest in order to determine whether the inner and outer canopy fruit had the same maturity. The intention of this particular study was to use inside and outside canopy fruit of comparable maturity, therefore, if the pears differed in maturity a further harvest would have been scheduled.

Inner and outer canopy pears of the same replication were packed in the same box, thereby giving rise to a split plot design with harvest date as the main factor and canopy position as the subplot factor. Fruit were placed on pear pulp trays and then packed into cartons lined with a polyethylene bag (37.5 µm), which was folded over to cover the fruit completely. Pears from the different harvests were each stored at -0.5°C for a period of 12 weeks, and then ripened at room temperature (20ºC) for seven days before physicochemical analyses, sensory analyses and consumer preference assessment. Additional firmness measurements were taken on 50 inner canopy fruit and 50 outer canopy fruit after 4 and 11 days of ripening, respectively. Of the nineteen remaining pears, five were used for physicochemical analyses (per replicate), five for additional firmness measurements (per replicate), four (per replicate) for descriptive sensory analysis and five (per replicate) to assess consumer preference.

### 3.3 Physicochemical measurements

The five pears from the same replicate were viewed as composite samples. All the physicochemical measurements were taken from the same set of 'Forelle' pears after each 12 week cold storage period and subsequent ripening at 20°C for seven days. Firmness was determined after 4, 7 and 11 days of ripening. All the physicochemical measurements were performed as described in Chapter 2.

### 3.4 Descriptive sensory analysis

Inner and outer canopy 'Forelle' pear samples were presented to the panel according to the methodology described in Chapter 2. The definitions used for the sensory attributes (Chapter 2, Table 1) are similar to those used by Daillant-Spinnler *et al*. (1996).

### 3.5 Consumer preference

Consumer sensory analyses were conducted on approximately one-hundred and twenty recruited South African pear consumers living in the Stellenbosch area. Consumers were presented with a questionnaire that consisted of four sections to gather socio-demographic, fruit purchasing and consumption information; and to assess the degree of liking for the texture, flavour, overall eating quality, as well as the appearance (Fig. 1) as described in Chapter 2.

### 3.6 Statistical procedures

Inner and outer canopy 'Forelle' pears were compared using physicochemical analysis, descriptive sensory analysis, as well as consumer preference data. The experimental design was a split plot. All data was analyzed 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 & Wilk, 1965). Student's t-least significant difference (LSD) was calculated at the 5%

significance level to compare treatment means. Pearson's correlations were performed between physicochemical, sensory and consumer eating quality attributes. Principal component analysis (PCA) and discriminant analysis (DA) were carried out to identify variables that associate with certain treatments (XLStat, Addinsoft, France).

# 4. RESULTS

## 4.1 Physicochemical measurements

Outer canopy pears were significantly larger with an average weight of 157 g compared to the inner canopy pears that were 146 g. At the start of the export picking window (H1), the inner canopy pears had an average flesh firmness of 6.6 kg and outer canopy pears had an average flesh firmness of 6.5 kg (Table 1). Outer canopy pears harvested at the middle of the export picking window (H2) had an average flesh firmness of 6.2 kg and inner canopy pears an average firmness of 6.4 kg. Inner canopy pears harvested at the lower end of the middle export picking window (H3) had an average flesh firmness of 5.7 kg while outer canopy pears had an average flesh firmness of 6.0 kg.

The ground colour of the outer canopy pears were slightly, but significantly more yellow compared to the inner canopy pears after 12 weeks cold storage at -0.5ºC and 7 days ripening at 20ºC (Table 2). As expected, the exposed side of outer canopy 'Forelle' pears had a red blush while inner canopy pears were uniformly yellow according to the hue angle (Table 2). Outer canopy H3 pears had a slightly more yellow ground colour compared to pears from H1 and H2 (Table 2). After 12 weeks cold storage at -0.5°C and 7 days ripening at 20°C inner canopy pears at H1 and H2 had significantly higher chroma values compared to all other treatments (Table 3). The chroma values for inner and outer canopy pears at H3 did not differ from each other. Outer canopy H3 pears had a higher chroma compared to H1 and H2 pears.

Inner canopy pears were slightly firmer than outer canopy pears after 4 days of ripening at room temperature (20°C) while the outer canopy pears were slightly firmer after 11 days of ripening (Table 4). The firmness of H1 and H3 pears did not differ from each other at 4 and 11 days of ripening, while the firmness of the H2 fruit was significantly lower after 4 and 11 days of ripening. Canopy position had no effect on the firmness of pears ripened for 7 days at 20°C; however 'Forelle' pears had a significantly higher firmness at H3 compared to the other two harvest dates (Table 4). The firmness of mealy and non-mealy pears did not differ significantly from each other at the different harvests (data not presented).

Canopy position had no effect on DMC (Table 5). H2 pears showed a significantly higher DMC compared to H1 and H3. Higher ethylene levels were observed in outer canopy pears, as well as H3 pears. Outer canopy pears had a significantly higher incidence of mealiness compared to inner canopy pears (Table 5). The incidence of mealiness was much higher in H3 fruit compared to H1 and H2 fruit, which did not differ in their incidence of mealiness.

Outer canopy and H3 pears were significantly higher in TSS (Table 5). Inner and outer canopy pears at H1 and outer canopy pears at H2 had similar TA, which was higher than the other pear samples (Table 6). The TA of the inner and outer canopy pears at H1 and the inner canopy pears at H2 did not differ from each other. Inner canopy pears at H2 and H3 had a similar TA concentration. Outer canopy pears at H3 had the lowest TA concentration compared to all the other pear samples. The TSS:TA ratio was significantly higher in outer canopy pears at H3 compared to all the other samples. The TSS:TA ratio for inner and outer canopy pears at H1 and H2 did not differ from each other; however the ratio was significantly lower than the TSS:TA ratio for the H3 pears.

## 4.2 Sensory attributes

Canopy position had no effect on flavour characteristics (pear flavour and taste) of ‘Forelle’ pears (Table 7). In addition, scores for pear flavour and sweetness did not differ between the different harvests. H2 pears scored significantly lower for sour taste compared to H1 and H3 pears. Inner canopy pears were significantly higher in melt character compared to outer canopy pears. Canopy position had no effect on juiciness and sensory mealiness. H1 and H2 pears had a significantly higher melt character and were also juicier than H3 pears while H3 pears scored significantly higher for mealiness. H1 pears were perceived as slightly but significantly harder than H2 and H3 pears; however the hardness scores were quite low overall (Table 8). Outer canopy pears from H2 and pears from H3 did not differ in scores for hardness. Outer canopy pears at H2 and H3 received the highest scores for grittiness. Inner canopy pears from H2 did not significantly differ from H1 pears and inner canopy pears from H3 in terms of grittiness. Mean scores for astringency and bitterness were extremely low (data not presented).

## 4.3 Consumer preference

### *4.3.1 Consumer socio-demographic information*

A total of 362 consumers of which 28% were males and 72% females took part in the study. Twenty eight percent of the consumers were 18 to 25 years old, 25% were 25 to 36 years old, 21%

between 36 and 50 years old and the remaining 15% over 51 years old. More than half (54%) of the consumers were white, 32% coloured and 11% black. Eleven percent of the consumers consume pears on a daily basis, 36% two to three times a week, 30% two times per month and 21% only sometimes.

#### *4.3.2 Consumer preference for eating quality and appearance*

Inner canopy pears at H1 and H2 received significantly higher hedonic scores for texture, flavour and eating quality than outer canopy and H3 inner canopy fruit (Table 9). Hedonic scores for texture, flavour and eating quality for outer canopy H2 pears and inner canopy H3 pears did not differ from each other. Outer canopy H1 and H3 pears received significantly lower hedonic scores compared to all other samples for texture, flavour and eating quality. Consumers significantly, but only slightly preferred the appearance of outer canopy 'Forelle' pears while there was no difference in the scores for the appearance of the pears of the different harvests (Table 10).

### 4.4 Multivariate analyses

The Principal Component Analysis (PCA) bi-plot for 'Forelle' pears explains 83% of the variation in the bi-plot considering the first two principal components (Fig. 2). The first component (F1 or PC1) explained 65% of the total variability in the data with the attributes of melt character, mealiness sensory, TSS, juiciness, TSS:TA, TA, mealiness incidence, eating quality liking, firmness, sweet taste, pear flavour and grittiness indicated on PC1. Sour taste, hardness and DMC contributed to variability on the second principal component (F2 or PC2) which explained 19% of the total variability in the data. Therefore, the attributes on PC1 was more important as it explained the most variability in this data-set. The pear samples harvested at varying maturity stages are situated in different quadrants of the bi-plot, which portrays the sensory and physicochemical differences between them. Inner and outer canopy pear samples harvested on the same day were quite similar.

Inner and outer canopy pears from H1 and H2 are separated from H3 pears on PC1. Inner and outer canopy pears from H3 are associated with sensory mealiness and mealiness incidence. Eating quality liking had significant negative Pearson's correlations with mealiness incidences (r = -0.96) and TSS (r = -0.84). H2 pears associate with DMC while outer canopy pears from H1 associate with sensory attributes such as hardness, pear flavour, sweetness, juiciness and melt character.

Sweet taste had significant positive correlation with juiciness (r = 0.87) and melt character (r = 0.86). Juiciness had significant positive correlations with sour taste (r = 0.87) and melt character (r = 0.97) while negative correlations were found with sensory mealiness (r = -0.94), firmness (r = -0.82) and TSS (r = -0.88). Sensory mealiness correlated significantly with mealiness incidence (r = 0.86), TSS (r = 0.95) and TSS:TA (r = 0.90), and was inversely correlated with TA (r = -0.90) and melt character (r = -0.96).

Discriminant analysis (Fig. 3) carried out on sensory attributes corresponds with the PCA bi-plot in the variation between the fruit harvested at different maturities. The main factor discriminating H3 fruit from H1 and H2 fruit is sensory mealiness on PC1.

# 5. DISCUSSION

### 5.1 The effect of harvest maturity and canopy position on the physicochemical and sensory attributes of 'Forelle' pears

It is evident from this research that harvest maturity has a significant effect on the sensory and physicochemical attributes of pears. The firmness values of inner and outer canopy 'Forelle' pears from the three harvests (H1, H2 & H3) in our study were within the standards set out for the commercial picking window (4.5 kg to 6.8 kg) in South Africa (Hurndall, 2011). It might have been better if the H1 fruit were harvested a little earlier (≥6.8 kg) and H3 fruit were harvested at a later stage (≤4.5 kg) to maximize the differences between the fruit while portraying the whole harvest spectrum. In previous seasons fruit were harvested at high firmness values (>6.4 kg) because there was always the pressure of entering the market early in the season; therefore the chances of fruit harvested at a low firmness (≈4.5 kg) was small (E.M.Crouch, Department of Horticulture, Stellenbosch University, Stellenbosch, South Africa, 2013, personal communication). Some producers may also try to increase the TSS concentration by harvesting later as is the case during treatment for 1-MCP, not realizing that this is futile when yellowing and mealiness is considered (E.M.Crouch, Department of Horticulture, Stellenbosch University, Stellenbosch, South Africa, 2013, personal communication). Carmichael (2011) found that post-optimum harvested 'Forelle' pears were more prone to mealiness with a shorter storage life compared to pre-optimum and optimum harvested fruit. As found in our study, a delay in harvest date results in lower firmness of fruit at harvest (Zerbini, 2002; Crouch *et al*., 2005). After cold storage and 7 days shelf-life, H3 fruit were firmer, higher in ethylene, mealiness, TSS and lower in TA while H1 and H2 fruit were higher in melt character, juiciness, sourness and TA. PCA (Fig. 2) and discriminant analysis (Fig. 3) clearly separates between the different harvest maturities based on their physicochemical and sensory profiles. The main factor discriminating H3 fruit from H1 and H2 fruit is sensory mealiness on F1 (54.7%).

Stebbins *et al*. (1998) stated that pears that are allowed to ripen or become too mature on the tree will develop a mealy texture. Furthermore these authors found that fruit that were harvested too early but just slightly immature will ripen to better eating quality than pears that are harvested too late in the season. A study by Carmichael (2011) confirms that post-optimum harvested 'Forelle' pears had higher incidences of mealiness. This is in accordance with our research where pears harvested later in the season (H3) developed an extremely high incidence of mealiness (90%) compared to fruit harvested at the start of the export picking window (53%) and fruit harvested in the middle of the export picking window (42%). Previous research indicated that mealy fruit had a lower firmness than non-mealy fruit (Barreiro *et al*., 1998; Abbott *et al*., 2004). However, in our research, the firmness of mealy and non-mealy fruit did not differ significantly, corresponding with the findings in Chapter 2. The development of mealiness in 'Forelle' pears starts at the 'neck' of the fruit and then moves downward and spreads out to the sides of the fruit (E.M.Crouch, Department of Horticulture, Stellenbosch University, Stellenbosch, South Africa, 2013, personal communication). Penetrometer readings were taken halfway between the calyx and the stem end of each pear on two equatorial sites that were peeled. It is possible that mealiness development in some pears had not progressed to the point where it could influence firmness readings. Another possible explanation is that the penetrometer is not equipped to detect fine differences in texture between pears. Sensory panels associated an increase in mealiness with a decrease in juiciness and hardness (Barreiro *et al*., 1998). H1 and H2 pears were scored significantly higher in melt character and juiciness compared to the H3 pears.

Most sensory attributes of inner and outer canopy pears harvested on the same date were similar as indicated by the discriminant analysis (DA) plot (Fig. 3). The lack of a positional effect on DMC, as well as sweet and sour taste is consistent with findings in Chapter 2. Inner and outer canopy pears harvested at different stages of maturity differ in some physicochemical and sensory characteristics and these differences, most notably in the incidence of mealiness, affects consumer preference after cold storage and ripening. Consistent with findings in Chapter 2, outer canopy pears showed a higher TSS and a mealiness incidence almost double that of inner canopy pears. The sensory trained panel could not detect a difference between inner and outer canopy pears with regards to mealiness, possibly because they assessed the level of mealiness for each sample and not the incidence of mealiness as was done in the physicochemical assessment. This was despite a significant correlation between physicochemical mealiness and sensory mealiness (r=0.86). It is important to note that only 20 samples were analysed during the sensory assessment of mealiness while 100 samples were evaluated during assessment of physicochemical mealiness. During sensory analyses, a 100 mm unstructured line scale, where the left side of the scale corresponded to the absence of mealiness and the right hand side to the highest mealiness intensity was used. No scale was used to determine the level of mealiness development in the physicochemical assessment; a pear was either classified mealy or non-mealy.

Our results corroborate previous findings that TSS is higher in fruit harvested at greater maturity (De Belie *et al*., 2000; Błaszczyk, 2010). Similarly, the more mature fruit also had lower TA levels as reported by Mielke *et al*. (2005). TSS and sweet taste and also TA and sour taste did not correlate significantly. Panellists may perceive sweetness as a lack of sourness, and *vice versa* (Van der Merwe, 2012). A poor correlation between sweet taste and TSS could be ascribed to the effect of the acid level on sweet taste that is under- or overestimated in the presence of a high and low acid taste, respectively (Visser *et al*., 1968). Van der Merwe (2012) found that apples tasted sweeter (intensity score >50) due to their low TA values although they had a lower TSS (<10 °Brix) compared to other apples with a higher TSS.

Previous studies have established that astringency in apples and pears are linked to the maturity of the fruit (Young *et al*., 1999; Mielke *et al*., 2005). Persimmon fruit that are harvested too early are most likely immature, contain high tannin levels and will subsequently be perceived as astringent (Ramin & Tabatabaie, 2003). ‘Forelle’ pears harvested early in the season with an average firmness of 7.4 kg showed the highest astringency, therefore firmer fruit tend to be more astringent (Carmichael, 2011). Fruit harvested at a greater maturity with an average firmness of 6.1 kg after eight weeks of cold storage showed a great reduction in astringency. After seven days of ripening at 15°C, firmness dropped to an average of 2.3 kg and no astringency was observed. The sensory panel of judges could not detect astringency during our study, probably because pears of all the harvest maturities ripened too close to the optimum consumption firmness (≈1.5 kg) (Vayasse *et al*., 2005) after storage at -0.5°C for 12 weeks and ripening at room temperature for 7 days. When cold storage treatments are adequate, the characteristic pear ripening process will unfold in a loss of firmness, green colour, malic acid and an increase in ethylene, which will result in an increase in protein and water soluble polyuronides which will result in a juicy fruit (Zerbini, 2002).

Red-blushed cultivars only develop red blush on the side of fruit exposed to solar radiation, while the shaded inner canopy fruit remains green (Steyn *et al*., 2005). Our results confirm the previous finding where outer canopy ‘Forelle’ pears developed a red blush on the exposed side. H3 fruit were considerably brighter in red colour after storage. The intensification of red colour for outer canopy H3 fruit probably relates to more advanced chlorophyll degradation and a consequently lighter background colour in these fruit.

### 5.2 The effect of harvest maturity and canopy position on consumer preference for eating quality and appearance

Consumer preferences for eating quality within a certain apple cultivar are often defined by the degree of ripeness (Harker *et al*., 2003). Canopy position and harvest maturity interacted significantly in the preference for texture, flavour and eating quality of ‘Forelle’ pears (Table 9).

Inner canopy pears at H1 and H2 received significantly higher scores for texture, flavour and eating quality than inner canopy H3, as well as outer canopy fruit. Although preferred less than H1 and H2 inner canopy pears, H3 inner canopy pears were also preferred to outer canopy H3 pears. Thus, this research reaffirms the apparent eating quality preference for inner over outer canopy pears (Chapter 2). The reasons for the generally higher liking of inner canopy pears and the more specific preference of H1 and H2 inner canopy pears are unclear from the physicochemical and sensory results. However, multivariate analyses showed that eating quality had significant negative Pearson's correlations with mealiness incidences (r = -0.96) which associated with H3 pears. The incidence of mealiness was generally higher in outer canopy fruit. Previous studies showed that mealiness is the main reason for consumer dislike in apples (Jaeger *et al*., 1998; Andani *et al*., 2001) and pears (Manning, 2009). Consumer opinions of various pear characteristics indicated their preference for pears that are sweet, juicy and have a prominent pear flavour while mealiness and bitterness were rated undesired attributes (Chapter 2). These results are similar to findings in studies conducted by Jaeger *et al*. (2003) and Manning (2009) in the search for the "ideal pear". Mealiness is a negative driver of consumer liking and its generally higher incidence in H3 fruit of all canopy positions is most likely the reason why consumers disliked these pears. With regard to outer canopy pears, consumers preferred H2 over H1 and H3 fruit. The dislike for H3 outer canopy fruit most likely relates to the high incidence of mealiness and maybe even a too low TA which makes the fruit taste bland. H2 fruit also had a lower firmness, higher DMC and lower sour taste than H1 and H3 fruit.

The main question that we aimed to answer in this study was when producers should harvest 'Forelle' pears to ensure optimum eating quality, i.e. the greatest consumer preference. Harvest maturity for 'Forelle' pears in South Africa ranges from 4.5 kg to 6.8 kg (Hurndall, 2011). The firmness values of all three harvests in our study were within the standards set out for the commercial picking window. Carmichael (2011) viewed the optimum eating ripeness for 'Forelle' pears to be at a firmness of 3.5 kg, however, the pears in our research were more advanced in ripening as they had a lower mean firmness, which was more towards the optimum consumption firmness (≈1.5 kg) for pears that was proposed by Vayasse *et al*. (2005). However, it is important to keep in mind that the harvest maturity, length and ripening temperature of Carmichael's study differed from the conditions used in this study. Pears that are at optimum maturity should have a good sugar-acid balance (Visser *et al*., 1968), distinctive pear aroma, juiciness as well as a melting, buttery texture (Zerbini, 2002). However, due to the severe dislike of mealy fruit, positive sensory attributes will not increase consumer satisfaction of a mealy fruit. Therefore, the aim should be to minimize the incidence of mealy fruit. Since consumers indicated lower hedonic scores for eating quality of H1 outer canopy pears picked at a higher firmness, possibly due to lower levels of some sensory attributes, outer canopy pears should be harvested close to 6.2 kg firmness. Considering the above, our results suggest that harvesting 'Forelle' pears at a firmness

~6.2 kg will ensure that both inner and outer canopy pears have acceptable eating quality. However, Martin (2002) and Carmichael (2011) found that the level of mealiness may differ between seasons even when fruit is harvested at the same maturities. Therefore, this research should be repeated for a few consecutive seasons.

As in Chapter 2, consumers indicated a higher liking for the attractive red blushed outer canopy 'Forelle' pears. However, it is important to note that the preference for the appearance of outer canopy red blushed pears was only slight and that the yellow appearance of the inner canopy pears still received a high score for appearance liking. Consumers may associate the yellow appearance of inner canopy Forelle pears with the appearance of Bon Chretien, the third most commonly grown (Hortgro Services, 2011) and a well-liked (Manning, 2009) cultivar in South Africa.

This research confirms the finding in Chapter 2 that inner canopy 'Forelle' pears should not be viewed as inferior to outer canopy fruit with regard to both eating quality and appearance. However, it is important to keep in mind that our findings apply only to the specific conditions prevalent during the season of the trial. There are numerous other ways pears can be treated eg. post-optimum harvest in combination with 1-MCP treatment as well as prolonged storage periods, however, this was not part of our focus in this particular study. It is important to mention that preference is very much also linked to a specific TSS, TA and texture for a specific storage and treatment, which means that our results are not universally true for all inner and outer canopy 'Forelle' pears in the industry.

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**Table 1** The effect of canopy position (inner canopy versus outer canopy) and harvest date (23, 27 Feb. or 13 March) for ‘Forelle’ pears harvested at Glen Brae, Elgin, Western Cape, South Africa. Flesh firmness is a parameter used by the South African deciduous fruit industry to determine harvest maturity of ‘Forelle’ and ranges from 4.5 kg (over-mature standard) to 6.8 kg (release criterion). For the purpose of this study pears harvested at the start of the export picking window (H1) firmness ranges from 6.8-6.5 kg, pears harvested at the middle of the export picking window (H2) firmness 6.4-6.1 kg and pears harvested at the lower end of the middle export picking window (H3) firmness 6.0-5.5 kg. Values are means ± SE (n=10).

| Harvest | Canopy position | Firmness (kg) |
|---|---|---|
| H1 | Inside | 6.6 ± 0.17 |
| | Outside | 6.5 ± 0.15 |
| H2 | Inside | 6.4 ± 0.14 |
| | Outside | 6.2 ± 0.12 |
| H3 | Inside | 5.7 ± 0.09 |
| | Outside | 6.0 ± 0.04 |

**Table 2** The effect of canopy position (inner canopy versus outer canopy) and harvest date (23, 27 Feb. or 13 March 2012) on the ground colour and hue values of 'Forelle' pears harvested at Glen Brae, Elgin, Western Cape, South Africa. Hue was measured at the reddest position. Average hue values at the different harvest times are not indicated because it is senseless to combine hue values for outer canopy and inner canopy fruit. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Treatment** | **Ground colour**[x] | **Hue (°)** |
|---|---|---|
| **Canopy position** | | |
| Inside | 3.5 b[z] | 98 a |
| Outside | 3.7 a | 38 b |
| **Harvest** | | |
| H1 | 3.6 b[z] | - |
| H2 | 3.5 b | - |
| H3 | 3.7 a | - |
| ***P value*** | | |
| **Position** | *0.0005* | *<0.0001* |
| **Harvest** | *0.0294* | - |
| **P*H** | *0.0505* | - |

[x] Chart values 0.5-5: where 0.5= dark green; 5= deep yellow

[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) and harvest date (23, 27 Feb. or 13 March 2012) on the chroma of 'Forelle' pears harvested at Glen Brae, Elgin, Western Cape, South Africa. Chroma is the degree of departure from gray or white towards the pure hue colour and is a measure of colour saturation. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Harvest** | **Canopy position** | **Chroma (C*)** |
|---|---|---|
| H1 | Inside | 47.5 a[z] |
| | Outside | 39.3 c |
| H2 | Inside | 46.7 a |
| | Outside | 39.8 c |
| H3 | Inside | 44.1 b |
| | Outside | 45.3 b |
| ***P-value*** | | |
| **Position** | | *<0.0001* |
| **Harvest** | | *0.0058* |
| **P*H** | | *<0.0001* |

[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) and harvest date (23, 27 Feb. or 13 March 2012) on firmness of ‘Forelle’ pears harvested at Glen Brae, Elgin, Western Cape, South Africa. Measurements were performed after 4, 7 and 11 days of ripening at room temperature (20°C) after a storage period of 12 weeks at -0.5°C.

| **Treatment** | **Firmness (4 days)** | **Firmness (7 days)** | **Firmness (11 days)** |
|---|---|---|---|
| **Canopy position** | | | |
| Inside | 3.4 a[z] | 1.8 [NS] | 1.3 b |
| Outside | 3.2 b | 1.8 | 1.4 a |
| **Harvest** | | | |
| H1 | 3.7 a | 1.7 b | 1.4 a |
| H2 | 2.9 b | 1.7 b | 1.2 b |
| H3 | 3.4 a | 2.0 a | 1.4 a |
| ***P-value*** | | | |
| **Position** | *0.0379* | *0.7878* | *<0.0001* |
| **Harvest** | *<0.0001* | *<0.0001* | *<0.0001* |
| **P*H** | *0.1606* | *0.4326* | *0.5221* |

[NS] Not significant

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

**Table 5** The effect of canopy position (inner canopy versus outer canopy) and harvest date (23, 27 Feb. or 13 March 2012) on DMC (dry matter concentration), ethylene evolution rate, mealiness incidence and total soluble solids (TSS) of 'Forelle' pears harvested at Glen Brae, Elgin, Western Cape, South Africa. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Treatment** | **DMC (%)** | **Ethylene (μL kg$^{-1}$ h$^{-1}$)** | **Mealiness incidence (%)** | **TSS (° Brix)** |
|---|---|---|---|---|
| **Canopy position** | | | | |
| Inside | 30.1 [NS] | 3.35 b[z] | 45 b | 16.9 b |
| Outside | 29.5 | 4.16 a | 78 a | 17.4 a |
| **Harvest** | | | | |
| H1 | 29.2 b | 3.38 b | 53 b | 16.9 b |
| H2 | 31.8 a | 3.15 b | 42 b | 16.9 b |
| H3 | 28.5 b | 4.74 a | 90 a | 17.7 a |
| ***P-value*** | | | | |
| **Position** | *0.1739* | *0.0012* | *<0.0001* | *0.0002* |
| **Harvest** | *<0.0001* | *<0.0001* | *<0.0001* | *<0.0001* |
| **P*H** | *0.2339* | *0.0594* | *0.1624* | *0.0656* |

[NS] Not significant

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

**Table 6** The effect of canopy position (inner canopy versus outer canopy) and harvest date (23, 27 Feb. or 13 March 2012) on titratable acidity (TA) and TSS:TA ratio for 'Forelle' pears harvested at Glen Brae, Elgin, Western Cape, South Africa. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Harvest** | **Canopy position** | **TA (% malic acid)** | **TSS/TA** |
|---|---|---|---|
| H1 | Inside | 0.27 ab[z] | 65 c |
| | Outside | 0.27 ab | 65 c |
| H2 | Inside | 0.25 bc | 67 c |
| | Outside | 0.28 a | 62 c |
| H3 | Inside | 0.23 c | 76 b |
| | Outside | 0.17 d | 107 a |
| ***P-value*** | | | |
| **Position** | | *0.0863* | *0.0005* |
| **Harvest** | | *<0.0001* | *<0.0001* |
| **P*H** | | *<0.0001* | *<0.0001* |

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

**Table 7** The effect of canopy position (inner canopy versus outer canopy) and harvest date (23, 27 Feb. or 13 March 2012) on the overall means of 'Forelle' sensory attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis. Pears were harvested at Glen Brae, Elgin, Western Cape, South Africa and subjected to cold storage for 12 weeks followed by 7 days at room temperature (20°C).

| **Treatment** | **Pear flavour** | **Sweet taste** | **Sour taste** | **Melt character** | **Juiciness** | **Mealiness** |
|---|---|---|---|---|---|---|
| **Canopy position** | | | | | | |
| Inside | 49 $^{NS}$ | 48 $^{NS}$ | 24 $^{NS}$ | 34 a$^{z}$ | 34 $^{NS}$ | 32 $^{NS}$ |
| Outside | 47 | 47 | 22 | 28 b | 30 | 40 |
| **Harvest** | | | | | | |
| H1 | 49 $^{NS}$ | 49 $^{NS}$ | 23 a | 36 a | 37 a | 27 b |
| H2 | 48 | 47 | 20 b | 33 a | 33 a | 29 b |
| H3 | 47 | 47 | 25 a | 25 b | 25 b | 52 a |
| ***P-value*** | | | | | | |
| **Position** | *0.1154* | *0.2655* | *0.1034* | *0.0069* | *0.0854* | *0.0884* |
| **Harvest** | *0.7577* | *0.3994* | *0.0012* | *0.0006* | *0.0011* | *0.0001* |
| **P*H** | *0.3733* | *0.9735* | *0.6017* | *0.7237* | *0.9135* | *0.7534* |

$^{NS}$ Not significant

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

**Table 8** The effect of canopy position (inner canopy versus outer canopy) and harvest date (23, 27 Feb. or 13 March 2012) on 'Forelle' sensory texture attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2012. Pears were harvested at Glen Brae, Elgin, Western Cape, South Africa and subjected to cold storage at -0.5°C for 12 weeks followed by 7 days of ripening at room temperature (20°C).

| **Harvest** | **Canopy position** | **Hardness** | **Grittiness** |
|---|---|---|---|
| H1 | Inside | 12 a[z] | 23.6 d |
| | Outside | 12 a | 24.1 d |
| H2 | Inside | 8 c | 24.4 cd |
| | Outside | 10 b | 27.5 a |
| H3 | Inside | 10 b | 25.9 bc |
| | Outside | 9 bc | 26.5 ab |
| ***P-value*** | | | |
| **Position** | | *0.3957* | *0.0028* |
| **Harvest** | | *<0.0001* | *0.0002* |
| **P*H** | | *0.0231* | *0.0375* |

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

**Table 9** The effect of canopy position (inner canopy versus outer canopy) and harvest date (23, 27 Feb. or 13 March 2012) on the overall degree of liking of 'Forelle' pears with regards to texture, flavour and eating quality in 2012. A nine-point hedonic scale was used where 9=Like extremely and 1=Dislike extremely. 'Forelle' pears were harvested at Glen Brae, Elgin, Western Cape, South Africa and stored for 12 weeks at -0.5°C.

| **Harvest** | **Canopy position** | **Texture** | **Flavour** | **Eating Quality** |
|---|---|---|---|---|
| H1 | Inside | 6.2 a[z] | 6.7 a | 6.3 a |
| | Outside | 4.5 c | 5.1 c | 4.7 c |
| H2 | Inside | 6.2 a | 6.9 a | 6.3 a |
| | Outside | 5.2 b | 6.0 b | 5.5 b |
| H3 | Inside | 5.0 b | 5.8 b | 5.2 b |
| | Outside | 4.3 c | 5.0 c | 4.4 c |
| ***P-value*** | | | | |
| **Position** | | *<0.0001* | *<0.0001* | *<0.0001* |
| **Harvest** | | *<0.0001* | *<0.0001* | *<0.0001* |
| **P*H** | | *0.0203* | *0.0202* | *0.0226* |

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

**Table 10** The effect of canopy position (inner canopy versus outer canopy) and harvest date (23, 27 Feb. or 13 March 2012) on the overall degree of liking of appearance. A nine-point hedonic scale was used where 9=Like extremely and 1=Dislike extremely. 'Forelle' pears were harvested at Glen Brae, Elgin, Western Cape, South Africa and stored for 12 weeks at -0.5°C.

| Treatment | Appearance |
|---|---|
| **Canopy position** | |
| Inside | 7.3 b[z] |
| Outside | 7.6 a |
| **Harvest** | |
| H1 | 7.5[NS] |
| H2 | 7.5 |
| H3 | 7.5 |
| ***P-value*** | |
| **Position** | *0.0013* |
| **Harvest** | *0.8338* |
| **P*H** | *0.9149* |

[NS] Not significant

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

**INNER CANOPY**

**OUTER CANOPY**

**Figure 1** Images of representative inner and outer canopy ‘Forelle’ pears from Glen Brae, Elgin, Western Cape, South Africa. Photographs were taken after cold storage and subsequent ripening at room temperature (20°C) for 5 days.

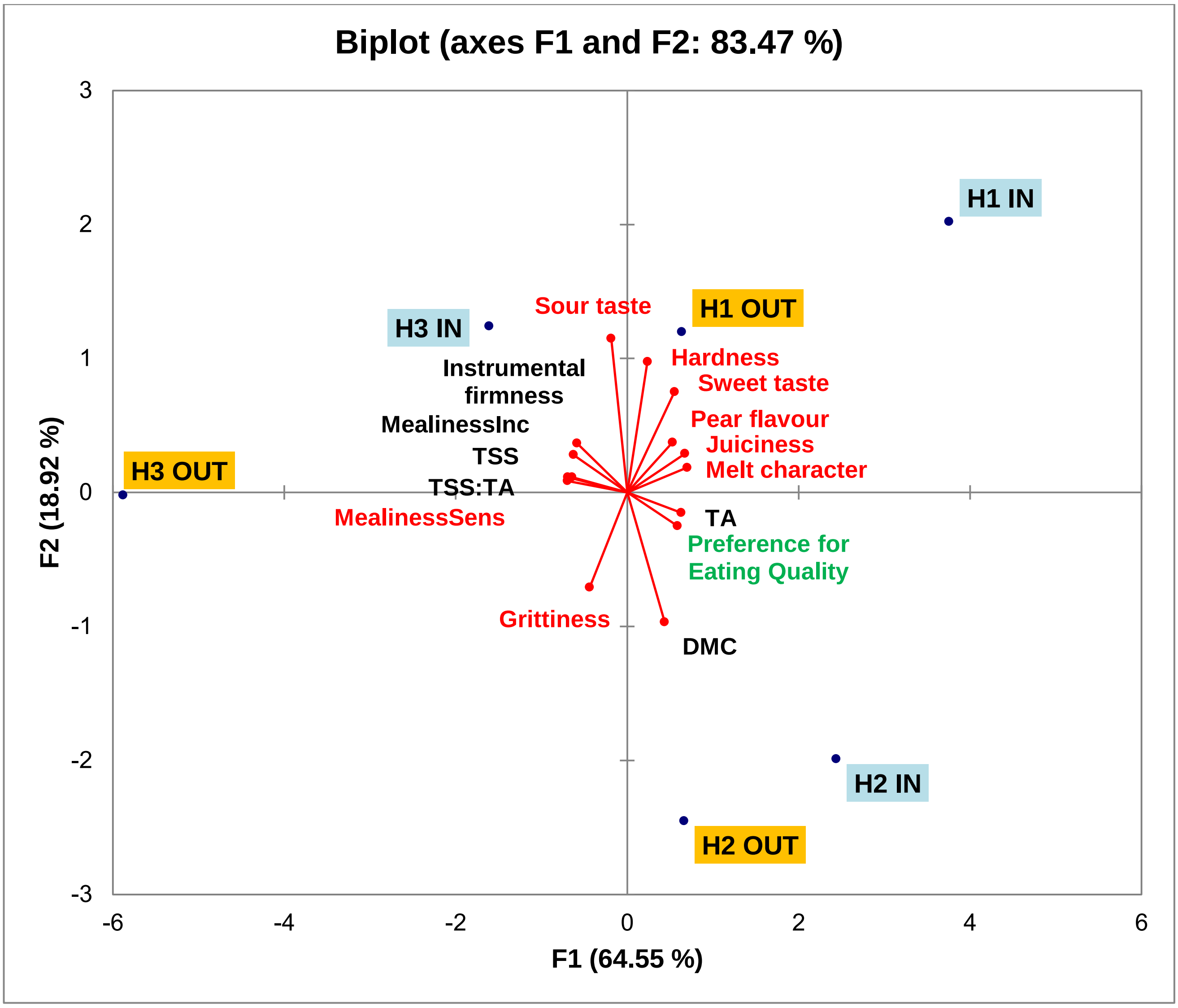


**Figure 2** Principal component analysis bi-plot indicating the position of consumer preference for overall eating quality (green) in relation to sensory attributes (red) and physicochemical measurements (black) of inner and outer canopy 'Forelle' pears harvested in 2012 at H1, H2 and H3 where TSS - total soluble solids, TA - titratable acidity, DMC - dry matter concentration, MealinessInc- mealiness incidence, MealinessSens- sensory mealiness.

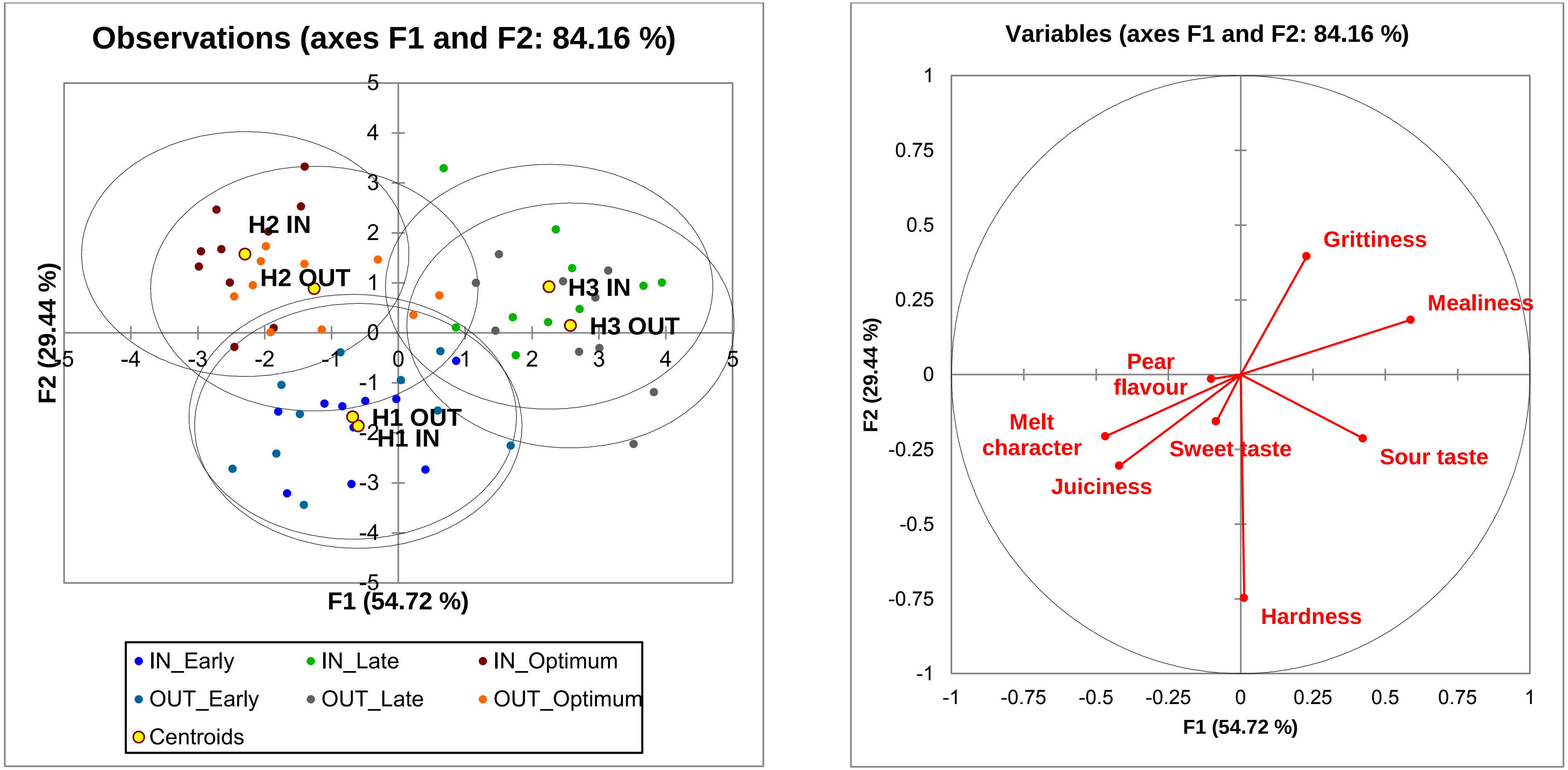


**Figure 3** Discriminant analysis plot (a) and variable loadings (b) plot for three different harvest dates for 'Forelle' pears based on results of descriptive sensory analysis. The coloured dots inside each cluster resemble the replicates of each treatment (IN Early= H1 IN; OUT Early=H1 OUT; IN Optimum= H2 IN; OUT Optimum=H2 OUT; IN Late= H3 IN; Out Late= H3 OUT)

# CHAPTER 4

# EFFECT OF CANOPY POSITION AND ORCHARD SITE ON THE PHYSICOCHEMICAL AND SENSORY CHARACTERISTICS OF 'FORELLE' PEARS AFTER COLD STORAGE AND RIPENING

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# 1. ABSTRACT

This study was conducted to determine the effect of orchard site on the physicochemical and sensory quality of inner and outer canopy 'Forelle' pears. 'Forelle' pears were sourced from two divergent production regions, viz. Elgin and Ceres, Koue Bokkeveld, in the Western Cape, South Africa. Fruit were harvested in 2012 at commercial firmness (≈6.4 kg) from two orchards per area, viz. Glen Fruin and Glen Brae in Elgin, and Lindeshof A and Lindeshof B in Ceres. Fruit were stored at -0.5°C for 12 weeks and thereafter ripened at room temperature (20°C) for seven days before physicochemical and sensory analyses were conducted. Previous studies have indicated that 'Forelle' pears from warmer areas are more prone to develop mealiness while mealiness incidence also varies between orchards. We aimed to confirm these findings for pears of different canopy positions. Weather stations in the different regions near the orchards showed that the pears in the Elgin region were exposed to slightly higher minimum and maximum temperatures compared to the Ceres Koue Bokkeveld region. After ripening, quality attributes such as flesh firmness, mealiness incidence, peel colour, total soluble solids concentration (TSS), titratable acidity (TA), ethylene measurement and dry matter concentration (DMC) were assessed, while a trained panel performed descriptive sensory analyses on the pear samples. The TSS was higher in the Elgin pears while the flavour attributes were more pronounced in Ceres pears. In both areas, the outer canopy pears were higher in TSS and lower in TA while canopy position had no effect on sweet and sour taste. Red blush colour development in pears cultivated in Elgin and Ceres were similar. Our results show that mealiness incidence was high in fruit from the Elgin area, as well as in one of the Ceres orchards. Outer canopy pears at Glen Fruin, Glen Brae and Lindeshof B showed a mealiness incidence that was more than double that of inner canopy pears. Lindeshof A is the only orchard in this study where outer canopy pears also had low incidences of mealiness, similar to that of inner canopy pears. Consequently, no definite conclusion can be reached regarding regional differences in mealiness incidence. There are, however, differences between orchards and therefore further research over consecutive seasons is needed to determine the reasons for orchard differences in mealiness incidence.

# 2. INTRODUCTION

'Forelle' (*Pyrus communis* L.) is a red blushed pear that originated in Germany and has been cultivated since 1670 (Crouch & Bergman, 2010). Forelle is currently the second highest exported pear cultivar in South Africa (Hortgro Services, 2011). 'Forelle' pears cultivated in South Africa experience problems with mealiness and astringency if they are not stored at -0.5°C for at least 12 weeks (Martin, 2002; Crouch *et al*., 2005; Crouch & Bergman, 2010). A ripened pear with good eating quality will generally have a juicy, buttery, melting texture accompanied by a characteristic pear flavour (Zerbini, 2002). Texture is a critical feature of pear quality as it relates to changes in cell components during ripening and consequently influences consumer acceptance.

Previous research has indicated that geographical and seasonal differences affect the incidence of mealiness in 'Forelle' pears (Wand *et al.*, 2008; Carmichael, 2011). In South Africa, 'Forelle' pears are mainly produced in the Western Cape where the growing areas have varying climates that may affect the harvest maturity and ripening potential of the fruit (Wand *et al*., 2008). Carmichael (2011) found that 'Forelle' pears from warmer areas such as the Warm Bokkeveld and Elgin were more prone to mealiness compared to cooler areas such as the Koue Bokkeveld. Both region and harvest maturity could have played a role in mealiness development as the Koue Bokkeveld pears were harvested less mature. Mellenthin and Wang (1976) found that 'd'Anjou' pears exposed to high temperatures six weeks before harvest developed more mealiness. In addition to differences in mealiness development, 'Forelle' pears produced in warm areas may be prone to poor blush colour development (Steyn *et al*., 2005), may develop sunburn and may be smaller in size (Wand *et al*., 2008).

The effect of canopy position on pear eating quality is extensively investigated in this thesis. In Chapter 2 we investigated the effect of cold storage duration (9, 12 and 16 weeks) over two seasons (2011/ 2012) on the physicochemical and sensory characteristics of inner and outer canopy 'Forelle' pears and how possible differences between the latter pears may influence consumer preference. In both seasons, outer canopy pears at 9 and 12 weeks had a significantly higher incidence of mealiness compared to inner canopy pears. In Chapter 3 we investigated the relationship between mealiness, canopy position and harvest maturity. A general dislike for fruit harvested at greater maturity and outer canopy fruit seemed to relate to high incidences of mealiness. The objective of this study, carried out in 2012, was to determine whether inner and outer canopy 'Forelle' pears from different orchards differ in quality attributes and mealiness incidence.

# 3. MATERIALS AND METHODS

## 3.1 Plant material

‘Forelle’ pears were sourced from two climatically different production areas in the Western Cape, South Africa in 2012. Fruit were harvested from two orchards per area, viz., Glen Fruin and Glen Brae in Elgin (latitude: 34°10’ S, longitude: 19°03’ E), as well as Lindeshof A and Lindeshof B in Ceres, Koue Bokkeveld (latitude: 33°08’ S, longitude: 19°23’ E). Outer canopy pears were harvested from the periphery of the canopy while the inner canopy pears were harvested from the more shaded inner canopy. The data for the ‘Forelle’ pears from Elgin were obtained from Chapter 2 (Glen Fruin) and Chapter 3 (Glen Brae).

‘Forelle’ pears were harvested on 2 March 2012 at Glen Fruin while pears from Glen Brae were harvested on 27 February 2012. ‘Forelle’ pears from Lindeshof A and Lindeshof B were harvested on 8 March 2012. Glen Fruin had the oldest ‘Forelle’ orchard, followed by Glen Brae, Lindeshof A and then Lindeshof B (Table 1). The plant spacing between trees differed between all the orchards while all trees were trained to a central leader system. Lindeshof A was planted in an E/W row direction while Lindeshof B and the two orchards from Elgin (Glen Fruin & Glen Brae) were planted in a N/S direction. Lindeshof A was situated at the highest altitude, closely followed by Lindeshof B and then Glen Fruin and Glen Brae (Table 1). The soil types of the different orchards were as follows: Glen Brae & Glen Fruin orchards (loam); Lindeshof A (clay-loam) and Lindeshof B (clay) (Table 1). An automatic industry weather station in the Elgin region showed slightly but significantly higher average minimum temperatures compared to the weather station in the Ceres Koue Bokkeveld region during the 2011/12 growing season (Table 2). There was, however, no difference in average maximum temperatures for the two regions.

### 3.2 Experimental design

The experimental design was a complete randomized design with ten replications per orchard. Ten fruit from each canopy position were harvested per replication from each of the Ceres orchards, which comprises to 400 pears in total. The Elgin fruit were harvested as described in Chapter 2 (Glen Fruin) and Chapter 3 (Glen Brae). One fruit per replication (i.e., 10 fruit per canopy position from each orchard) was randomly selected and subjected to a firmness test immediately after harvest in order to determine whether the inner and outer canopy fruit had comparable maturity. Fruit were placed on pear pulp trays and then packed into cartons lined with polyethylene bags (37.5 μm), which were folded to close the bags and cover the fruit completely. Pears were stored at -0.5°C for 12 weeks, and then ripened at room temperature (20ºC) for seven days before commencement of physicochemical and sensory descriptive analysis.

## 3.3 Physicochemical measurements

The five pears from the same replicate were viewed as composite samples. All the physicochemical measurements were taken from the same set of 'Forelle' pears after a 12 week cold storage period and subsequent ripening at 20°C for seven days. Physicochemical measurements were conducted as explained in Chapter 2.

### 3.4. Descriptive sensory analysis

Sensory analysis was carried out as explained for Chapter 2. The definitions used for the sensory attributes (Chapter 2, Table 1) were similar to those used by Daillant-Spinnler *et al*. (1996).

### 3.5. Consumer preference

The fruit from the different areas were harvested on different dates and therefore could not be compared for consumer preference analysis on the same day. Therefore, no consumer preference analysis was done for this study.

### 3.6 Statistical procedures

All data were analyzed 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 & Wilk, 1965). Student's t-least significant difference (LSD) was calculated at the 5% significance level to compare treatment means. Pearson's correlations were performed between physicochemical and sensory attributes. Principal component analysis (PCA) and discriminant analysis (DA) were carried out to identify variables that associate with certain treatments (XLStat, Addinsoft, France).

# 4. RESULTS

## 4.1 Physicochemical measurements

Outer canopy pears were slightly higher in firmness at harvest compared to inner canopy pears while there was no significant difference regarding firmness between the orchards (Table 3). Hue angles were lower for the outer canopy fruit in all four orchards; which means that the exposed side of outer canopy 'Forelle' pears had a red blush while inner canopy pears were uniformly yellow (Table 3). No significant difference in hue angle was noted between fruit from the different orchards. Canopy position did not affect the ground colour of fruit from Glen Fruin and Lindeshof B (Table 4). The ground colour of outer canopy Glen Brae and Lindeshof A fruit were more yellow compared to inner canopy pears. Outer canopy fruit from Glen Brae had the yellowest ground colour. The chroma values indicating the colour intensity of the outer canopy pears from the different orchards were similar and lower than the chroma values for inner canopy pears (Table 4). The highest chroma value for inner canopy pears was recorded at Glen Fruin, followed by Lindeshof B and then Glen Brae and Lindeshof A.

Firmness after cold storage and shelf-life was inconsistent with regard to canopy position (Table 5). Inner canopy fruit were firmer at Glen Fruin and Lindeshof B compared to outer canopy fruit, while outer canopy fruit were firmer at Lindeshof A. Glen Brae fruit were the least firm and firmness did not differ between canopy positions. Fruit from Ceres had the highest firmness with the inner canopy Lindeshof B and outer canopy Lindeshof A pears being the firmest. Outer canopy pears were significantly larger at all the orchards except Glen Brae where canopy position had no effect on fruit weight (Table 5). The largest fruit were harvested from the outer canopy of the Glen Fruin orchard followed by the inner canopy Glen Fruin fruit. The outer canopy Lindeshof A and Lindeshof B fruit did not differ from each other in terms of fruit weight and diameter. The smallest fruit were harvested from inner canopy Lindeshof A and Lindeshof B pears. Inner and outer canopy Glen Brae fruit, as well as outer canopy Lindeshof A pears were a little larger. Significantly higher mealiness incidences were observed in outer canopy pears for all orchards except Lindeshof A where canopy position had no effect on mealiness incidence (Table 5). The lowest mealiness incidence was observed for inner and outer canopy Lindeshof A, as well as inner canopy Lindeshof B pears.

Except for Glen Brae, outer canopy fruit from the different orchards had significantly higher TSS concentrations than inner canopy fruit (Table 6). The difference in TSS between outer and inner canopy fruit seemed to be considerably greater for fruit from Ceres. Outer canopy fruit from Glen

Fruin and inner canopy Lindeshof A and Lindeshof B fruit had the highest and lowest TSS concentrations, respectively. Inner canopy fruit from all orchards had higher TA concentrations than outer canopy fruit, with the inner canopy Glen Brae fruit having the highest TA concentration (Table 6). Outer canopy fruit from the two Ceres orchards had lower TA concentrations than fruit from the Elgin orchards. Outer canopy pears had higher TSS:TA ratios than inner canopy pears for all orchards (Table 6). Outer canopy Lindeshof A and Lindeshof B pears had the highest TSS:TA ratios. Outer and inner canopy Glen Brae fruit had lower TSS:TA ratios compared to outer and inner canopy fruit from the other orchards.

Both outer and inner canopy Lindeshof A and Lindeshof B pears had higher ethylene levels than pears from Elgin (Table 6). Outer canopy pears from the Ceres orchards had higher ethylene levels compared to the inner canopy pears whereas ethylene levels did not differ between canopy positions for the Elgin orchards. Outer canopy Lindeshof B pears had the highest level of ethylene while both inner and outer canopy Glen Brae pears had the lowest ethylene level. Inner canopy pears had a 1% higher DMC concentration than outer canopy pears while Glen Fruin fruit had a 5% lower DMC concentration compared to fruit from the other orchards (Table 7).

### 4.2 Sensory attributes

Canopy position had no effect on pear flavour, sweet and sour taste, melt character or sensory mealiness of ‘Forelle’ pears (Table 8). Mean scores for astringency and bitterness were extremely low (data not presented). Glen Brae fruit had a lower pear flavour and sweet taste compared to fruit from the other orchards. Glen Fruin fruit had the lowest score for sour taste while Glen Brae fruit scored significantly lower in sour taste than fruit from Lindeshof B. Glen Fruin fruit scored higher in melt character compared to fruit from Lindeshof A and B while fruit from these two orchards scored significantly lower compared to the Elgin orchards in sensory mealiness. Inner canopy Lindeshof A fruit and outer canopy Lindeshof B fruit scored significantly harder than all the other orchard and position combinations (Table 9). Inner canopy fruit scored softer than outer canopy fruit in the case of Lindeshof B and Glen Brae, but harder in the case of Lindeshof A. Glen Brae fruit scored the lowest for hardness followed by Glen Fruin. Inner canopy Lindeshof A and Lindeshof B fruit received higher and lower juiciness scores, respectively, compared to outer canopy fruit. Glen Fruin fruit scored lower in grittiness compared to fruit from other orchards. In the case of Glen Brae, outer canopy fruit scored higher in grittiness than inner canopy fruit.

### 4.3 Multivariate analyses

The first two principal components of the PCA bi-plot explain 74% (50% PC1 and 24% PC2) of the variation (Fig. 1). Pear flavour, sweet taste, sour taste, hardness, juiciness, sensory mealiness, grittiness, firmness, TSS and TA are indicated on PC1 while melt character, mealiness incidence and DMC are indicated on PC2. TSS:TA contributed to variability on the third principal component (results not shown). The bi-plot shows that production region is separated along the horizontal axis, which explains 50% of the variation. Differences between orchards are apparent while canopy differences are evident only for Lindeshof B separated on PC2.

Pears from Glen Fruin seemed to associate with mealiness incidence, TSS and melt character while pears from Glen Brae seemed to associate with sensory mealiness and TA. It is important to remember that although certain attributes might seem to be strongly correlated on the PCA bi-plot; this is not always the case. Therefore, it is necessary to investigate correlation coefficients. Sensory mealiness did not correlate with TA although it seemed that way on the bi-plot. Mealiness incidence correlated significantly with TSS (r = 0.82). Sensory mealiness had significant negative correlations with pear flavour (r = -0.86), sweet taste (r = -0.89), sour taste (r = -0.76), hardness (r= -0.94), juiciness (r = -0.84) and firmness (r = -0.72).

Sweet taste is situated between the outer canopy samples from Lindeshof B and the inner and outer canopy samples from Lindeshof A and had significant positive correlations with pear flavour (r = 0.93), hardness (r = 0.91), juiciness (r = 0.81) and firmness (r = 0.78). Hardness and firmness correlated significantly (r = 0.85) and are associated with pears produced in Ceres. Juiciness and pear flavour correlated significantly (r = 0.92) and are associated with outer canopy pears from Lindeshof B and inner and outer canopy pears from Lindeshof A.

Discriminant analyses (DA) carried out on sensory attributes corresponds with the PCA bi-plot (Fig. 2). Clear differences were observed between the two Elgin with the two Ceres orchards. Glen Fruin and Glen Brae are separated along the horizontal axis which explains 58% of the variation. Glen Brae pears associated with sensory mealiness while Glen Fruin pears associated with melt character and to a lesser extent with mealiness. The sensory profiles of inner and outer canopy pears from Lindeshof A and Lindeshof B were very similar and associated with sweet and sour taste, as well as hardness. DA carried out on physicochemical attributes indicated that there were clear differences between the orchards from the different production areas, as well as between inner and outer canopy fruit although there was some overlap (Fig. 3). Production region is separated along the horizontal axis, which explains 70% of the variation, while inner and outer canopy fruit from the different areas are separated along the vertical axis, which explains 17% of the variation. Outer canopy pears from Glen Brae and Glen Fruin associated with mealiness incidence and TSS while outer canopy pears from Lindeshof B were situated more towards TSS:TA ratio. Inner canopy pears from Lindeshof A and B were firmer and inner canopy fruit from Glen Brae had the highest TA.

# 5. DISCUSSION

'Forelle' pears cultivated in four separate orchards in two production areas (Elgin and Ceres, Koue Bokkeveld) differed in their physicochemical and sensory profiles (Fig's. 1-3). Fruit quality differences between orchards can be related to the orchard location, harvest maturity and also to how the interception and distribution of light is affected by the orchard system (Shahak *et al*., 2004). Light responses are dependent on both the quantity and quality of light. The distribution of light within the tree canopy affects fruit quality attributes such as fruit size, fruit colour (Wagenmakers & Callesen, 1995), TSS, TA (Lewallen, 2000) and DMC (Nilsson & Gustavsson, 2007; Hamadziripi, 2012). The appearance of the fruit was influenced by canopy position. The exposed side of outer canopy 'Forelle' pears had a red blush while inner canopy pears were uniformly yellow. Red-blushed pear cultivars only develop red blush on the side of fruit exposed to solar radiation due to the light requirement for anthocyanin synthesis in the peel, while the shaded inner canopy fruit remains green (Steyn *et al*., 2005).

The two Ceres orchards were planted at a higher tree density (Table 1) and trees in these orchards consequently have smaller canopies. Smaller canopies tend to have better light distribution (Hampson *et al*., 2002). Hamadziripi (2012) found that consumers could not as readily distinguish between inner and outer canopy fruit that originated from smaller compared to large apple tree canopies. However, we found a consistent trend in the physicochemical results between inner and outer canopy fruit from the different orchards. Outer canopy fruit tended to be higher in TSS, TSS:TA ratio and lower in TA. In three of the orchards, outer canopy fruit had a higher concentration of TSS while inner canopy pears were higher in TA in all four orchards. Our results are consistent with previous findings in the literature, as well as findings in Chapter 2 and 3. Fruit that receive adequate light normally have higher TSS and are consequently perceived as being sweeter while Dussi *et al*. (2005) found that shading decreased TSS in pears. Nilsson and Gustavsson (2007) found that outer canopy apple fruit had a higher TSS and a lower TA. Outer canopy pears from the warmer Elgin area had a slightly higher TSS compared to the outer canopy Ceres fruit. Outer canopy pears at Glen Fruin, Glen Brae and Lindeshof B showed mealiness incidences that were more than double that of inner canopy pears. This is consistent with findings in Chapter 2 and 3. TSS correlated significantly with mealiness incidence (r = 0.82) which can be related to outer canopy pears generally having higher mealiness incidence and higher TSS. The lack of a positional effect on sweet and sour taste is in accordance with findings in Chapter 2 and 3. Pear flavour and sweet taste were less pronounced in Glen Brae fruit while the TSS was high. This finding corresponds with previous research (Visser *et al*., 1968; Hoehn *et al*., 2003; Van der Merwe, 2012), as well as Chapters 2 and 3 where TSS and sweet taste did not correlate. The sensory panel of judges could not detect astringency during our study, probably because pears of all four orchards ripened to close to the optimum consumption firmness (≈1.5 kg) (Vayasse *et al*., 2005) after storage at -0.5°C for 12 weeks and ripening at room temperature for 7 days.

Canopy position had no effect on mealiness incidence in fruit from Lindeshof A. The only apparent difference between this orchard and the other three orchards used in the study is in row direction (Table 1). Lindeshof A was planted in an E/W row direction while Lindeshof B and the two orchards from Elgin (Glen Fruin & Glen Brae) were planted in a N/S direction (Table 1). Row direction has been found to influence the distribution of light in orchards (Palmer, 1989). It is important to note that fruit were harvested from both sides of the row at all four orchards. Orchards planted in east-west row orientation have poorer light distribution compared with orchards planted in a north-south orientation and light is mainly intercepted on the north side of east-west rows in the Southern hemisphere (Middleton & McWaters, 2001). This difference in row orientation for the Lindeshof A orchard could have resulted in the slightly lower TSS and TA values compared to other orchards; however, the overall quality of these fruit was not poorer than the other orchards. In fact, these pears had the lowest mealiness incidence and were scored just as high in sensory flavour attributes compared to other orchards.

The weather station in the Elgin region showed slightly but significantly higher average minimum temperatures between 1 September 2011 and 29 February 2012 compared to the weather station in the Koue Bokkeveld region. There was, however, no statistical difference between the average maximum temperatures for the two regions. We postulated that pears cultivated in “warmer” areas would show higher incidences of mealiness as found in previous studies (Carmichael, 2011). Our results partially correspond with previous findings in that the incidences of mealiness were high in outer canopy pears that were harvested in the two Elgin orchards. However, mealiness incidences were also high in one of the orchards in the Ceres Koue Bokkeveld area. In contrast, Lindeshof A pears cultivated in the Ceres area showed very little incidences of mealiness. Unfortunately the sensory trained panel could not detect a difference between inner and outer canopy pears with regard to sensory mealiness, possibly because they assessed the level of mealiness for each sample and not the incidence of mealiness as was done in the physicochemical assessment. Therefore, incidences of mealiness and sensory mealiness did not correlate with each other (see the extended discussion on this issue in Chapter 2). Mealiness cannot be detected at a high firmness; therefore fruit needs to soften before mealiness can be perceived. The pears in our study were adequately ripened for 7 days at 20°C to a firmness of approximately 2 kg. Pears from the Ceres area were firmer and had a higher ethylene concentration after storage than pears from Elgin although they were harvested at more or less the same firmness (Table 3). This was also confirmed by the greener ground colour of the Lindeshof pears after storage and 7 days of ripening. Studies have found that ethylene evolution rates is significantly influenced by factors such as cultivar, production region, orchards within that region as well as the growing season

(Watkins, 2003). Therefore, ethylene evolution rate should always be used in conjunction with other maturity indices (Carmichael, 2009). The firmness of mealy and non-mealy pears did not differ significantly, corresponding with the findings in Chapter 2 and 3 (data not presented). The development of mealiness in 'Forelle' pears starts at the 'neck' of the fruit and then moves downward and spreads out to the sides of the fruit (E.M.Crouch, Department of Horticulture, Stellenbosch University, Stellenbosch, South Africa, 2013, personal communication). Penetrometer readings were taken halfway between the calyx and the stem of each pear on two equatorial sites that were peeled. It could be that mealiness development in some pears had not progressed to the point where it could influence firmness readings. Sensory panels associated an increase in mealiness with a decrease in juiciness and hardness (Barreiro *et al*., 1998). One would further expect that the melt character of mealy pears would be low. It was surprising to note that the Elgin pears, which were scored higher in sensory mealiness, were also scored higher in melt character. However, both melt character and sensory mealiness scores were quite low overall. It is important to remember that although certain attributes might seem to be strongly correlated on the PCA bi-plot; this is not always the case. Therefore, it is necessary to investigate correlation coefficients as well as significant differences. Mealiness incidence seems to associate with melt character, however, there was no significant correlation between these attributes.

The fruit from the different areas were harvested on different dates and therefore could not be compared by consumer preference analysis on the same day as the pears would have been at different ripening stages. Hence, variation in the sensory data could have resulted from the conduction of the sensory analysis for the four orchards on different dates. For a future study, we recommend the testing of consumer preference for eating quality and appearance of fruit from different orchard locations at their optimum ripening stage on different days and then comparing the results statistically. Also, this research should be repeated in more orchards for a few consecutive seasons in order to obtain a good representative data-set of the different fruit production locations. Regarding mealiness, it would be advisable for a future study to perform evaluations directly after cold storage as well as after 4, 7 and 11 days of ripening at 15°C rather than 20°C as mealiness increases and then decreases during the ripening process. Further recommendations would be to measure the PAR (photosynthetically active radiation) on the inside versus the outside of the canopy.

We can conclude that 'Forelle' pears from different orchards differ in physicochemical and sensory attributes after cold storage for 12 weeks at -0.5 ºC and shelf-life for 7 days at 20 ºC. The TSS concentration was higher in the Elgin pears while the flavour attributes were more pronounced in Ceres pears. In both areas, the outer canopy pears were higher in TSS and lower in TA while canopy position had no effect on sweet and sour taste. Weather stations in the different regions near the orchards showed that the pears in the Elgin region were exposed to slightly higher minimum temperatures compared to the Ceres Koue Bokkeveld region whereas there was no difference between two regions for maximum temperatures, although this may vary between seasons. Incidences of mealiness were high in fruit from the warmer Elgin region, as well as in the Lindeshof B orchard that is situated in the Ceres Koue Bokkeveld region. As a result, no conclusion can be made regarding differences between regions. There is, however, evidence of orchard differences in mealiness incidence. Therefore, further research over consecutive seasons is needed to establish the factors causing differences in mealiness incidence between orchards. In addition, it would be wise to include more orchards in each area.

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**Table 1** The details of the orchards from which fruit were harvested.

| Harvest date | Orchard | Age of orchard (yr) | Row Orientation | Plant spacing (m) | Altitude (m) | Soil type |
|---|---|---|---|---|---|---|
| 02/03/2012 | Glen Fruin | 42 | N/S | 4.3 x 2.7 | 338 | loam |
| 27/02/2012 | Glen Brae | 28 | N/S | 4.5 x 2.5 | 188 | loam |
| 08/03/2012 | Lindeshof A | 19 | E/W | 4.0 x 1.3 | 911 | clay-loam |
| 08/03/2012 | Lindeshof B | 18 | N/S | 4.0 x 2.0 | 906 | clay |

**Table 2** Average minimum and maximum temperature (for 24 hours) from 01/09/2011 to 29/02/2012 in Elgin and Ceres Koue Bokkeveld region.

| Harvest area | Minimum temperature | Maximum temperature |
|---|---|---|
| Elgin | 11.4 a | 22.4 [NS] |
| Ceres | 9.8 b | 22.0 |
| **P-value** | *0.0021* | *0.6184* |

[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) on the mean values for firmness after harvest (n=10) and hue values after cold storage (n=100) of 'Forelle' pears harvested at Glen Fruin & Glen Brae (Elgin) and Lindeshof A & B (Ceres), Western Cape, South Africa. Hue value measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Treatment** | **Firmness (kg)** | **Hue (°)** |
|---|---|---|
| **Canopy position** | | |
| Inside | 6.3 b | 98.9 a |
| Outside | 6.5 a | 38.2 b |
| **Orchard** | | |
| Glen Fruin | 6.5 [NS] | 69.2 a |
| Glen Brae | 6.4 | 68.2 a |
| Lindeshof A | 6.4 | 68.2 a |
| Lindeshof B | 6.4 | 68.8 a |
| ***P-value*** | | |
| **Position** | *0.0066* | *<0.0001* |
| **Orchard** | *0.2517* | *0.3285* |
| **P*O** | *0.3400* | *0.1185* |

[NS] Not significant

[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) on the physical appearance of 'Forelle' pears harvested in Elgin and Ceres, Western Cape, South Africa. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Orchard** | **Canopy position** | **Ground colour**[x] | **Chroma (C*)** |
|---|---|---|---|
| Glen Fruin | Inside | 3.4 b[z] | 48.9 a |
| | Outside | 3.4 b | 38.4 c |
| Glen Brae | Inside | 3.4 b | 47.5 b |
| | Outside | 3.7 a | 39.3 c |
| Lindeshof A | Inside | 2.8 d | 47.5 b |
| | Outside | 3.1 c | 39.3 c |
| Lindeshof B | Inside | 3.0 c | 48.3 ab |
| | Outside | 2.9 cd | 39.2 c |
| ***P-value*** | | | |
| **Position** | | *0.0021* | *<.0001* |
| **Orchard** | | *<.0001* | *0.8154* |
| **P*O** | | *0.0052* | *0.0426* |

[x] Chart values 0.5-5: where 0.5= green; 5= pale green/ yellow

[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) on firmness, weight, diameter and mealiness incidence for 'Forelle' pears harvested in Elgin and Ceres, Western Cape, South Africa. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Orchard** | **Canopy position** | **Firmness (kg)** | **Weight (g)** | **Diameter (mm)** | **Mealiness incidence (%)** |
|---|---|---|---|---|---|
| Glen Fruin | Inside | 2.3 d[z] | 182 b | 66 b | 34 b |
| | Outside | 2.2 e | 195 a | 68 a | 72 a |
| Glen Brae | Inside | 1.7 f | 134 d | 61 d | 22 bc |
| | Outside | 1.7 f | 143 d | 63 c | 62 a |
| Lindeshof A | Inside | 2.7 b | 113 e | 58 e | 0 d |
| | Outside | 2.9 a | 145 cd | 62 cd | 8 cd |
| Lindeshof B | Inside | 2.8 a | 115 e | 58 e | 10 cd |
| | Outside | 2.5 c | 156 c | 64 c | 68 a |
| ***P-value*** | | | | | |
| **Position** | | *0.0015* | *<0.0001* | *<0.0001* | *<.0001* |
| **Orchard** | | *<.0001* | *<0.0001* | *<0.0001* | *<.0001* |
| **P*O** | | *<.0001* | *00020* | *0.0006* | *0.0016* |

[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) on total soluble solids (TSS), titratable acidity (TA), TSS:TA ratio and ethylene for 'Forelle' pears harvested in Elgin and Ceres, Western Cape, South Africa. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Orchard** | **Canopy position** | **TSS (° Brix)** | **TA (% malic acid)** | **TSS:TA** | **Ethylene** |
|---|---|---|---|---|---|
| Glen Fruin | Inside | 16.6 bc[z] | 0.25 b | 66 d | 4.34 de |
| | Outside | 17.4 a | 0.22 c | 78 b | 4.43 d |
| Glen Brae | Inside | 16.7 bc | 0.29 a | 58 e | 3.05 f |
| | Outside | 17.0 ab | 0.24 bc | 72 c | 3.24 ef |
| Lindeshof A | Inside | 15.0 d | 0.23 c | 67 cd | 8.12 c |
| | Outside | 16.4 c | 0.17 d | 99 a | 10.46 b |
| Lindeshof B | Inside | 15.6 d | 0.25 b | 64 d | 8.49 c |
| | Outside | 16.8 bc | 0.18 d | 95 a | 11.66 a |
| ***P-value*** | | | | | |
| **Position** | | *<.0001* | *<.0001* | *<.0001* | *<.0001* |
| **Orchard** | | *<.0001* | *<.0001* | *<.0001* | *<.0001* |
| **P*O** | | *0.0335* | *0.0125* | *<.0001* | *0.0017* |

[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) on dry matter concentration (DMC) of 'Forelle' pears harvested in Elgin and Ceres, Western Cape, South Africa. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Treatment** | **DMC (%)** |
|---|---|
| **Canopy position** | |
| Inside | 31 a[z] |
| Outside | 30 b |
| **Orchard** | |
| Glen Fruin | 27 b |
| Glen Brae | 32 a |
| Lindeshof A | 32 a |
| Lindeshof B | 32 a |
| ***P-value*** | |
| **Position** | *0.0359* |
| **Orchard** | *<.0001* |
| **P*O** | *0.1076* |

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

**Table 8** The effect of canopy position (inner canopy versus outer canopy) on 'Forelle' sensory attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis. Pears were harvested in Elgin and Ceres, Western Cape, South Africa. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Treatment** | **Pear flavour** | **Sweet taste** | **Sour taste** | **Melt character** | **Mealiness** |
|---|---|---|---|---|---|
| **Canopy position** | | | | | |
| Inside | 53 [NS] | 51 [NS] | 20 [NS] | 35 [NS] | 18 [NS] |
| Outside | 53 | 51 | 19 | 33 | 22 |
| **Orchard** | | | | | |
| Glen Fruin | 56 a[z] | 52 a | 16 c | 39 a | 22 a |
| Glen Brae | 48 b | 47 b | 20 b | 33 ab | 29 a |
| Lindeshof A | 57 a | 53 a | 23 ab | 29 b | 9 b |
| Lindeshof B | 56 a | 54 a | 23 a | 30 b | 9 b |
| ***P-value*** | | | | | |
| **Position** | *0.6556* | *0.7397* | *0.5483* | *0.3461* | *0.2807* |
| **Orchard** | *<.0001* | *0.0018* | *0.0001* | *0.0035* | *0.0007* |
| **P*O** | *0.1299* | *0.4867* | *0.0791* | *0.1421* | *0.1178* |

[NS] Not significant

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

**Table 9** The effect of canopy position (inner canopy versus outer canopy) on 'Forelle' sensory attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis. Pears were harvested in Elgin and Ceres, Western Cape, South Africa. Measurements were taken after 12 weeks of cold storage at -0.5°C followed by 7 days of ripening at room temperature (20°C).

| **Orchard** | **Canopy position** | **Hardness** | **Juiciness** | **Grittiness** |
|---|---|---|---|---|
| Glen Fruin | Inside | 14 c[z] | 40 ab | 20 d |
| | Outside | 12 c | 38 abc | 20 d |
| Glen Brae | Inside | 8 e | 34 bc | 24 c |
| | Outside | 10 d | 32 c | 28 b |
| Lindeshof A | Inside | 21 a | 44 a | 29 ab |
| | Outside | 17 b | 35 bc | 30 a |
| Lindeshof B | Inside | 17 b | 34 bc | 28 ab |
| | Outside | 22 a | 45 a | 29 ab |
| ***P-value*** | | | | |
| **Position** | | *0.6311* | *0.4631* | *0.0023* |
| **Orchard** | | *<0.0001* | *0.0389* | *<0.0001* |
| **P*O** | | *<0.0001* | *0.0477* | *0.0286* |

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

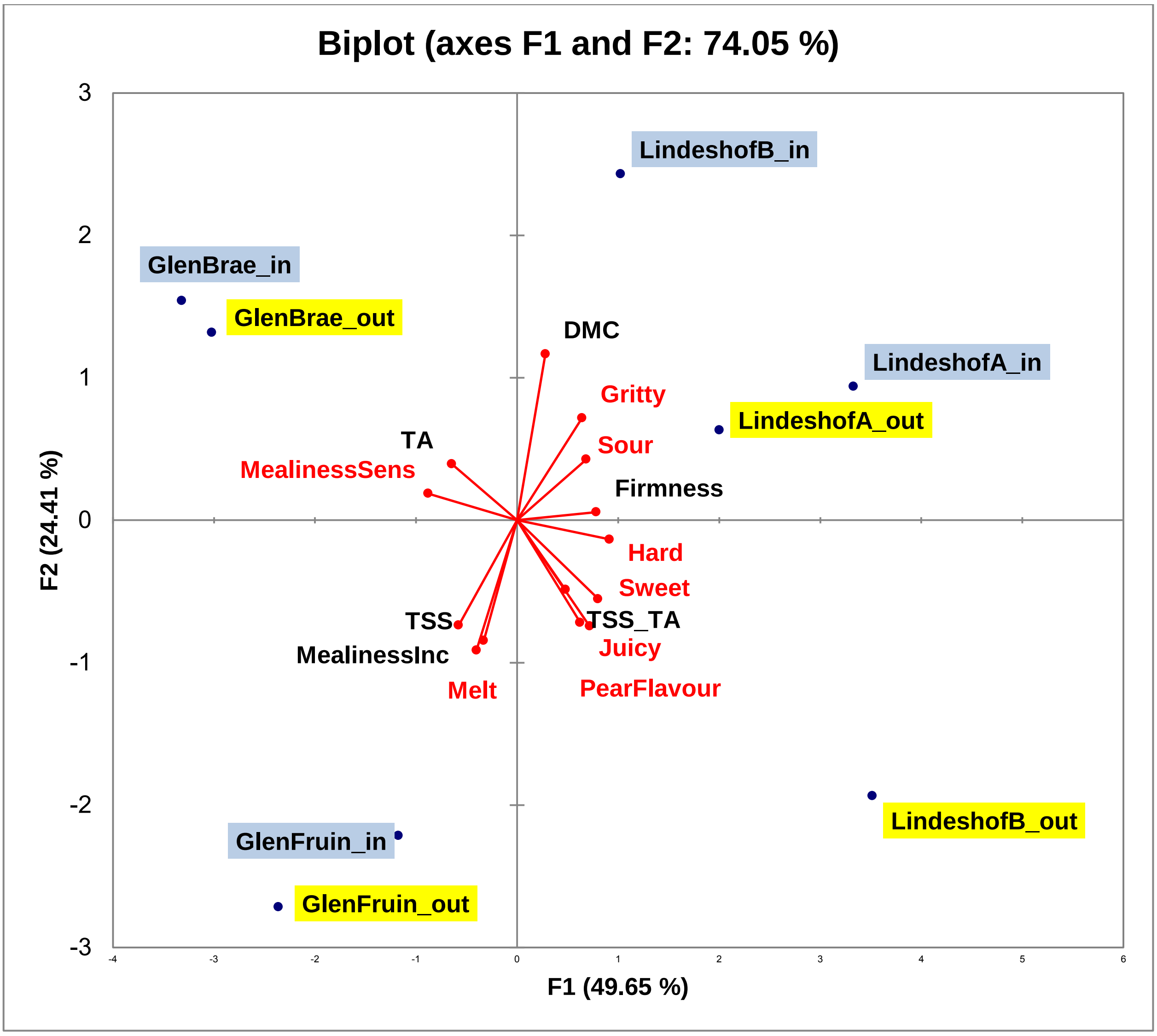


**Figure 1** Principal Component Analysis (PCA) bi-plot indicating the position of the sensory attributes (indicated in red) and the physicochemical measurements (indicated in black), in relation to inner and outer canopy pear samples from Elgin (Glen Fruin & Glen Brae) and Ceres (Lindeshof A & Lindeshof B) in 2012.

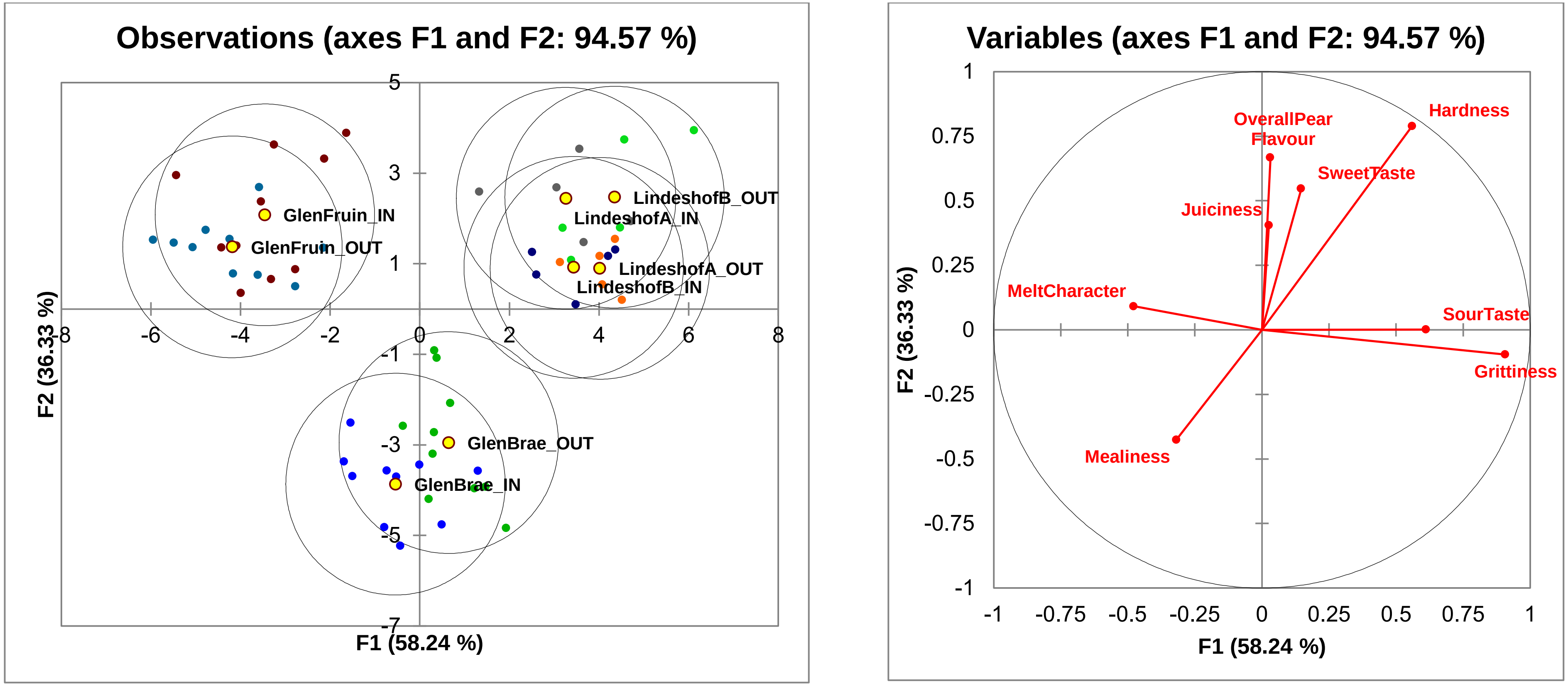


**Figure 2** Discriminant analysis (DA) observation maps for four orchards (Glen Fruin, Glen Brae, Lindeshof A, Lindeshof B) from two climatically diverse production areas (Elgin & Ceres) for 'Forelle' pears based on results of descriptive sensory analysis.

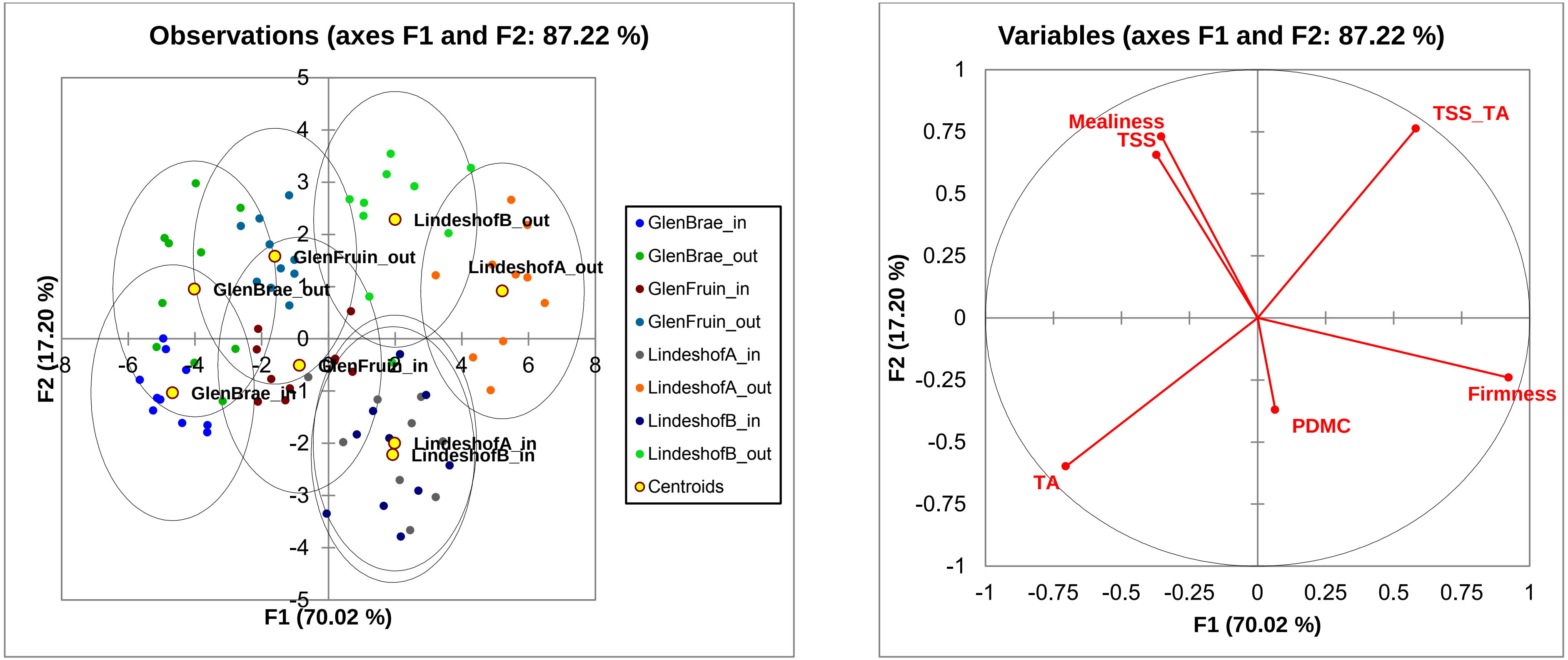


**Figure 3** Discriminant analysis (DA) observation maps for four orchards (Glen Fruin, Glen Brae, Lindeshof A, Lindeshof B) from two climatically diverse production areas (Elgin & Koue Bokkeveld) for 'Forelle' pears based on results of physicochemical measurements

# CHAPTER 5
# THE EFFECT OF CANOPY POSITION ON CONSUMER PREFERENCE FOR THE APPEARANCE AND EATING QUALITY OF 'BON CHRÉTIEN' AND 'BON ROUGE' PEARS

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## 1. ABSTRACT

Microclimatic differences in temperature and irradiance within the canopy of a pear tree may affect the appearance and taste of the fruit. The objective of this study was to determine whether outer and inner canopy pears differ in quality attributes and how these differences, if any, relate to consumer preference for the appearance and eating quality of the pears. 'Bon Chrétien' (green/yellow) and 'Bon Rouge' (red) pears were harvested from the inner and outer canopy in January 2011 at optimum commercial firmness and stored at -0.5°C until experimental analyses. Fruit firmness, size, density, colour, total soluble solids concentration (TSS), titratable acidity (TA), ethylene and dry matter concentration were determined. A trained panel of eight judges assessed the flavour and texture of the pear samples during descriptive sensory analysis. Separate consumer preference assessments were held for each cultivar and 120 consumers participated in each. Consumers were presented with peeled pear samples, representative photos of the pears as well as some general questions regarding fruit consumption. A nine point hedonic scale was used where they had to score their liking of the eating quality and appearance of the pear fruit. Despite a higher TSS:TA ratio in outer canopy 'Bon Rouge' pears and a higher TSS and dry matter concentration in outer canopy 'Bon Chrétien', canopy position did not affect sensory eating quality attributes. For unknown reasons, consumers preferred the eating quality of inner canopy 'Bon Chrétien' pears. Canopy position had no effect on consumer preference for the eating quality of 'Bon Rouge' pears. Consumers slightly preferred the redder outer canopy 'Bon Rouge' pears over the less red inner canopy fruit. No significant differences in colour and consumer preference for appearance were found between outer and inner canopy 'Bon Chrétien' pears. Seen overall, results indicate that canopy position has a rather minor effect on consumer preference for 'Bon Chrétien' and 'Bon Rouge' eating quality and appearance.

## 2. INTRODUCTION

The position of fruit within the pear tree canopy may affect the internal and external fruit quality characteristics. Irradiance and temperature are two factors that differ highly in the tree canopy. A study on the irradiance levels within 'Granny Smith' apple trees showed that outer canopy fruit on the northern side of the tree were exposed to 53% of full sunlight while inner canopy fruit near the trunk received only 2% of full sunlight (Fouché *et al*., 2010). Exposed fruit on the northern side of the row had the highest peel temperature throughout the season, approximately 5°C higher on average than the average ambient air temperature (24°C). In contrast, the inner canopy fruit did not differ from the ambient air temperature. The quality and quantity of incident sunlight during fruit development influence the composition and flavour of fruit (Mattheis & Fellman, 1999; Hamadziripi, 2012). Outer canopy apple fruit were exposed to higher irradiance and temperatures; accumulated more ascorbic acid and had higher antioxidant capacities in their peel. Apple flavour and sweet taste was more pronounced in outer canopy apples; TSS and DMC were higher while the TA was lower (Hamadziripi, 2012).

The colour of fruit is influenced by the concentration and distribution of anthocyanins, carotenoids and chlorophylls (Steyn, 2012). Anthocyanin synthesis in pear peel is dependent on light; therefore good light exposure is extremely important for red colour development (Steyn *et al*., 2005). Awad *et al*. (2000) found the highest anthocyanin, quercetin 3-glycosides and total flavonoid concentrations in upper canopy apple fruit, followed by the outer canopy fruit, and lastly the inner canopy fruit.

An established set of physicochemical measurements have been used to determine fruit quality as these measurements are considered as being objective and repeatable (Hampson *et al.,* 2000). Firmness, TSS and TA are physicochemical measurements that are used to determine the eating quality of apples (Hoehn *et al*., 2003). However, these measurements are indirect and do not necessarily reflect the sensory attributes perceived by humans. For example, although sensory panellists perceived differences in the hardness of 'Gala' apples, there was no difference in instrumental firmness (Hoehn *et al*., 2003). In another example of research on apples, Harker *et al*. (2002) found that acid taste or sourness might be predicted on a basis of TA, however, this was not the case with sweet taste and TSS. The latter researchers therefore recommend that the analysis of sweet taste should continue to require assessment by a trained sensory panel. Furthermore, Zerbini (2002) indicated that perceived sweetness and sourness to be better predictors of liking than analytical measurements of TSS and TA. Consequently, sensory analysis of eating quality attributes should be used alongside instrumental analyses when testing attributes such as colour, hardness, juiciness, flavour and taste.

This study was performed during the 2011 harvest season with the aim to determine the physicochemical and sensory (flavour and textural) differences between inner and outer canopy 'Bon Chrétien' and 'Bon Rouge' pears. In addition, we also studied the relationship between canopy position and consumer preference for the appearance and eating quality of these pears.

## 3. MATERIALS AND METHODS

### 3.1 Plant material

Two commercial pear cultivars were used in this study, viz. Bon Chrétien (green/yellow) and Bon Rouge (red). 'Bon Chrétien' and 'Bon Rouge' pears were harvested on 24 January 2011 at commercial harvest maturity (firmness 6 – 8 kg) at Glen Fruin farm in Elgin (latitude: 34°10' S, longitude: 19°03' E), South Africa. The 'Bon Chrétien' trees were planted in 1970 at a spacing of

4.28 m x 2.65 m in an E/W row orientation. The 'Bon Rouge' trees were planted in 1995 at a spacing of 4.0 m x 1.5 m in an N/S row orientation. Trees in both orchards were trained to a central leader training system.

### 3.2 Experimental design

A total of 150 inner canopy fruit as well as 150 outer canopy fruit were harvested for both 'Bon Chrétien' and 'Bon Rouge' constituting ten replicates of 15 fruit each with three adjacent trees per replicate. The experimental design was a complete randomized design with ten replications. One fruit per replication (i.e., 10 fruit per canopy position) was randomly selected and subjected to a firmness test immediately after harvest in order to determine whether the inner and outer canopy fruit had the same maturity. The intention of this particular study was to use inside and outside fruit of comparable maturity; therefore, if the pears had differed in maturity, a further harvest would have been scheduled. Fruit were placed on pear pulp trays and then packed into cartons lined with a polyethylene bag (37.5 μm), which was folded over to cover the fruit completely. 'Bon Chrétien' and 'Bon Rouge' pears were stored at -0.5°C for 5 and 6 weeks, respectively, and then ripened at room temperature (20ºC) for five days before commencement of physicochemical analysis, sensory analysis and consumer preference assessment. Of the14 remaining fruit, five were used for physicochemical analyses, four for descriptive sensory training and testing the reliability of the judges and lastly five pears were used to assess consumer preference.

### 3.3 Physicochemical analyses

The five pears from the same replicate were viewed as composite samples. All the physical and chemical measurements were taken from the same set of pears. Density is defined as a material's mass per unit volume. The volume of the composite sample was determined through the displacement of water. The fruit density was then calculated from the known mass and the measured volume of water replaced. Ethylene evolution rate and physicochemical measurements were conducted as explained in Chapter 2.

### 3.4 Descriptive sensory analyses

Sensory analysis was carried out as explained in Chapter 2. The definitions used for the sensory attributes (Chapter 2, Table 1) are similar to those used by Daillant-Spinnler *et al*. (1996).

### 3.5 Consumer preference

Consumer analyses were conducted on 120 South African pear consumers living in the Stellenbosch area. Consumers were presented with a questionnaire that consisted of four sections to gather demographical, fruit purchasing and consumption information, and to assess the degree of liking for the overall eating quality as well as the appearance as described in Chapter 2.

On each consumer evaluation date (4 and 9 March for 'Bon Chrétien' and 'Bon Rouge', respectively), each consumer received an inner and outer canopy sample. By evaluating the two cultivars separately we avoided a sample effect influencing the outcome of the results. Consumers assessed pear eating quality as described in Chapter 2.

Photographs of whole pear fruit were presented to the consumers for assessment (Fig. 1). Four photo-sets of each canopy position, presented in a randomized order, were used in the study. A photo of the inner, as well as the outer canopy fruit of each cultivar was provided as part of the questionnaire in order for the consumers to assess the appearance.

### 3.6 Statistical procedures

Inner and outer canopy 'Bon Chrétien', as well as inner and outer canopy 'Bon Rouge' pears were compared for physicochemical analysis, descriptive sensory as well as consumer preference data. The cultivars were analysed separately.

Physicochemical analysis data were subjected to analysis of variance (ANOVA) by general linear models (GLM) using SAS version 9.2 (SAS Institute Inc., 2008, Cary, NC, USA). The Shapiro-Wilk test was performed on the residuals to test for non-normality (Shapiro & Wilk, 1965). If non-normality was significant ($P \leq 0.05$) and due to scewness, the outliers were identified and removed until the residuals were normally or symmetrically distributed (Glass *et al*., 1972). The final analysis of variance (ANOVA) was performed after the pre-processing procedures had taken place. Student's t-least significant difference (LSD) was calculated at the 5% significance level to compare treatment means.

For the descriptive sensory analysis of the samples, a randomized complete block design was used where each judge received 20 samples; ten inner canopy samples and ten outer canopy samples, i.e. one sample from each replicate. The data were subjected to test-retest ANOVA by GLM to test for reliability as temporal stability between judge and replication and internal consistency between judge and treatment using SAS statistical software. The Shapiro-Wilk test was performed and implemented on the residuals as described above. LSD was calculated at the 5% significance level to compare treatment means.

## 4. RESULTS

### 4.1 'Bon Chrétien'

Inner and outer canopy 'Bon Chrétien' pears did not differ in firmness, size or colour (Table 1, 2). Outer canopy fruit were significantly higher in TSS and DMC (Table 3), but did not differ from inner canopy fruit in any other physicochemical and sensorial attribute (Table 3 - 5).

The 'Bon Chrétien' consumer panel consisted of 120 consumers with 70% females and 30 males. Seventy three percent of the consumers were between the ages of 18 and 30. With regard to ethnicity, 9% of the consumers were black, 20% coloured and 71% white. Of these consumers, 5% indicated that they consume pears daily, 38% indicated that they consume pears two or more times a week, another 38% indicated that they consume pears approximately twice per month and another 14% of consumers, four times per year. Consumers significantly preferred the eating quality of inner over outer canopy 'Bon Chrétien' pears (Table 6). There was no significant difference between canopy positions with regards to consumer preference for appearance.

### 4.2 'Bon Rouge'

Outer canopy 'Bon Rouge' pears were slightly, but significantly firmer than inner canopy pears while canopy position had no effect on fruit size (Table 1). Based on colorimeter data, outer canopy 'Bon Rouge' pears were redder, darker and duller in colour than inner canopy pears, but ground colour did not differ significantly (Table 2). Apart from a slightly higher TSS:TA ratio in outer canopy fruit (Table 3), canopy position had no effect on any other physicochemical or sensorial attribute (Table 3 - 5).

The 'Bon Rouge' consumer panel consisted of 120 consumers with 70% females and 30% males. Eighty two percent of the consumers were between the ages of 18 and 30. With regard to ethnicity, 39% of the consumers were black, 19% coloured and 42% white. Of these consumers, 8% indicated that they consume pears daily, 37% indicated that they consume pears two or more times a week, another 37% indicated that they consume pears approximately twice per month and another 18% of consumers, four times per year. Consumers preferred the appearance of outer canopy 'Bon Rouge' pears, but there was no significant difference in preference for eating quality between inner and outer canopy 'Bon Rouge' pears.

## 5. DISCUSSION

Microclimatic differences within the fruit tree canopy may cause differences in appearance and eating quality between inner and outer canopy fruit. More light is intercepted by the outer canopy leaves and fruit, which results in higher levels of photo-assimilates in outer canopy fruit (Johnson & Lakso, 1986). Fruit that are supplied by light-exposed leaves will have more soluble sugars and total carbohydrates (Robinson *et al*. 1983; Woolf & Ferguson, 2000). TSS is a good indicator of the concentration of sugar in apples and therefore the perceived sweetness (Hoehn *et al*., 2003).

Fruit that receives adequate light normally have higher TSS concentrations and are consequently perceived as being sweeter while Dussi *et al*. (2005) found that shading decreased TSS in pears. Nilsson and Gustavsson (2007) found that outer canopy apple fruit had a higher TSS and a lower TA. TSS was higher in outer canopy 'Bon Chrétien' and 'Bon Rouge' fruit, but the difference was only significant in 'Bon Chrétien' fruit. Outer canopy 'Bon Rouge' pears did have a slightly higher TSS:TA ratio. Canopy position did not affect titratable acidity in 'Bon Chrétien' and 'Bon Rouge' pears. This data is contrary to recent findings by Hamadziripi (2012) for inner and outer canopy 'Starking', 'Golden Delicious' and 'Granny Smith' apples as well as findings for TA in 'Forelle' pears (Chapter 2, Table 2). During maturation, storage and ripening, malic acid decreases in apples (Ackermann *et al*., 1992) and pears (Martin, 2002). The fact that pears were quite ripe when analysed could have resulted in the occurrence of malic acid breakdown before analyses were conducted.

Dry matter concentration (DMC) is an indicator of metabolic and physiological processes that contributes to final fruit composition (Harker *et al*., 2009). After finding that high DMC 'Royal Gala' apples were higher in TSS, TA and firmness and were also preferred by consumers, Palmer *et al*. (2010) proposed that DMC could be a new indicator to predict apple eating quality. They found higher DMC in outer canopy fruit. Studies performed in New Zealand found that consumers preferred higher DMC avocado (Gamble *et al*., 2010) and kiwifruit (Harker *et al*., 2009; Jaeger *et al*., 2011). Outer canopy 'Bon Chrétien' pears had a higher DMC. Canopy position had no effect on fruit density and therefore, the higher DMC of outer canopy 'Bon Chrétien' pears is probably not related to differences in cell number or size.

Despite the aforementioned differences in internal quality parameters, canopy position had no effect on the sensory characteristics of 'Bon Chrétien' and 'Bon Rouge' pears. The fact that the pears were quite ripe, as evident from the low firmness, could have been a contributing factor to the trained panel not being able to discern between the inner and outer canopy pears. The similar ethylene levels also suggest that fruit were equally ripe. Flesh firmness was slightly higher in outer canopy fruit, but the difference was only significant in 'Bon Rouge'. Canopy position or the light environment does not have a consistent effect on the flesh firmness of fruit (Seeley *et al*., 1980; Lewallen, 2000; Feng-li *et al*., 2008). The overall sensory profile of both inner and outer canopy 'Bon Chrétien' and 'Bon Rouge' pears can be described as extremely juicy with a strong melt character, as well as a strong pear flavour with a good sweet and sour balance. The process of ripening leads to the development of flavour, texture, aroma and the loss of astringency, which consequently contribute to optimum sensory eating quality (Wills *et al*., 2007). During the process of fruit ripening, carbohydrate polymers are broken down and starch is converted to sugars. This impacts the taste (the rise in sugars makes the fruit much sweeter) and texture of the fruit (Wills *et al*., 2007).

This research showed that consumers preferred the eating quality of inner canopy 'Bon Chrétien' fruit. This is contrary to studies in other fruit kinds where a higher DMC associated with higher consumer preference (Harker *et al*., 2009; Gamble *et al*., 2010; Palmer *et al*., 2010; Jaeger *et al*., 2011), but corresponds with our data on 'Forelle' pear (Chapter 2, 3). Hamadziripi (2012) found that consumers generally preferred the taste of outer canopy 'Starking', 'Golden Delicious' and 'Granny Smith' apples due to higher TSS, TSS:TA ratio, sweet taste and apple flavour. The slightly higher TSS:TA ratio of outer canopy 'Bon Rouge' fruit had no effect on taste and therefore also no effect on consumer preference of eating quality. Bitterness, a negative taste attribute, was slightly higher in outer canopy 'Bon Chrétien' pears when tasted with peel. However, since the difference was not significant, this cannot be argued as the reason for the higher preference of the eating quality of inner canopy 'Bon Chrétien' pears. Also, the consumer panel received peeled slices of 'Bon Chrétien' pears while the sensory panel scored bitterness in unpeeled 'Bon Chrétien' pears. Astringency is associated with a dry puckering mouthfeel that is caused by plant phenolic compounds that bind with oral muco-polysaccharides during the process of mastication (Baxter *et al*., 1997). The process of ripening leads to the loss of astringency (Zerbini & Spada, 1993; Mielke & Drake, 2005; Wills *et al*., 2007) and therefore the sensory panel could not detect any astringency as the pears were quite ripe (data not presented).

Canopy position did not affect the colour and consumer preference for the appearance of 'Bon Chrétien' pears. Outer canopy 'Bon Rouge' pears were redder, darker and duller in colour than inner canopy pears, probably due to higher anthocyanin concentrations. Higher irradiance in the outer canopy enhances anthocyanin synthesis (Awad, 2000; Steyn *et al*., 2005). Consumers indicated a preference for the appearance of the outer canopy 'Bon Rouge' fruit. As suggested by Hamadziripi (2012) for outer compared to inner canopy 'Starking' apples, consumer preference for redder fruit of red cultivars probably relates to the positive association created on the market between redness and quality. In addition, consumers may have perceived redder fruit to be sweeter (Daillant-Spinnler *et al*., 1996).

## 6. CONCLUSION

Unlike a similar study on three apple cultivars, sensory attributes of flavour and texture did not differ between inner and outer canopy 'Bon Chrétien' and 'Bon Rouge' pears. Nevertheless, consumers preferred the eating quality of inner canopy 'Bon Chrétien' pears, while no preference difference was found between inner and outer canopy 'Bon Rouge' pears. The reasons for the preference for the taste of inner canopy 'Bon Chrétien' pears are uncertain. The redder appearance of outer canopy 'Bon Rouge' pears was slightly preferred. This research indicates that there are only a few slight differences in taste and appearance between inner canopy and outer canopy 'Bon Chrétien' and 'Bon Rouge' pear fruit. These differences do not have a major effect on consumer preference.

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**Table 1** The effect of canopy position (inner canopy versus outer canopy) on flesh firmness and fruit size for 'Bon Chrétien' and 'Bon Rouge' pears harvested on 24 January 2011 at Glen Fruin, Elgin, Western Cape, South Africa. Measurements were taken after 5 and 6 weeks of cold storage, respectively, at -0.5°C followed by 5 days of ripening at room temperature (20°C).

| | **Firmness (kg)** | **Weight (g)** | **Diameter (mm)** |
|---|---|---|---|
| **Bon Chrétien** | | | |
| Inside Canopy | 1.5 $^{NS}$ | 163 $^{NS}$ | 69 $^{NS}$ |
| Outside Canopy | 2.4 | 168 | 69 |
| *P-value* | *0.1432* | *0.6110* | *0.8927* |
| **Bon Rouge** | | | |
| Inside Canopy | 1.179 b$^{z}$ | 184 $^{NS}$ | 69 $^{NS}$ |
| Outside Canopy | 1.370 a | 192 | 70 |
| *P-value* | *0.0064* | *0.0916* | *0.1577* |

$^{NS}$ Not significant

$^{z}$ 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) on the physical appearance of 'Bon Chrétien' and 'Bon Rouge' pears harvested on 24 January 2011 at Glen Fruin, Elgin, Western Cape, South Africa. Measurements were taken after 5 and 6 weeks of cold storage, respectively, at -0.5°C followed by 5 days of ripening at room temperature (20°C).

| | **Ground colour (colour chart)[x]** | **Lightness** | **Chroma** | **Hue angle (°)** |
|---|---|---|---|---|
| **Bon Chrétien** | | | | |
| Inside Canopy | 2.82 [NS] | 68.5 [NS] | 48.3 [NS] | 101.0 [NS] |
| Outside Canopy | 2.95 | 66.8 | 47.3 | 101.0 |
| *P-value* | *0.5706* | *0.1872* | *0.0655* | *0.9900* |
| **Bon Rouge** | | | | |
| Inside Canopy | 3.84 [NS] | 42.8 a[z] | 40.2 a | 33.4 a |
| Outside Canopy | 3.69 | 36.3 b | 35.1 b | 28.5 b |
| *P-value* | *0.0574* | *<0.0001* | *<0.0001* | *<0.0001* |

[NS] Not significant

[x] Chart values 0.5 - 5: where 0.5= green and 5= pale green/yellow

[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) on total soluble solids (TSS), titratable acidity (TA), TSS:TA ratio, density, ethylene and dry matter concentration (DMC) for 'Bon Chrétien' and 'Bon Rouge' pears harvested on 24 January 2011 at Glen Fruin, Elgin, Western Cape, South Africa. Measurements were taken after 5 and 6 weeks of cold storage, respectively, at -0.5°C followed by 5 days of ripening at room temperature (20°C).

| | **TSS (° Brix)** | **TA (% malic acid)** | **TSS:TA** | **Density (g $ml^{-1}$)** | **Ethylene (µL $kg^{-1}$ $h^{-1}$)** | **DMC (%)** |
|---|---|---|---|---|---|---|
| **Bon Chrétien** | | | | | | |
| Inside Canopy | 13.30 b[z] | 0.2950 [NS] | 43 [NS] | 1.777 [NS] | 10.41 [NS] | 17.8 b |
| Outside Canopy | 13.86 a | 0.3030 | 46 | 2.015 | 10.85 | 18.9 a |
| *P-value* | *0.0201* | *0.4758* | *0.3018* | *0.3372* | *0.8680* | *0.0283* |
| **Bon Rouge** | | | | | | |
| Inside Canopy | 12.07 [NS] | 0.2810 [NS] | 43 b | 1.010 [NS] | 28.03 [NS] | 20.7 [NS] |
| Outside Canopy | 12.58 | 0.2730 | 46 a | 1.052 | 29.07 | 22.5 |
| *P-value* | *0.4232* | *0.5643* | *0.0083* | *0.5028* | *0.7465* | *0.2936* |

[NS] Not significant

[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) on 'Bon Chrétien' and 'Bon Rouge' sensory flavour attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2011. Pears were harvested on 24 January 2011 at Glen Fruin, Elgin, Western Cape, South Africa and subjected to cold storage at -0.5°C for 5 ('Bon Chrétien') or 6 ('Bon Rouge') weeks followed by 5 days of ripening at room temperature (20°C).

| | **Pear flavour** | **Sweetness** | **Sourness** | **Bitterness (with peel)** |
|---|---|---|---|---|
| **Bon Chrétien** | | | | |
| Inside Canopy | 64 $^{NS}$ | 64 $^{NS}$ | 18 $^{NS}$ | 19 $^{NS}$ |
| Outside Canopy | 65 | 66 | 20 | 24 |
| *P-value* | *0.5339* | *0.3001* | *0.1809* | *0.1652* |
| **Bon Rouge** | | | | |
| Inside Canopy | 63 $^{NS}$ | 60 $^{NS}$ | 25 $^{NS}$ | - |
| Outside Canopy | 64 | 62 | 26 | - |
| *P-value* | *0.4509* | *0.5853* | *0.3092* | |

Scale where 0=None and 100=Extreme values

$^{NS}$ Not significant

**Table 5** The effect of canopy position (inner canopy versus outer canopy) on the overall means of 'Bon Chrétien' and 'Bon Rouge' sensory texture attributes measured on a 100 mm unstructured line scale during descriptive sensory analysis in 2011. Pears were harvested on 24 January 2011 at Glen Fruin, Elgin, Western Cape, South Africa and subjected to cold storage at -0.5°C for 5 weeks and 6 weeks, respectively, followed by 5 days of ripening at room temperature (20°C).

| | **Hardness** | **Melt character** | **Juiciness** | **Mealiness** | **Grittiness** |
|---|---|---|---|---|---|
| **Bon Chrétien** | | | | | |
| Inside Canopy | 6 [NS] | 80 [NS] | 72 [NS] | 9 [NS] | 21 [NS] |
| Outside Canopy | 6 | 81 | 73 | 12 | 20 |
| *P-value* | *0.9027* | *0.5972* | *0.7145* | *0.3207* | *0.7073* |
| **Bon Rouge** | | | | | |
| Inside Canopy | 5 [NS] | 71 [NS] | 73 [NS] | 20 [NS] | 34 [NS] |
| Outside Canopy | 5 | 73 | 75 | 17 | 34 |
| *P-value* | *0.6416* | *0.4551* | *0.1483* | *0.2565* | *0.9851* |

Scale where 1=None and 100=Extreme values

[NS] Not significant

**Table 6** The effect of canopy position (inner canopy versus outer canopy) on the overall degree of liking of pear eating quality and appearance for the total group of Stellenbosch consumers for 'Bon Chrétien' and 'Bon Rouge' pears harvested on 24 January 2011 at Glen Fruin, Elgin, Western Cape, South Africa. Pears were subjected to cold storage at -0.5°C for 5 weeks and 6 weeks, respectively, followed by 5 days of ripening at room temperature (20°C).

| | **Bon Chrétien** | | **Bon Rouge** | |
|---|---|---|---|---|
| | **Eating Quality** | **Appearance** | **Eating Quality** | **Appearance** |
| Inside Canopy | 7.5 a | 7.2 $^{NS}$ | 7.4 $^{NS}$ | 6.0 b |
| Outside Canopy | 7.0 b | 7.2 | 7.4 | 6.4 a |
| *P-value* | *0.0080* | *1.0000* | *0.6894* | *0.0205* |

Nine point hedonic scale used where 9=Like extremely and 1=Dislike extremely

$^{NS}$ Not significant

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

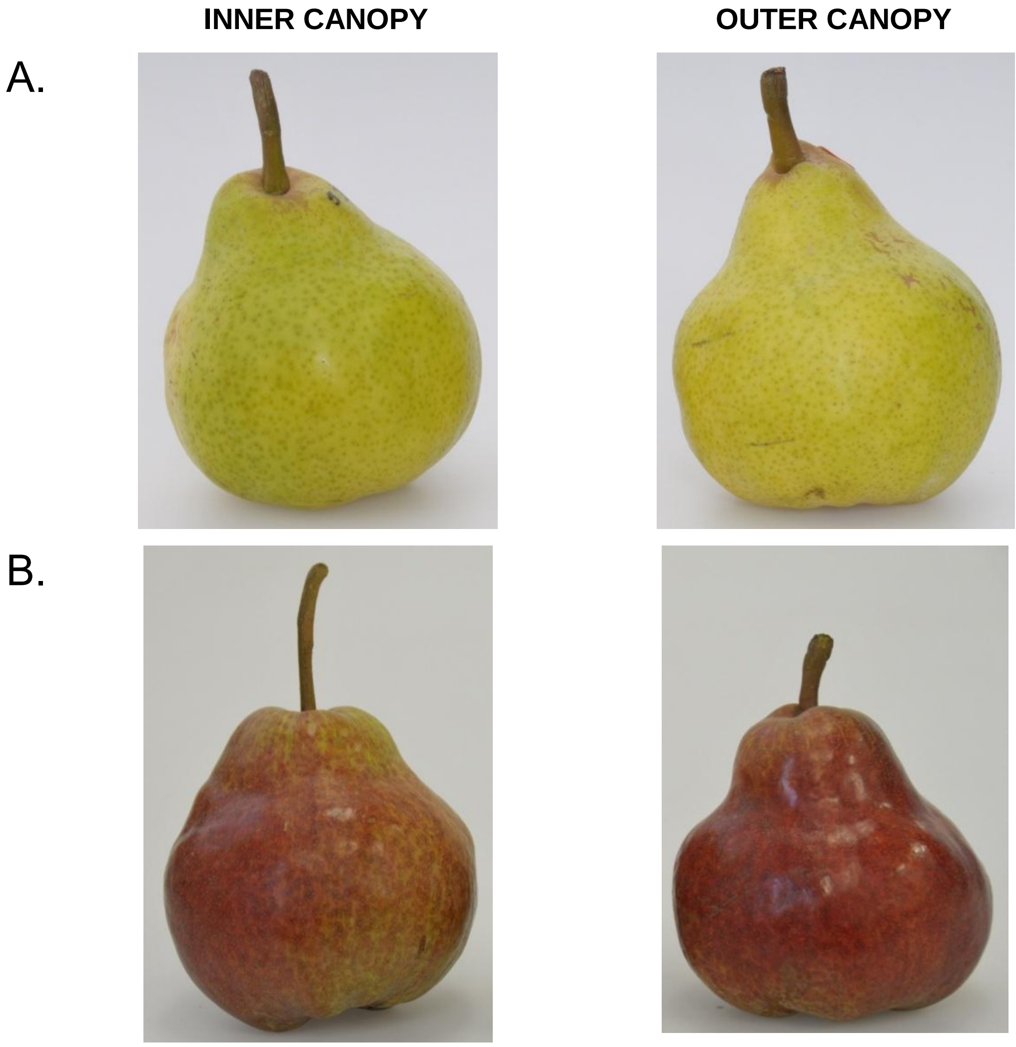


**Figure 1** Images of representative inner and outer canopy fruit of 'Bon Chrétien' (A) and 'Bon Rouge' (B) harvested on 24 January 2011 from Glen Fruin, Elgin, Western Cape, South Africa. Photographs were taken after 5 and 6 weeks of cold storage, respectively, at -0.5°C followed by 3 days of ripening at room temperature (20°C).

# GENERAL DISCUSSION AND CONCLUSION

Fruit are produced throughout the canopy and are therefore exposed to varying irradiance and temperatures that may affect postharvest fruit quality characteristics and influence consumer preference regarding eating quality and appearance (Bramlage, 1993; Frick, 1995; Hamadziripi, 2012). A study in apple found that outer canopy 'Granny Smith' fruit on the northern side of the tree were exposed to 53% of full sunlight while inner canopy fruit near the trunk received only 2% of full sunlight during the fruit growth period (Fouché *et al*., 2010). Exposed fruit on the northern side of the row had the highest peel temperature throughout the season, approximately 5°C higher on average than the average ambient air temperature (24°C). In contrast, the inner canopy fruit did not differ from the ambient air temperature. Leaves exposed to high irradiance had increased photosynthesis and this resulted in an increased supply of assimilates to outer canopy fruit (Johnson & Lakso, 1986). The increase in assimilate supply is likely to result in increased total soluble solids (TSS), lower titratable acidity (TA) and an increase in sweetness and apple flavour (Hamadziripi, 2012). We set out to determine how microclimatic variations brought about by canopy position influence fruit quality attributes and consequently the consumer preference for the eating quality and appearance of pears. Physicochemical, descriptive sensory and consumer preference assessments were conducted for 'Forelle' (red-blushed), 'Bon Chrétien' (green/ yellow) and 'Bon Rouge' (red) pears. The four research chapters of the study were underpinned by a literature review (Chapter 1) on the effect of differential light exposure of fruit within the tree canopy on postharvest fruit quality and consumer preference.

Forelle (*Pyrus communis* L.), a late season red blush pear, is South Africa's second most planted pear cultivar at 26% of the area under pear production (Hortgro Services, 2012). 'Forelle' pears cultivated in South Africa are prone to mealiness if they are not stored at -0.5°C for at least 12 weeks (De Vries & Hurndall, 1993; Martin, 2002; Crouch *et al*,. 2005; Crouch & Bergman, 2010; Carmichael, 2011). Mealiness, a dry textural disorder, is associated with a floury sensation in the mouth, with loss of juiciness, crispness and hardness (Barreiro *et al*., 1998). A ripened pear with good eating quality should have a juicy, buttery melting texture accompanied by a characteristic pear flavour (Zerbini, 2002). Mealiness seems to peak after 6 to 8 weeks of cold storage, but when storage is extended longer than 12 weeks at -0.5°C, mealiness seems to decrease (Martin, 2002; Carmichael, 2011). Consequently, South African 'Forelle' pears have a mandatory 12 week cold storage period at -0.5°C for fruit to ripen to an acceptable eating quality and to minimize the incidence of mealiness. The industry aims to have a continuous market supply of premium quality SA bi-colour pear cultivars, but the mandatory 12 weeks cold storage requirement for Forelle causes a market gap after the supply of Rosemarie and Flamingo (Crouch & Bergman, 2010). This prevents South African 'Forelle' pears from accessing earlier markets that offer premium prices (De Vries & Hurndall, 1993) and may result in potential consumers buying earlier packed fruit from South America, a switch that often remains permanent, even when South African 'Forelle' pears enter the market. Hence, South African 'Forelle' pears with good eating quality should be available in Europe from week 15 (Crouch *et al*., 2013). Several research projects have examined the possibility of shortening the mandatory cold storage period; with varying levels of success (Du Toit *et al*., 2001; Crouch & Bergman, 2010; Carmichael, 2011; Crouch, 2011). Results from the 'Forelle' Early Market Access (FEMA) programme suggest the possibility of shortening the 12 week mandatory cold storage period (Crouch *et al*., 2013). Pears in the FEMA programme are allowed to mature on the trees until they reached a flesh firmness of between 6.0 and 5.5 kg, and a TSS of at least 14%. Directly after harvest, fruit are treated with the ripening inhibitor SmartFresh$^{SM}$ (1-methylcyclopropene), then immediately packed into 20 μm low density polyethylene (LDPE) bags, and shipped to reach offshore markets by week 15. SmartFresh$^{SM}$ retards fruit ripening, thereby eliminating mealiness and resulting in a crispy, sweet pear. More recent research found that later harvested 'Forelle' can be marketed as "Crisp and Sweet" within four to six weeks of harvest if SmartFresh$^{SM}$ application is used at harvest (Crouch *et al*., 2013). Untreated 'Forelle' pears attain the ability to ripen before 12 weeks of cold storage (even as soon as four to six weeks), but the eating quality improves with longer storage due to mealiness and astringency reduction and probably also due to the improvement of pear flavour and TSS:TA levels after prolonged storage (Carmichael, 2011; Crouch, 2011).

In light of the above, the objective of our first trial carried out over two seasons (2011/ 2012) was to determine whether outer and inner canopy 'Forelle' pears harvested at commercial maturity (≈6.4 kg) and subjected to increasing cold storage duration (9, 12 and 16 weeks) differ in quality attributes and how these differences, if any, relate to consumer preference for the eating quality of the pears (Chapter 2). This study revealed that the incidence of mealiness was significantly greater in outer canopy fruit in 2012 (all storage periods) and after 9 and 12 weeks cold storage in 2011. Consumers showed an equal liking for pears stored for 12 and 16 weeks in 2011, however, for different reasons. While the preference for inner canopy pears after 12 weeks storage may relate to the lower incidence of mealiness and possibly good TSS:TA balance, reasons for the preference after 16 weeks cold storage are uncertain. In 2012, the incidence of mealiness in outer canopy pears was double that of inner canopy pears, which may explain the general consumer preference for inner canopy pears. Mealiness incidences decreased from 9 and 12 weeks cold storage to 16 weeks cold storage in 2012. As expected, preference for eating quality increased with storage duration from 9 to 12 weeks and longer. Consumer preferences for eating quality were closely associated with juiciness in 2012 while a combination of factors was involved in 2011. This study thus provides support for the mandatory 12 weeks cold storage period for 'Forelle' pears that do not form part of the FEMA programme. In fact, the percentage of mealy pears will be lower if pears are stored for 16 weeks at -0.5°C. Further research is needed to clarify the mechanisms by which canopy position affects mealiness in 'Forelle' pears.

Maturity at harvest has a direct affect on the period for which pears can be stored without losing quality (Kvale, 1990; Kader, 1999) and it also affects the ripening potential (Kader, 1999; Crouch *et al*., 2005). Previous experience with climacteric fruit has shown that immature fruit will not ripen adequately after removal from cold storage and that these fruit will have poor sensory quality (Peirs *et al*., 2001). In order to avoid the risk of over-ripening and decay, growers harvest fruit too early; resulting in fruit with poor eating quality (Zerbini & Spada, 1993). Immature 'd' Anjou' pears did not develop an acceptable flavour after ripening (Boonyakiat *et al*., 1987). Previous studies established that astringency in apples and pears are linked to the maturity of the fruit (Mielke *et al.*, 2005; Carmichael, 2011). In persimmon, this relates to the higher tannin levels of less mature fruit which is most likely to be perceived as astringent (Ramin & Tabatabaie, 2003). Studies have shown that fruit harvested later in the picking window develop higher amounts of volatiles (Zerbini & Spada, 1993), are lower in TA and higher in TSS:TA ratio (Mielke *et al*., 2005). Apples harvested at an advanced stage of maturity have a short cold storage life where after they quickly soften during ripening and become mealy (Peirs *et al*., 2001). Carmichael (2011) found that post-optimum harvested 'Forelle' pears were more prone to develop mealiness compared to pre-optimum and optimum harvested fruit. Therefore, it is of the utmost importance that optimum harvest maturity must be well defined to reduce postharvest losses and maintain good eating quality after storage (Hansen & Mellenthin, 1979). There are often large differences in texture at harvest between fruit from the same cultivar due to differences in maturity (Sams, 1999). Carmichael (2011) found that the rate of change in firmness together with ground colour is the most reliable variable to determine harvest maturity of 'Forelle' pears. However, maturity indices are greatly influenced by climatic conditions and may differ between seasons (Frick, 1995; Van Rensburg, 1995; Lötze & Bergh, 2005). Inner and outer canopy fruit may also vary in harvest maturity due to exposure to different microclimatic conditions (Predieri *et al*., 2005). In previous seasons, 'Forelle' pears were harvested at high firmness (>6.4 kg) because there was always the pressure of entering the market early in the season; therefore there was little chance of fruit being harvested at a low firmness (≈4.5 kg) (E.M.Crouch, Department of Horticulture, Stellenbosch University, Stellenbosch, South Africa, 2013, personal communication).

The aim of our second trial carried out in 2012 was to determine whether outer and inner canopy 'Forelle' pears harvested at different maturity stages within the commercial picking window differ in quality attributes and how these differences, if any, relate to consumer preference for the eating quality of the pears (Chapter 3). Flesh firmness is used by the South African deciduous fruit industry to determine harvest maturity of 'Forelle' and ranges from 4.5 kg (over-mature standard) to 6.8 kg (harvest release criterion). 'Forelle' fruit were harvested from the inner and outer canopy in

2012 at three different maturity stages within the commercial harvesting window (start of export picking window or H1≈6.8-6.5 kg; middle of export picking window or H2≈6.4-6.1 kg; lower end of middle export picking window or H3≈6.0-5.5 kg) and stored under regular atmosphere at -0.5°C for 12 weeks and ripened thereafter for seven days at room temperature (20°C). Inner canopy pears of harvest 1 (23 February) and harvest 2 (27 February) were significantly preferred in terms of eating quality. With regard to outer canopy pears, consumers preferred H2 over H1 and H3 fruit. After cold storage and 7 days shelf-life, H3 fruit were firmer, higher in ethylene, mealiness incidence, TSS and lower in TA while H1 and H2 fruit were higher in melt character, juiciness, sourness and TA. Our results corroborate previous findings that TSS is higher in fruit harvested at greater maturity (De Belie *et al*., 2000; Błaszczyk, 2010). Similarly, the more mature fruit also had lower TA levels as reported by Mielke *et al*. (2005). Pears that are allowed to ripen or become too mature on the tree show higher incidences of mealiness (Stebbins *et al*., 1998; Carmichael, 2011). Previous studies showed that mealiness is the main reason for consumer dislike in apples (Jaeger *et al*., 1998; Andani *et al*., 2001) and pears (Jaeger *et al*., 2003; Manning, 2009). Therefore, the dislike for H3 outer canopy fruit most likely relates to the high incidence of mealiness and maybe even a too low TA that makes the fruit taste bland. Sensory panels associate an increase in mealiness with a decrease in juiciness and hardness (Barreiro *et al*., 1998). H1 and H2 pears were scored significantly higher in melt character and juiciness compared to the H3 pears. H2 fruit also had a lower firmness, higher dry matter concentration (DMC) and lower sour taste than H1 and H3 fruit. Our results suggest that harvesting 'Forelle' pears at a firmness ≈6.2 kg will ensure that both inner and outer canopy pears have acceptable eating quality. However, Martin (2002) and Carmichael (2011) found that the level of mealiness may differ between seasons even when fruit are harvested at the same maturities. Therefore, this research should be repeated for a few consecutive seasons.

The aim of our third trial conducted during the 2011/12 season was to determine the effect of orchard site on the physicochemical and sensory quality of inner and outer canopy 'Forelle' pears. In South Africa, 'Forelle' pears are mainly produced in the Western Cape where the growing areas differ in climate. These differences might influence harvest maturity and ripening potential of fruit (Wand *et al*., 2008). Seasons that experienced high total heat units were associated with high mealiness incidences of 53% to 70% in pears (Hansen, 1961). Another study by Mellenthin and Wang (1976) found that 'd' Anjou' pears exposed to high temperatures six weeks before harvest had a high incidence of mealiness. 'Forelle' pears were sourced from two different production regions, viz. Grabouw and Ceres Koue Bokkeveld, in the Western Cape, South Africa. Fruit were harvested in 2012 at commercial firmness (≈6.4 kg) from two orchards per area, viz. Glen Fruin and Glen Brae in Grabouw, and Lindeshof A and Lindeshof B in Ceres Koue Bokkeveld. Carmichael (2011) showed that mealiness incidences in 'Forelle' vary between orchards. We aimed to confirm this finding for pears of different canopy positions. Incidences of mealiness were high in outer canopy fruit from the Grabouw region, as well as in the Lindeshof B orchard in the Ceres Koue Bokkeveld region, but nearly absent in both outer and inner canopy pears from Lindeshof A. Therefore, although we could not corroborate regional differences in mealiness incidence, there is, however, evidence of orchard differences in mealiness incidence. Weather stations in the vicinity of the orchards showed that the pears in the Grabouw region were exposed to slightly higher minimum temperatures compared to the Ceres Koue Bokkeveld region during the growing season whereas there was no difference between two regions in maximum temperatures. These temperature differences might have been insufficient to induce regional differences in mealiness incidence. However, fruit from the two regions did seem to differ in some quality parameters. The TSS concentration was higher in the Grabouw pears while flavour attributes were more pronounced in Ceres pears. In both areas, the outer canopy pears were higher in TSS and lower in TA while canopy position had no effect on sweet and sour taste. Further research over consecutive seasons and including more orchards is needed to establish the factors causing differences in mealiness incidence between orchards.

The objective of our fourth trial conducted during the 2010/11 season was to determine whether outer and inner canopy ‘Bon Chrétien’ and ‘Bon Rouge’ pears differ in quality attributes and how these differences, if any, relate to consumer preference for the eating quality of these pears (Chapter 5). Despite a higher TSS to TA ratio in outer canopy ‘Bon Rouge’ pears and a higher TSS and DMC in outer canopy ‘Bon Chrétien’ pears, canopy position did not affect sensory eating quality attributes. Seen overall, results indicate that canopy position has a minor effect on consumer preference for ‘Bon Chrétien’ and ‘Bon Rouge’ pear eating quality.

Canopy position affects the external quality of fruit. The synthesis of anthocyanins, responsible for red peel color in pears, requires light and therefore outer canopy pears tend be redder than inner canopy pears (Steyn *et al*., 2005). Appearance provides the first impression of the fruit that will either attract or repel the consumer (Kays, 1998). No significant differences in colour and consumer preference for appearance were found between outer and inner canopy ‘Bon Chrétien’ pears. Consumers preferred the redder outer canopy ‘Bon Rouge’ pears slightly more than the less red inner canopy fruit. Outer canopy ‘Forelle’ pears had a red blush while inner canopy pears had little red colour or were uniformly green. At present, outer and inner canopy ‘Forelle’ pears are marketed separately. Inner canopy ‘Forelle’ pears are marketed under the ‘Vermont Beauty’ label while red blushed outer canopy ‘Forelle’ pears receive higher prices on the export market (E.M.Crouch, Department of Horticulture, Stellenbosch University, Stellenbosch, South Africa 2013, personal communication). The assessment of preference for pear appearance revealed that the red blush colour of outer canopy ‘Forelle’ pears was slightly preferred in 2011. However, there was no significant difference in preference scores for appearance in 2012. In light of the above, inner canopy 'Forelle' pears should not be viewed as inferior to outer canopy pears. Manning (2009) found that European consumers had the highest preference for the appearance of yellow 'Bon Chretien' pears. Bon Chretien is the third most produced pear cultivar in South Africa (Hortgro Services, 2012) and we assume that most consumers are familiar with this cultivar. It is possible that the yellow appearance of inner canopy 'Forelle' pears resembled the appearance of 'Bon Chretien' pears. Gamble *et al*. (2006) found that Australian and New Zealand consumers responded to fruit colour in terms of familiarity.

Sensory mealiness scores and mealiness incidence levels did not correspond in all three 'Forelle' trials, possibly because the sensory panel assessed the level of mealiness for each sample and not the incidence of mealiness as was done in the physicochemical assessment. Only 20 samples were analysed during the sensory assessment of mealiness while 100 samples were evaluated during physicochemical mealiness. While a 100 mm unstructured line scale was used to rate the level of mealiness, a pear was either classified mealy or non-mealy for the assessment of mealiness incidence. For future research concerning mealiness, we suggest that more fruit are used during the sensory assessment of mealiness, primarily to illustrate a wider sensory range of mealiness. This will result in the establishment of more mealiness classes whilst training the panel. This would assist the sensory panel in the scoring different levels of mealiness, thus improving reliability of results.

The most important information to take from this study is that inner canopy 'Forelle' pears should not be viewed as inferior as the consumers consistently preferred the eating quality of these fruit while the preference for the appearance of outer canopy red blush pears were only slightly higher in only one season than the preference for inner canopy pears. However, it should be cautioned that our findings apply to the specific conditions under which our experiments were conducted. The preference for eating quality of 'Forelle' pears could be different if the pears were harvested at more advanced maturity and then exposed to a 1-MCP treatment as in the FEMA programme or if the pears are stored for a longer period (e.g. 21 weeks at -0.5˚C). The likelihood of mealiness will be low when 'Forelle' pears receive these treatments. Mealiness in inner and outer canopy fruit may also peak at different times during the shelf-life period due to different harvest maturities, which will affect the ripening potential of the fruit, or due to different ripening patterns. It is important to mention that preference is linked to a specific TSS, TA and texture for a specific storage and treatment, which means that our results are not necessarily valid for all inner and outer canopy 'Forelle' pears in the industry. However, consistent differences in mealiness incidence between inner and outer canopy 'Forelle' pears, except for the Lindeshof B orchard, opens up a new avenue for investigating mealiness development. For future studies, we recommend the testing of consumer preference for eating quality and appearance of fruit from different orchard locations at their optimum ripening stage on different days and then comparing the results statistically. Further research over consecutive seasons is needed to establish the factors causing differences in mealiness incidence between orchards.

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