POSTHARVEST LOSSES AND CHANGES IN PHYSICO-CHEMICAL PROPERTIES OF FRUIT (PEACHES, PEARS AND ORANGES) AT RETAIL AND DURING POST-PURCHASE STORAGE

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Declaration

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ABSTRACT

Postharvest fruit loss is a major challenge in addressing food security, sustainable management of resources and profitability of agribusiness. The incidence of postharvest loss and changes in physico-chemical properties of three types of fruit (peaches, pears and oranges) were evaluated at retail and during post-purchase storage. The amount of physical loss at the three retail outlets studied ranged from 3.61% to 18.09% among the fruit types, with the highest incidence occurring in peaches. The estimated annual national physical loss at retail was 418 tons for pears, 1000 tons for oranges, and 7 240 tons for peaches. Based on the WHO recommended 146 kg per capita per year consumption of fruit, the total loss of the three types of fruit was sufficient to meet the dietary fruit requirements of 50 000 people per annum. Similarly, based on the recommended daily allowance of 50 mg of ascorbic acid, these losses could meet the annual vitamin C needs of 82 000 people. The estimated monetary value of the losses at retail ranged from R2.2 million to R96.87 million per annum depending on fruit type and retail outlet. The land wasted to produce lost fruits was 1965 ha while energy wasted was 32.77 x 10^6 MJ. Greenhouse gas emission of the losses was 2870 tons CO_{2eq} and total water footprint 68 0000 m^3. Losses were mainly due to the presence of severe physical damage, rots and physiological disorders. There were significant variations in physico-chemical properties of fruit of the same type from different retail outlet. Although ambient temperature storage improved fruit colour and some chemical constituents responsible for palatability, it was associated with high physical and nutritional (vitamin C) losses. Results from this study show that appropriate harvesting maturity, packaging and maximum care in fruit handling is essential in reducing postharvest losses. Efficient cold chain management and fruit inspection for rots and damages could help to reduce subsequent spoilage at retail and during post-purchase storage. Given that the incidence of postharvest fruit loss observed at retail is the result of cumulative effects along the supply chain, further studies are warranted to map fruit history and magnitude of losses along the value chain.

Uittreksel

Naoesvrugteverlies is ’n groot uitdaging in die strewe na voedselsekerheid, volhoubare hulpbronbestuur en winsgewende landbousake. Die voorkoms van naoesverlies sowel as fisiko-chemiese naoesveranderinge by drie vrugtesoorte (perskes, pere en lemoene) is gevolglik by kleinhandelsafsetpunte én gedurende berging ná aankoop beoordeel. Die graad van fisiese verlies by die drie betrokke kleinhandelspunte het gewissel van 3,61% tot 18,09% tussen die vrugtesoorte, met die hoogste verlies by perskes. Die geraamde jaarlikse nasionale fisiese verlies by die kleinhandelspunte was 418 ton pere, 1 000 ton lemoene en 7 240 ton perskes. Op grond van die Wêreldgesondheidsorganisasie se aanbevole jaarlikse vrugte-inname van 146 kg per persoon, was die totale verlies van die drie vrugtesoorte genoeg om aan die vrugtedieetvereistes van 50 000 mense per jaar te voldoen. Op grond van die aanbevole daaglikse inname van 50 mg askorbiensuur, kan hierdie verlies eweneens in die jaarlikse vitamien C-behoeftes van 82 000 mense voorsien. Die geraamde geldwaarde van die verlies by die kleinhandelspunte strek van R2,2 miljoen tot R96,87 miljoen per jaar, na gelang van die vrugtesoort en bepaalde kleinhandelspunt. Die vermorste grond om die verlore vrugte te produseer, was 1 965 ha, terwyl energievermorsing op 32,77 x 10^6 MJ te staan gekom het. Kweekhuisgasvrystellings met betrekking tot die verlies was 2 870 ton CO_2e, en die totale watervoetspoor 68 0000 m^3. Vrugteverlies kon hoofsaaklik aan ernstige fisiese skade, verrotting en fisiologiese afwykings toegeskryf word. Daar was beduidende variasies in die fisiko-chemiese eienskappe van dieselfde vrugtesoort by verskillende kleinhandelaars. Hoewel berging by omgewingstemperatuur vrugtekleur en bepaalde chemiese komponente vir smaaklikheid verbeter, word dit ook met groot fisiese en voedingstof- (vitamien C-) verliese verbind. Die resultate van hierdie studie toon dat toepaslike oesrypheid, die regte verpakking en maksimum sorg in vrugtehantering noodsaaklik is om naoesverlies te verminder. Doeltreffende koelkettingbestuur en vrugte-inspeksie vir verrotting en skade kan latere bederf by kleinhandelsafsetpunte sowel as gedurende berging ná aankoop help beperk. Aangesien die naoesvrugteverlies wat by die kleinhandelspunte waargeneem is uit kumulatiewe faktore in die verskaffingsketting spruit, is verdere studies nodig om vrugtegeskiedenis na te spoor en die omvang van die verlies in die algehele waardeketting te bepaal.

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CONTENTS

The language and style used in this thesis are in accordance with the requirements of the *International Journal of Food Science and Technology*. This thesis represents a compilation of manuscripts where each individual entity and some repetition between chapters have been unavoidable.

Chapter 1

General Introduction

The problem of food losses was identified as a global crisis in 1945 during the establishment of Food and Agriculture Organisation (FAO) which led to the proposal of postharvest losses reduction as part of the solution in addressing world hunger in 1974 (Parfitt, 2010). Although the main focus was initially focused on durable grain, the scope of work was later broadened in the early 1990s to cover roots and tubers, and fresh fruits and vegetables (FFVs). However, a global literature review by Parfitt (2010) revealed that there is a dearth of data on food losses as much of the postharvest losses data was collected over 30 years back from the time the review was made. Recent studies by FAO (2011) suggested that approximately one-third of food produced for human consumption is lost or wasted globally amounting to about 1.2 billion tons per year. The per capita food loss in Europe and North-America is 280-300 $kg.yr^{-1}$, while Sub-Saharan Africa and South/Southeast Asia is 120-170 $kg.yr^{-1}$ while per capita production of food for human consumption is, in Europe and North-America, about 900 $kg.yr^{-1}$ and, in Sub-Saharan Africa and South/Southeast Asia, 460 $kg.yr^{-1}$ (FAO, 2011).

One of the constraints to consumption of fruit and vegetables is the high incidence of postharvest losses varying from 20% to more than 60% mostly due to bad packaging and transport conditions (Ganry, 2009). Based on FAO/WHO report, "Diet, Nutrition and Prevention of Chronic Diseases", it was concluded that very few countries are reaching the recommended intake of 400 g of fruits and vegetables per capita per day (Ganry, 2009). North America, Europe, and Asia were reported to be over the critical level of 150 kg per capita per year (400 $g.dy^{-1}$), South-America just reaching this level, and Africa far below with an average of around 100 kg per capita per year (FAO, 2000).

The South Africa Food Security Working Group (FSWG) (1996) described the experience of most South African households as characterised by continued poverty which is manifested in food insecurity, ill health and arduous work for low returns (FSWG, 1996). Food insecurity and micro-nutrient deficiencies were found to be most prevalent among women, children and elderly people in rural areas (Monde, 2003). Micronutrient-deficient diets lead to reduced mental and physical development, poor performance in school, loss of productivity in the work place and contribute to likelihood of poverty in future generations (Haddad *et al*., 2002). Vitamin

A deficiency alone weakens the immune system of 25% of children under the age of six years in South Africa (FSWG, 1996). In contrast healthy diets improve the learning capacity of children and the productivity of workers. The availability of fruits and vegetables in South Africa were reported to be 42 kg and 33.1 kg per capita per year, respectively, with a total of 75.1 kg which is only 50% of the FAO/WHO recommendation (Ganry, 2009). These figures highlight the need to increase fruit and vegetable availability in South Africa.

Most national plans for food security focus on staple food (calories) and addressing nutrient deficiencies through separate intervention, particularly with children and pregnant women (supplementations with Vitamin A, iron, food fortification, and salt iodisation) (Ganry, 2009). However, there is increasing evidence that consumption of whole foods is better that isolated food components such as dietary supplements and nutracenticals (Kader, 2002). For example, increased consumption of carotenoid-rich fruits were more effective than carotenoid supplements in increasing LDL oxidation resistance, lowering DNA damage and inducing higher repair activity in human volunteers who participated in a study conducted in France, Italy, Netherlands and Spain (Southon, 2000). Fruits are rich in vitamins (such as C, A, B_6, thiamine, niacin), mineral salts and dietary fibre and play an important role in reducing the problem of micronutrient deficiency. Additionally, horticultural crop production creates jobs, providing twice the amount of employment per hectare of production compared to cereal crop production (Ali *et al*., 2002).

Industrial food production involves deforestation, and huge consumption of fresh water and energy associated with greenhouse gases (GHG) emissions (Letete *et al.*, 2010; Gonzalez *et al*., 2011; Mekonnen & Hoekstra, 2011).These have an impact on availability of fresh water, changes in biodiversity and contribute to global warming. South Africa is the world's 13^{th} highest emitter of CO_2 with a relatively high per-capita CO_2 emissions rating of 8.59 metric-tons per year (Rousseau, 2012). The peach industry in South Africa takes up about 8 490 ha while pear and soft citrus use 11 435 ha and 5100 ha of land, respectively. The average South Africa water footprint for peaches is 1029, pear 532 and soft citrus 461 m^3 per ton of fruit reaching the market (Mekonnen & Hoekstra, 2011). Gonzalez *et al.* (2011) estimated the average GHG emission of fruit production to be 0.33 kg $CO_{2eq}.kg^{-1}$ and 3.88 MJ of energy used to produce one kilogram of fruit. Considering these values, fruit losses will imply wastage of resources and environmental damage proportional to amount of losses.

Reducing postharvest losses provides a sustainable, plausible and additional instrument in the fight against food and nutritional insecurity.The assessment of postharvest losses together with studies on physico-chemical properties is essential for postharvest technology implementation (Sigh & Reddy, 2006) to reduce losses and preserve fruit quality. Most fruit loss assessments focus on one specific point of the supply chain, like losses during transport, or losses at market (Ceponis & Cappellin, 1985; Caixeta-Filho, 1999; Murthy *et al*., 2009). Although this approach directly quantifies losses and identifies their causes, it is time consuming and only specific for a marketing event.

To date, there is a dearth of information on the incidence and magnitude of postharvest losses of fruit and other food crops in South Africa. Information on the nature and extent of fruit losses could assist in identifying factors responsible and the development of guidelines to prevent or reduce such losses.

The aim of this study was to assess the incidence of postharvest losses of selected types of fruit at retail level in South Africa. The specific objectives were to: (i) determine the magnitude of physical and nutritional postharvest losses, (ii) quantify the changes in physico-chemical properties related to quality, and (iii) estimate the economic and environmental impacts of postharvest fruit losses.

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Chapter 2

Literature Review

Background

Despite remarkable progress made in increasing fruit production at global level, reaching 595.63 million metric tons in 2009 (FAO, 2009), the per capita availability of fruits is lower than the recommended level of 400 $g.dy^{-1}$ (WHO, 2011). North America, Europe, and Asia were reported to be over the critical level of 150 kg per capita per year (400 $g.dy^{-1}$), South-America just reaching this level, and Africa far below with an average of around 100 kg per capita per year (FAO, 2000). One of the constraints to consumption of fruit and vegetables was attributed to postharvest losses varying from 20% to more than 60% (Ganry, 2009).This suggests that losses tend to be highest in those countries where the need for food is highest.

Fruit losses represent severe economic losses especially in developing countries that are struggling to escape from poverty. They are a major source of loss of important dietary nutrients for populations who are malnourished. Postharvest losses result in increased per unit cost of transport and marketing which affects both producers (reduced share in consumers' price) and consumers (reduced availability and higher prices), thereby contributing to food insecurity. Food security was defined by FAO as

> " a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for active and healthy lives"
> (FAO, 2002)

The existence of poverty and malnutrition demands the most efficient use of food supplies (Fehr & Romao, 2001). Identification of losses and waste and proposal of remedies contribute to sustainable development. Postharvest losses of fruits and vegetables represent a very significant loss of 10-50% of production output in developing countries (BAR, 2008). These losses also represent waste of labour, farm inputs, livelihoods, investments and scarce resources like water. When expressed in monetary terms, this could amount to billions of dollars on global scale. For example, in 2005, Philippine fruits and vegetables were worth US$1.95 billion (BAR, 2008), and the average loss of 30% amounted to US$585 million annually. A loss reduction of 1% is equivalent to US$19.5 million gain in productivity.

Increasing urbanisation has moved more people away from primary food production, and in turn has a negative impact on both the availability of a varied and nutritious diet with enough fruits and vegetables. As more fresh fruits are needed to meet rising demand, and as more fruits are transported to non-producing areas and stored longer to obtain a year round supply, postharvest technology measures become paramount. As long as the postharvest losses of food remain high, efforts to improve human nutrition and food security will not be sustainable. Reducing postharvest losses is more sustainable and economically more sound than increasing production areas to alleviate hunger and malnutrition. Reducing losses eliminates the wastage of energy used to produce and market the lost food and the problem of garbage disposal and consequent pollution will be reduced (Sparks, 1976).

Fruit and vegetables play an essential and critical role in lives of humans ranging from cosmetic, nutritional, medicinal functions to source of income. They are colourful, flavourful and nutritious components of our diets (Bruhn *et al*., 2007). For instance, although onions and garlic are not rich in nutrients, they make a vegetarian diet acceptable because of the savoury flavour they impart to the monotonous starchy diet. In parts of East, Central and West Africa, bananas and plantains serve as a staple food and daily consumption may exceed 2 $kg.dy^{-1}$ per person. These countries also rely on these fruit as source of income (Salunkhe & Desai, 1984).

Fruits generally contribute more dietary vitamins (C, A, B6, thiamine, niacin), mineral salts and dietary fibre than energy and proteins (Salunkhe *et al*., 1991). The absence of fruit and vegetables in the diet leads to nutritional deficiencies, which affect physical resistance to diseases (Gouveia, 1990; Pinazza, 1999). Adults require about 50 $mg.dy^{-1}$ of vitamin C, and many citrus, berries, cherries and guava contain this amount of ascorbic acid in less than 100g of fruit tissue. Fruits contain only small amounts of fats and oils except for avocados which contain 15 - 25% oils. All of the hungry and many of the overweight are afflicted with micronutrient deficiency (lack of vitamins and minerals), the vast majority being women and children (Gardner & Halwell, 2000; UN/SNC, 2004). Fruits play a vital role in solving this global micronutrient crisis and are most sustainable and affordable sources of micronutrients in diets (UN, 2004).

Horticultural crop production provides twice the amount of employment per hectare of production compared to cereal crop production (Ali *et al*., 2002). The move from cereal production towards high-value horticulture crops is an important contributor to employment opportunities in developing countries (Joshi *et al*., 2003). The horticultural commodity chain is also longer and more complex than the cereal crop one and as a result job opportunities are more abundant (Temple, 2001). Since horticultural production is very labour-intensive, landless labourers also benefit from employment opportunities created by horticultural crop production. These jobs usually provide more income than jobs obtained by the labourers in most other sectors (Weinberger & Genova, 2005; Weinberger & Lumpkin, 2005).

Early reviews on postharvest food losses focus on staple cereal grains (Bourne, 1977; Harris & Lindblad, 1978). More recent studies have included information on fruit and vegetables and other types of perishable foods (Kantor *et al*., 1983; Kader, 2009; Parfitt *et al*., 2010; FAO/WHO, 2011). Fruit losses have been assessed in combination with vegetables (Cappellini *et al*., 1984; Government of India, 1985; Scriven & Harrison, 1988; Tadesse, 1991; Fehr & Romao, 2001), or just reported as part of fresh produce or perishables (FAO, 1981; Coursey, 1983; Subrahmangan, 1986). Where the studies focus on fruit, the emphasis is usually on one specific point of the supply chain, such as transport market (Ceponis & Cappellini, 1985; Caixeta-Filho, 1999; Murthy *et al*., 2009). Fruit is an important commodity of the global food system and trade. Hence there is need for a comprehensive review focusing on the incidence and magnitude of postharvest losses. Therefore the aim of this review is to highlight global postharvest fruit losses along the supply chain, from field to fork.

Definition of concepts

The use of commodities as food varies according to differences in social lives, religions, cultures and locations. It is therefore necessary to define certain key words and terms used in this review to avoid confusion. Perception of loss is highly subjective and location-specific hence formulation of unambiguous definitions is rather difficult. The working definitions given below are based on those developed by Bourne (1977) and modified by the US National Academy of Science (1978), Harris and Lindblad (1978) and Salunkhe (1984).

General Concepts

'Food' is any commodity produced or harvested to be eaten by a particular society measured by weight of edible material calculated on a specific moisture basis that has been harvested, gathered or caught for human consumption and that is consumed by the population under consideration (Salunkhe, 1984). This definition includes fruits, vegetables, roots and tubers, grains and commodities from animal origin.

‘Food’ has also been defined as weight of wholesome edible material that would normally be consumed by humans, measured on a moisture-free basis (Harris & Lindblad, 1978). This definition for food focuses on grains while inedible portions such as hulls, stalks, and leaves are not considered as food.

‘Fruit’ is botanically defined as the developed ovary of a flower, the product of determinate growth (Salunkhe, 1984). However, the botanical definition does not include fruits like bananas developed by means of parthenocarpy (thus, without fertilisation) and are seedless. Other fruit such as apples and strawberry arise from structures other than the ovary (for example, receptacles or bract) and peduncle (pineapple). Consumers generally consider fruit as ‘the edible products with aromatic flavours which are either naturally sweet or sweetened before eating’ and are essentially desert foods (Samson, 1980). In horticulture, a fruit is “something which is eaten fresh and out of hand” (Salunkhe, 1984). Apples, bananas and oranges are thus ‘fruits’; tomatoes and plantains are “fruit vegetables” and peanuts and coconuts are “oil seeds” (Salunkhe, 1984). Quality of fruits is the combination of attributes that give them value as human food which consists of appearance, texture, taste, nutritional value and safety (Kader, 2002).

‘Damage’ is physical spoilage, often a partial deterioration or one subjectively judged (Salunkhe, 1984). The distinction between damaged and lost food is often difficult to make. Damage refers to apparent evidence of deterioration and its importance to the consumer depends on economic level and cultural background. Damaged portions of fruits may be cut off and lost for consumption. However, there are stages of deterioration at which the consumer decides that the whole fruit should be discarded.

Postharvest loss concepts

‘Harvest’ is the deliberate action to separate the food stuff (with or without associated inedible material) from its growth medium, e.g., reaping cereals, picking fruits, and lifting fish from water (Salunkhe, 1984).

'Postharvest' is the period between separation of food item from the medium of immediate growth or production and ends when the food enters the process of final consumption (Salunkhe, 1984).

'Postharvest' means after separation from the medium and site of immediate growth or production of food (Harris & Lindblad, 1978). This definition does not include steps between preparation and eating and Harris and Lindblad agree with Bourne to "not cover inefficiencies in human metabolism and utilisation of food" (Bourne, 1977). In this regard, fruit that falls from the plant and is allowed to rot on the ground is not postharvest loss because it was never harvested.

'Loss' is any change in the availability, edibility, wholesomeness or quality of food that prevents it from being consumed by people (Bourne, 1977). Building on this definition, Salunkhe (1984) described 'loss' as reduction in weight in the amount of food available for consumption. Three periods of time may be identified during which food may be lost:

a. 'Pre-harvest loss,' occurs before the process of harvesting begins.

b. 'Harvest loss,' occurs between the onset and completion of harvesting.

c. 'Postharvest loss,' occurs between the completion of harvest and the moment of human consumption.

Harvest and postharvest losses are sometimes combined into a single loss because there are some elements of common concern between them (Harris & Lindblad, 1978). A suitable term for these combined activities would be "post production losses". Food losses may be direct or indirect. A direct loss is disappearance of food by spillage, or consumption by insects, rodents, and birds. An indirect loss is the lowering of quality to the point where people refuse to eat it.

Food losses are at times defined with local context. For example, a fruit discarded because of discoloration is a loss (Salunkhe, 1984). Processing losses occur when edible portions of food are removed from food chain by the process (Harris & Lindblad, 1978). Apple seeds are inedible and hence their removal does not constitute a loss but apple skins diverted from the food chain are a loss. The handling of each similar situation needs to be clearly defined as it occurs. This helps to differentiate loss from waste. Where quality deterioration results in a loss in weight or in the food not being eaten at all, e.g. rejected in the marketplace, the rejected food is a loss (Bourne, 1977). In this review quality is a consideration in the case of qualitative postharvest fruit losses.

Types of Postharvest Losses

Quantitative Loss

Quantitative food loss is the weight of edible material that fails to reach the consumer or utilised for its intended purpose (Kader, 1984). This is also referred to as physical loss which can be measured as a percent or weight lost after comparing weight of received produce with the dispatching weight at each stage of the supply chain(Table 2.1). Quantitative loss can be partial or total weight loss (Holt *et al*., 1983; Scriven & Harrison, 1988). Partial loss is a result of moisture loss, loss of dry matter by respiration and removal of deteriorating or unwanted (trimming and peeling of edible parts) parts of the commodity (Holt *et al*., 1983; Salunkhe, 1984). However, the whole product is still usable or a portion of it is still fit for use. Total weight loss refers to the situation whereby the whole product is rendered not fit for use, in which case it is thrown away. An example is an entire banana found in the garbage which got there because the consumer let it rot, spoiled it, damaged it or simply did not want to eat it (Fehr & Romao, 2001). Fruits which are not fit to proceed from one stage to another in the chain are usually thrown away (FFTC, 1993). As we move from the producer to the plate the weight of edible material that reaches the table is reduced at each stage due to quantitative losses. Any incident, accident or procedure that renders the food not fit for use leads to quantitative loss.

Table 2.1 Example of quantitative postharvest Loss of Fruits in Brazil, 1992

Product	**Quantity Produced (x 10^3 t)**	**Quantity Lost (x 10^3 t)**	**% Loss of Production**
Banana	10195	4079	40
Mango	582	149	27
Grape	786	204	26
Pineapple	1086	258	23
Orange	18806	4137	22

t=tons

Qualitative Loss

Qualitative loss is the downgrading or rejection of food as compared to locally accepted standards for local market and international standards for export (Kader, 1983; Holt *et al*., 1983). Grade standards are developed to identify the degree of quality in various commodities which aid in establishing their usability and value.

They are important tools in the marketing of fresh fruits and vegetables because they provide a basis for making incentive payments for better quality and they help settle, damage claims and disputes between buyers and sellers (Kader, 1983).

During product exchange along supply chain, every role player has a particular quality standard. There is a tendency of downgrading and rejection of fruit (Table 2.2) from one stage to another. Wholesaler quality might not meet retailer's quality and retail quality might as well not meet consumer expectations in which case some of the commodities that do not meet the standards have their prices reduced. Besides the fruits being of lower quality they are still fit for consumption. Consumers and buyers are willing to pay more for high quality and less for lower quality. Fruit quality is usually based on visual attribute like size, shape, colour and blemishes. Change in appeal like shrivelling, bruising and splits leads to downgrading of fruits and hence lower price (Holt *et al*., 1983) (Table 2.3).

Table 2.2 Four year summary (1985-1988) of fruits supplied to the local market, sold as first grade and quantity rejected in Ethiopia (Tadesse, 1991)

Fruit type	**Supplied ($\times 10^3$ t)[a]**	**Sold as 1st grade ($\times 10^3$ t)**	**Rejected ($\times 10^3$ t)**	**Reject %**
Guava	315	160	155	49.21
Pineapple	1112	798	314	28.24
Mango	634	467	167	26.34
Mandarin	3162	2612	550	17.39
Papaya	653	578	75	11.48
Orange	28277	25686	2541	8.98
Banana	17673	16241	1432	8.10
Grape	1063	1017	46	4.33
Grape fruit	1303	1278	25	1.92
Lemon	703	694	9	1.28

Table 2.3 Qualitative loss: losses in acid lime fruit at various stages of marketing in Andhra Pradesh (India) (Ladaniya & Wanjari, 2002**)**

Stage of loss	**Types/Causes of loss**	**Loss (%)**	
Farm level		Hyderabad	Gudur(Nellore)
	1. Insect/mite damaged	0.08	0.10
	2. Very small-sized	0.21	0.10
	3. Thorn injury	0.17	0.19
	4. Bruises	0.11	0.09
	5. Splitting	0.12	0.16
	Total	***0.69***	***0.64***
Wholesale level			
	1. Bruising	0.14	0.14
	2. Rotting	0.23	0.19
	3. Rupture	0.18	0.11
	4. Very small-sized	0.14	0.12
	5. Insect damaged	0.11	0.14
	6. Over-mature	0.07	0.12
	Total	***0.87***	***0.82***
Retail level			
	1. Rotting	1.20	1.40
	2. Bruises, crushing, splitting	1.20	0.85
	3. Insect damaged	0.12	0.18
	Total	***2.52***	***2.43***
Grand total		**4.08**	**3.89**

Importing countries set the standards that potential trade partners must meet in order to protect human health or prevent the spread of pests and diseases. When developing countries export fruits to EEC countries, they use the EEC standards and any negative diversion from these standards leads to lower payments or even rejection of fruits. When fruits are rejected for export they are usually sold at local market probably for lower value (Kader, 1983). For example, the main European quality standards for the various grades of apples (Table 2.4) shows that apples graded as waste are dumped. Fruit which do not meet the prescribed quality standard are downgraded (quality loss) and in worst cases dumped (quantity loss).

Table 2.4 European apples quality standards, according to the grade (Davenel *et al*., 1988**)**

Grades	**Extra**	**1**	**2**	**3**	**Waste**
Colour	Dark green not admitted				
Size grade (diameter)	≥ 65mm	≥ 60mm	≥ 55mm		
Defects	None	≤ $1cm^2$	≤ $2.5cm^2$	≤ $5cm^2$	
Destination	Fresh market	Fresh market	Fresh market	Processing	Dump

Nutritive Loss

Nutritive loss is the loss of internal quality of fruits which can be measured by destructive (Salunkhe, 1984) or non-destructive methods. It is loss of nutrients which are not visible but very important because of the role of nutrition in food security (Gardner & Halwell, 2000). Physiological changes which are governed by aging and postharvest handling procedures determine the nutritional quality of the fruit at any point in the supply chain.

Consumers use external quality to judge the internal quality of fruit as in most cases the external quality can be related to internal quality. Nutritional comparisons of fresh, frozen and canned fruits and vegetables show some loss of vitamins and phenolic compounds during processing (Rickman *et al*., 2007). Degradation of vitamins depends on specific conditions during the postharvest handling, for example, temperature, presence of oxygen, light, moisture, pH, and duration of heat exposure (Table 2.5). The most labile vitamins during culinary processes are retinol (vegetable boiling, 33% retention), vitamin C (the most damaging factors are cooking and oxidation), folate (leaching into the cooking water, 40% retention), and thiamine (cooking, retention 20–80%) (Lešková *et al*., 2004). Fruits subjected to mechanical injury experience losses in mineral salts and water soluble vitamins during washing through leaching. Sugars used during respiration although beneficial to the fruit, are lost for human consumption.

Postharvest losses of fruits imply loss of nutrients that could have benefited people if they were consumed before deteriorating. The quantities of nutrients thrown away when fruits are lost depend on the nutrient density of fruits. For example, loss of citrus fruits means loss of Vitamin C and carotenoids that could have helped in solving nutrient deficiency problem in nutrition compromised people.

Table 2.5 Postharvest nutritive loss; effects of postharvest handling on vitamin C loss in fruits

Commodity	**Postharvest factor/ handling**	**Vitamin C loss (%)**	**Reference**
Apples	Storage at 0 °C for 6 months	59	Zubeckis,1962
Strawberry	Stored unwrapped at 1 C for 8 days	20-30	Nunes *et al*., 1998
Watermelon	Fresh-cut *vs.* whole fruit)	21.43	Opara & Al-Ani, 2010

Economic Loss

Economic loss expressed in monetary terms (Table 2.6) occurs when quantitative, qualitative or nutritional losses occur. If the food is stored to be sold at a later date and a portion of it is eaten by rodents or is damaged and becomes unsalable, it will lead to economic loss (Salunkhe, 1984). When the produce floods the postharvest system we have higher incidence of postharvest losses and prices are reduced so as to sell the produce as fast as possible before rotting. However, when demand surpasses the supply, prices rise and could on contrary result in economic gain.

Table 2.6 Economic postharvest losses in fruits

Country	**Produce**	**Loss(US$ million)**	**Reference**
Philippines	Fruits	114	Pantastico, 1977
	Vegetables	105	
Brazil	Banana	1378	Caixeta-Filho, 1999
	Orange	987	
	Grape	481	
	Pineapple	149	
	Mango	108	
India (2003-04)	Fruits	1682	Murthy *et al*., 2009
	Mango	859	
	Banana	760	
	Grapes	62	

Economic losses occur at local and international levels, where at international level the country as a whole loses foreign currency and the local market loses local currency. The values of postharvest losses are based on the prices at which the commodity can be exported or sold locally. If the food fails to meet domestic demand, it may be necessary to import some amount of that commodity and food will cost the foreign exchange required to import equivalent quantities of lost food. If food production exceeds internal or domestic demand, the surplus is available for export. Postharvest losses in such case will cost the amount of foreign currency sacrificed by the consequent reduction in export (Salunkhe, 1984). An example of economic loss was cited by Driouchi (1990) in Tunisia who mentioned losses caused by Mediterranean fruit fly "Ceratile" in which the annual loss was estimated to 3.6 million US dollars.

Social or indirect costs

Food losses affect the society or the nation as a whole because they have impact on food availability and hence food security (Salunkhe, 1984). Incidence of losses results in loss of dietary nutrients, thereby contributing to malnutrition loss of productivity.

The impact of food production practices on the environment is very critical considering the resources used to produce and transport food that would have been lost. Crouch & Moelich (2010) considered the rejection of fruit due to quality, including shrivelling, as the "ultimate fruit crime", not only in terms of the devastating financial losses, but also in terms of "carbon miles" because the impact of the production inputs of fruit on energy requirements and environment is substantially higher than the impact of packaging which is used to maintain fruit quality.

The amount of fruit thrown away is a major contributor to the production of greenhouse gases. The breakdown of food waste going to landfill sites produces methane - a greenhouse gas 25 times more powerful than carbon dioxide (WRAP, 2010). Gonzalez *et al.* (2011) estimated the average GHG emission of fruit production to be 0.33 kg $CO_{2eq}.kg^{-1}$ and that 3.88 MJ of energy is used to produce one kilogram of fruit.

Crop agriculture is positively correlated with levels of sediment, nitrates, and soluble reactive phosphorous in streams (Gregory & Primack, 2003). Furthermore, fruits and vegetables consume the highest amount of pesticides (26%) in the world (Pulamte, 2008). The largest impacts are on fresh water and marine ecosystems, which are greatly eutrophied by nitrogen and phosphorous from fields. Eutrophication can lead to loss of biodiversity, outbreaks of nuisance species, shift in structure of food chains, and impairment of fisheries. In addition to lethal effects on aquatic organisms, pesticides in runoff may have other negative effects. Herbicides have been shown to hinder photosynthesis in aquatic plants, and pesticides at sublethal concentrations lower the resistance of fish to other stresses (Uri, 1999). Nutrients from fertilisers used in orchards may contribute to eutrophication and hypoxia and this has threatened the livelihood of fishermen in the Gulf of Mexico who depended on high levels of oxygen to support aquatic life (Tilman, 1999).

Causes of Postharvest Losses

Causes of postharvest loss have been classified according to levels of action and mechanisms of fruit deterioration. Salunkhe *et al.* (1984) and FAO (1989) classified the causes of postharvest losses as primary and secondary, where primary causes are those causes that directly affect food and secondary causes are those that lead to conditions that encourage primary causes of loss (Table 2.7). Holt *et al.* (1983) categorised the causes as physiological, pathological and physical. However, Kader (1983) first classified the causes as pre- and postharvest, and then went on to further classify them as biological, environmental and socio-economic causes.

Table 2.7 Classification of causes of postharvest losses (Bourne, 1977)

Primary Causes	Secondary Causes
(i) Mechanical	(i) Inadequate harvesting
(ii) Pathological	(ii) Inadequate packaging, transportation and storage
(iii) Environmental	(iii) Inadequate marketing system
	(iv) Legislation

Mechanical Damage

Mechanical damage to horticultural produce may be categorised as bruising, splits, cuts, cracking and abrasion (Holt *et al*., 1983). Damage results from static and dynamic loads imposed on the produce during postharvest handling which is characterised by cell bursting in bruising, separation of tissue along shear surfaces in slip, tearing apart in cracking and by surface scuffing and scoring in abrasion.

The mechanism involved in mechanical damage is the transformation of energy. For instance, in bruising due to impact, kinetic energy is dissipated by bursting of cells in stressed regions while in cracking stored energy is released by cracking propagation (Holt & Schoorl, 1982). Bourne (1977), Kader (1983) and Salunkhe (1984) also described this as mechanical injury but did not explain the mechanisms. Salunkhe (1984) also noted that pests and birds contribute to mechanical injury in fruits and vegetables. However, mechanical injury of fruits and vegetables due to pressure during transportation, though not visible, leads to rupturing of inner tissues and cells. Such produce degrades faster during natural aging process (Salunkhe, 1984). All methods of harvesting are associated with bruising and damage to the cellular and tissue structure, in which enzyme activity is greatly enhanced as cellular components are, dislocated (Holdsworth, 1983). Mechanical damage can affect fruit appearance which results in lower market quality and price.

Pathological action

Pathological action (Holt *et al*., 1983; Kader, 1983; Salunkhe, 1984) results in microbiological damage (FAO, 1989). Due to their high water activity and soft texture, fruits and vegetables are prone to microbial spoilage caused by bacteria, yeast and moulds. It is estimated that 36% of vegetable decay is caused by soft rot bacteria (Salunkhe, 1984). Major postharvest diseases of fresh fruits and vegetables and their casual micro-organisms have been described by Eckert (1977) together with estimated losses for some produce due to pathological diseases ranging from 2% for 'McIntosh' apples from Nova Scotia to 52% for 'Sanguinello' oranges from Italy. The capability of a micro-organism to initiate a postharvest disease depends on factors associated with the micro-organism, the host or environment (Rippon, 1980). Micro-organisms usually directly consume small amounts of food but they damage the food to an extent that it becomes unacceptable because of rotting or other defects.

Physiological Factors

Softening, change of colour, wilting, chilling injury, freeze injury, browning, and sunburn are all physiological changes that are directly associated with the produce environment, e.g. temperature, vapour pressure deficit, gas composition and light (Holt *et al*., 1983; Kader, 1983; Salunkhe, 1984). However, cosmetic disorders like sunburn and uneven skin colour might not cause any change in chemical composition of the fruit while wilting, browning and freeze injury are associated with metabolic modifications. Early stages of physiological disorders lead to downgrading of fruits while extreme cases result in total rejection.

The rate of deterioration of fruits increases two to three fold with every 10 C increase in temperature. Temperature below optimum range cause rapid deterioration of fruit due to chilling injury and freezing. Chilling injury occurs when fruits are subjected to temperatures above their freezing points but below chilling threshold temperature. It is associated with surface and internal discolouration, pitting, water soaking, failure to ripe, uneven ripening, development of off flavours and increased susceptibility to pathogen attack. Disruption of caused by freezing results in immediate collapse of tissues and total loss of cellular integrity (Salunkhe, 1984; Kader, 2005).

The moisture holding capacity of air increases with temperature. Water loss is directly proportional to the vapour pressure difference (VPD) between the fruit and its environment while relative humidity (RH) is inversely proportional to the VPD. RH can influence water loss, decay development, the incidence of some physiological disorders, and uniformity of fruit ripening. However, appropriate RH range for storage of fruits is 85% to 95% (Salunkhe, 1984; Kader, 2005).

Atmospheric composition (concentrations of oxygen, carbon dioxide and ethylene) influence the rate of biological deterioration. Ethylene promotes senescence associated with loss of green colour, change in texture and flavour. Respiration rate can be slowed by limiting the oxygen or raising the carbon dioxide concentration of the fruit environment and vice versa. Uncontrolled atmospheric gas composition may lead to fast ripening or uneven ripening leading to rejection of fruit due to over ripening or failure to ripe (Salunkhe, 1984).

Socio-economic Factors

Socio-economic factors described by Kader (1983) are also classified as secondary factors (Salunkhe, 1984; FAO, 1989) because they lead to conditions that encourage primary causes. Some examples of these factors includes, inadequate harvesting, packaging, storage, handling skills, transportation and marketing facilities.

Unavailability of needed tools and equipment adversely affect most developing countries during postharvest handling of fruits. Most equipment is neither manufactured locally nor imported insufficient quantity to meet the demand. Various government regulations in some countries do not permit direct importation by producers. However, most fruit handlers involved directly in harvesting, packaging, transportation, and marketing in developing countries have limited or no knowledge on the need for, or how, to maintain quality. In most developing countries, roads are not adequate for proper transportation of fruits. Additionally, transport vehicles and other modes, especially refrigerated trucks are in short supply (Kader, 2005).

Legal standards affect the retention or rejection of food for human consumption by being too lax or unduly strict (FAO, 1989). The degree of government controls especially on wholesale and retail prices of fresh fruits and vegetables varies from one country to another (Kader, 1983). Variation in economic development between regions leads to the differences in technology level, education standards of growers and handlers, availability of resources and operating capital. These factors indirectly lead to primary causes of postharvest losses.

Some of the causes of losses interact and even might have synergistic effects (Salunkhe, 1984). Pathological causes, for example, depend on the environment and the fruits would have been made susceptible to attack by mechanical damage which is a result of improper postharvest handling. Mechanical damage is also dependent on the ability of the fruit to resist whatever force exerted on it due to its nature or previous environmental exposure like water stress softening the skin which makes it susceptible to cuts or bruises (Alzamora *et al*., 2000).

Methods of assessing postharvest fruit losses

At whatever level of precision postharvest fruit loss is defined, the value will be specific in that time and for location. This is due to the fact that loss is a function of the material, the prevailing environment, the nature and intensity of bio-degenerating organisms and postharvest handling. None of these are constant therefore crop loss determined will always be variable. It would be useful to have a standard method of assessing losses for each type of commodity but this is a difficult task due to crop diversity, inherent perishability, and the complexity of marketing, distribution channels and complexity of fruit utilisation (FAO, 1989). However, different approaches have been used (Table 2.8) by researchers in assessing fruit losses which included field sampling of produce, surveys and expert knowledge.

Table 2.8 Examples of studies in which different types of methods were used

Method	Product	LOSS (%)	Country	Reference
Sampling	Mango	70	Benin	Vayssieres *et al*., 2008
	Banana	18.2- 45.8	Kenya	George & Mwangandi, 1984
	Guava	20	India	Roy, 1993
Survey	Orange	9	Ethiopia	Tadesse, 1991
	Fruits & vegetables	15-35	China	Feng, 2001
	Papaya	29.8	Costa Rica	Arauz & Mora, 1983
Guestimates	Fresh Fruits	32	America	Kantor, 1995
	Safou (African plum)	40-50	Africa	Silou *et al*., 2006
	Fruits & vegetables	10-50	Developing countries	BAR, 2008

Sampling

Direct sampling from the supply chain has been used to quantify physical and qualitative losses. Measurements target specific links in the supply chain (Johart, 2005). Sampling is done to carry out laboratory trials to assess the response of fruits under different handling and storage conditions. Laboratory simulations directly identify sources of deterioration quickly and provide corrective measures (Bollen, 2006). However, sampling is time consuming and only specific to marketing event. Sampling of specific links in the supply chain gives an incomplete assessment of the supply chain therefore tagging and tracing becomes more appropriate in assessing the supply chain. Tagging and tracing is used to obtain statistically valid and meaningful results in which the actual loss of any given type are most accurate when data takes the form of a continuous measurable variable (NAS, 1978). Tagging and tracing involves fieldwork, with both destructive and non-destructive sampling at the points of interest along the supply chain. However experimental design and statistical analysis are important for precise and concise loss estimation using this method. The method is also expensive as it involves all the role players of the particular supply chain and depends on the cooperation of each member to have two way flow of information during estimation.

Surveys

Surveys involve the use of questionnaires and interviews. The use of questionnaires is usually referred to as questionnaire loss assessment (QLA). Surveys have been used extensively to estimate economic losses (NAS, 1978; FFTC, 1994; Fehr & Romao, 2000; Murthy *et al*., 2007; Gangwar *et al*., 2007; Barry, *et al*., 2009). QLA is based on survey in which formal questionnaires are used to interview stakeholders in the supply chain within a specific location for a specific fruit (Newman *et al*., 2008; Barry *et al*., 2009). The method can be used to quantitatively assess postharvest losses of all types except for nutritional losses. The precision of results depends on good experimental design particularly sampling method, sample size and data analysis.

Questionnaires and interviews are more effective where there are limited resources and they are rapid in giving. However, when interviewing respondents, they sometimes have difficulties in giving absolute figures in which case relative amounts such as fractions or percentages are used which distorts the actual amount of postharvest loss to be measured. Information used in policy- and decision-making is usually generated using this method (War & Jeffries, 2000). Researchers collect data from farmers, packhouse, wholesalers, retailers, consumers and relevant organisations. Organisations usually involved includes charitable organisations that run units which receive donations in form of fruits and vegetables that buyers do not want but are still edible at a consumer's discretion (Fehr & Romao, 2000). Agricultural departments, marketing organisations and municipalities also provide some data for researchers (Murthy *et al*., 2007; Gangwar *et al*., 2009).

Estimation

Estimation is the interpretation of a number of scientific measurements based on expert knowledge, experience and judgment of the observer (NAS, 1978). These estimates are based on personal experiences and give unreliable data because the amount of loss given will not have been obtained by measurement. There are often temptations to cite "worst cases or minor cases" figures in trying to defend ideas concerning losses (FAO, 1983). Estimates are useful in raising awareness to the problem of postharvest losses. Observers use data from published studies, press reports and discussions with product experts. Guestimates are sometimes preferred as they are less expensive and rapid in giving results. They can however overestimate or under estimate the situation where insufficient information is used in the estimation. In a research by Kantor *et al.* (1995) in USA, limitations inherent in the food supply data suggested that the loss estimated for consumer, retail and food serving sectors understate losses for most agricultural commodities due to limitations in the published studies on which these estimates were based.

Magnitude of postharvest losses

Losses of fresh produce in developed and developing countries

Losses of fresh produce (Table 2.9) were reported to be higher in developing countries (7-70%) than in developed countries (7-53%). Developing countries experience higher losses from production to retail sites (5-50%) while in developed countries higher losses were recorded at retail, food services and consumer sites (5-30%). Since these reported losses were obtained using surveys, estimates like means and ranges were used distorts the precision of the data to the real situation being experienced. One of the challenges in using such data on fresh produce loss is that they do not indicate the type of fresh produce and type of supply chain, thereby making it difficult to interpret and apply in loss reduction intervention programmes.

Table 2.9 Estimated postharvest losses of fresh produce in developed and developing countries (NAS, 1978)

Locations	**Developed countries**		**Developing countries**	
	Range (%)	Mean (%)	Range (%)	Mean (%)
From production to retail sites	2-23	12	5-50	22
At retail, foodservices, and consumer sites	5-30	20	2-20	10
Cumulative total	7-53	32	7-70	32

Fruit and vegetable postharvest losses

Often, data on postharvest losses are reported as a combination of fruit and vegetables. Postharvest losses of fruit and vegetables (Table 2.10) range from 2% to 50%. African countries have the highest recorded losses (28-45%) while Japan, Taiwan (FFTC,1992) and UK (Garnett, 2006) have the least recorded losses (10%). Fruit and vegetables belong to a broad group of products with large difference in physiology and method of utilisation. To obtain more practical information it is therefore better to report the data separately for specific crops.

Table 2.10 Fruit and vegetable postharvest losses recorded in different countries

Region	Country	Loss (%)	Method	Reference
Africa	Zimbabwe	35-45	Estimate	Masanganise, 1994
	Ethiopia	25-35	Estimate	Tadesse, 1991
	Nigeria	30-50	Estimate	Aworth, 2009
	Ghana	20-50	Estimate	BAR, 2010
Asia	Philippines	42	Survey	FFTC, 1994
	Korea	26	Survey	FFTC, 1994
	Taiwan	10	Survey	FFTC,1992
	India	25-40	Estimate	Sarawathy *et al*., 2010
	China	15-35	Interviews	Feng, 2001
	Japan	10-30	Survey	FFTC ,1994
	Indonesia	15-40	Survey	Bautista, 2002
South America	Brazil	10-30	Estimate	CETEA, 1998
North America	USA	2-23	Estimate	Cappellini & Ceponis, 1984
Europe	UK	10	Estimate	Garnett, 2006
	UK	24 - 40	Estimate	Stuart, 2009

Collective postharvest loss assessment of fruits

Several reports have also presented data on postharvest loss of fruits, thus separating them from vegetables and other types of fresh food products. Literature evidence showed that postharvest fruit losses range from 10% to 40%. Most of the data (Table 2.11) was obtained using surveys and recorded mostly in Asian countries. Only Egypt (Blond, 1984) was found with collective recorded fruit losses in Africa in which interviews were used to obtain the data. Losses at retail, foodservices and consumer level were categorised as, storage losses (occur because of improper storage), preparation losses (mostly seeds and peels), serving losses (that which is left on serving dishes), leftovers (prepared and never served) and plate waste (what the diner leaves on plate) (Engstrom & Carlsson-Kanyama, 2004). High losses in Asian countries were reported to be associated with constrains in collecting and transporting small quantities of produce from numerous small farms and trying to collect these into large quantities for efficient domestic marketing or export (Amorin *et al*., 2008) . Since the produce is collected from several farms, there is high variation in quality that makes it difficult to apply standardised grading and storage procedures (FFTC, 1988). Some of the reports targeted specific links within the supply chain giving a lower value for overall fruit loss. These values could have been high if the whole supply chain was assessed.

Table2.11 Collective postharvest losses of fruits recorded for different countries

Country	Site/ Location assessed	(%)Loss	Method	Reference
USA	Retail , foodservices & consumer	32	Estimate	Kantor *et al*., 1997
Philippines	Shipping	28	Survey	Bautista, 2002
Taiwan	Wholesale & retail	22	Survey	FFTC, 1992
Egypt	From production to consumer	20	interviews	Blond, 1984
Thailand	Shipping	14	Survey	Bautista, 2002
South Korea	Farm to consumer	10	Survey	FFTC, 1988
Brazil	Farm to consumer	10.9-23	sampling	Amorin *et al*., 2008
Vietnam	Farm to consumer	25-40	Survey	Bautista, 2002

Surveys were used in most collective fruit losses assessment because they are rapid in giving results at a large scale considering the number of different types of fruits and the areas to be covered. Most of the objectives for general loss assessment focused on economic losses in which surveys are extensively used. (NAS, 1978; FFTC, 1994; Fehr & Romao, 2000; Murthy *et al*., 2007; Gangwar *et al*., 2007; Barry, *et al*., 2009).

Postharvest losses of specific fruits

Postharvest losses of individual fruit (Table 2.12) can be as high as 100% as reported on papaya in some developing countries (NAS, 1978). Highest recorded losses for banana was 44% in Costa Rica (Arauz & Mora, 1983), orange 22% in Brazil (Caixeta-Filho, 1999), grapes 27% in developing countries (NAS, 1978), papaya 100% in Developing countries (NAS, 1978), and pineapple 28% in Ethiopia (Tadesse, 1991). Papaya, banana and mango being more susceptible to physical damage and pathological attack when ripe tend to have higher losses than other reported fruits. Although pomegranates have a tougher skin, they are more sensitive to extreme heat causing them to scorch and crack leading to losses. Furthermore, they are also vulnerable to insect attack (moth and borer), diseases (black spot), compression and friction injury (Murthy *et al*., 2009).

Table 2.12 Postharvest losses of specific fruits

Produce	% Loss	Country	Reference
Mango	44	Costa Rica	Arauz & Mora, 1983
	36	Pakistan	Malik, 2008
	28	Brazil	Choudhury &,Costa, 2004
	26	Ethiopia	Tadesse, 1991
	26	India	Roy, 1993
Guava	19	Supaul, India	ASET India, 2003
	18	Shaharsa, India	ASET India, 2003
	17	Purnia, India	ASET India, 2003
	15	Bihar, India	ASET India, 2003
Pomegranate	35	India, distant market	Murthy *et al*., 2009
	18	India, co-operative market	Murthy *et al*., 2009

The values reported by NAS (1978) provided the earliest comprehensive review on postharvest food losses, especially in developing countries. However, a review of the global literature did not reveal any major studies on quantification of postharvest losses during the following decade. Thereafter, reports from Ethiopia, Brazil and India (Table 2.12) have records on almost every fruit found in the literature (Tadesse, 1991; Caixeta-Filho, 1999; Jorhat, 2005). Variation of losses of the same fruit between countries was reported as a result of differences in postharvest handling technologies among reported countries.

Table 2.12 Postharvest losses of specific fruits (continue)

Produce	% Loss	Country	Reference
Banana	20-80	Developing countries	NAS, 1978
	18- 46	Kenya	George &,Mwangangi, 1994
	40	Brazil	Caixeta-Filho, 1999
	22	India	Jorhat, 2005
	8.1	Ethiopia	Tadesse, 1991
Orange	43	Libya	Tamzini et al., 1992
	22	Brazil	Caixeta-Filho, 1999
	19	Brazil	Carvallio *et al*., 2003
	14	India	Jorhat, 2005
	13	Albania	Skende *et al*., 1996
	9	Ethiopia	Tadesse, 1991
	6	Italy	Zarba, 1992
Grapes	27	Developing countries	NAS, 1978
	26	Brazil	Caixeta-Filho, 1999
	15	Albania	Skende *et al*., 1996
	14-21	India	Murthy *et al*., 2009
	10	Egypt	Blond, 1984
	4	Ethiopia	Tadesse, 1991
Papaya	44-100	Developing countries	NAS, 1978
	30	Costa Rica	Arauz & Mora, 1983
	12	Ethiopia	Tadesse, 1991
Pineapple	28	Ethiopia	Tadesse, 1991
	23	Brazil	Caixeta-Filho, 1999
	18	Costa Rica	Arauz & Mora, 1983
	8	India	Jorhat, 2005
Lemon	18	Libya	Tamzini *et al*., 1992
	2	Italy	Zarba, 1992
	1	Ethiopia	Tadesse, 1991
Apple	12	Pakistan	Shah *et al*., 2002
	11	Albania	Skende *et al*., 1996
	5	Uk	Berrie, 1989

Differences in physiology and composition which affect the rate of deterioration contribute to the variation of losses between fruit types (Table 2.13). Climacteric fruits can be harvested when mature but before ripening has begun; at this stage they will be more resistant to physical damage (Crisosto, 1994). However, there is a tendency of rough handling during transportation of which the injuries will be pronounced as the fruit ripens. Mechanical injury received by fruits due to pressure thrust during transportation, though not visible, leads to rupturing of inner tissues and cells (Holt & Schoorl, 1982). Such produce degrades faster during natural aging process (Salunkhe, 1984).

Table 2.13 Summary of percentage postharvest losses of specific fruits from table 2.12

PRODUCE	MEAN	RANGE	N^{o} Of Reports Cited
Papaya	37.77	11.50-100.00	3
Mango	32.20	26.00 - 44.30	5
Banana	30.42	8.10 - 80.00	5
Pomegranate	26.88	18.30 - 35.40	2
Orange	22.69	6.00 - 42.50	7
Pineapple	19.50	8.00 - 28.20	4
Grapes	17.20	4.30 - 27.00	6
Guava	17.25	15.00 -19.00	4
Apple	9.43	5.00 - 12.00	3
Lemon	7.16	1.30 - 18.20	3

Postharvest losses of fruits along the supply chain in Africa

African countries lose most of their fruit at farm level (9.62%) and retail level (13.17%), (Table 2.14). Average fruit loss throughout the supply chain was calculated to range from 20.13% to 38.47%. Most of the losses were reported as a result of lack of or inefficient use of cold rooms, transportation in non-refrigerated open trucks and poor packaging (use of bags instead of boxes) (Bechir, 1992). Some of the factors reported to be contributing to the losses included the behaviour of some workers towards the products (such as carelessness), lack of motivation, low salary and ignorance (Bechir, 1992). There is less handling of fruit at wholesale level and holding period is shorter than at farm and retail level therefore wholesalers experience lower losses. Overall losses were also associated with the time and length of different supply chains in which longer supply chains tend to have higher losses.

Table 2.14 Percentage postharvest losses of fruits along the supply chain in Africa

Country	Fruit	Supply Chain Level Farm	Wholesale	Retail	Total	Reference
Egypt	Grape [a]	4.5	2.5	10.0	17.0	Blond, 1984
	Grape [b]	15.1	6.9	6.0	28.0	Blond, 1984
Tunisia	Pear	7.0	5.0-10.0	n/a	12.0-17.0	Bechir, 1992
	Apple	9.8	10.0-15.0	n/a	19.8-24.8	Bechir, 1992
Libya	Orange	13.6	9.2	19.7	42.5	Tamzini *et al*., 1992
	Lemon	7.6	4.3	6.3	18.2	Tamzini *et al*., 1992
Ghana	Mango	6.0	8.0	n/a	14.0	WFLO, 2010
Benin	Orange	9.0	12.0	9.0	30.0	WFLO, 2010
Rwanda	Banana	14.0	36.0	28.0	78.0	WFLO, 2010
Mean		**9.62**	**7.2-8.55**	**13.17**	**28.83-29.94**	

Grape a: Based on interviews

Grape b: Based on sampling

n/a: not available

Methods used to assess losses also tend to have an effect on the real situation such as the case of grape losses in Egypt (Blond, 1984) where two different assessment methods were used. Sampling method indicated that most of the losses occurred at farm level while interviews reported that most of the losses occurred at retail level. However, sampling method is more reliable than interviews/survey in giving a better presentation on what is happening within the supply chain because it involves actual loss measurement rather than approximations by interviewed traders. Bananas had the highest losses reported throughout the supply chain (78%) where most of them were being lost at wholesale level (36%). Incomplete loss assessment like in Tunisia (Bechir, 1992) makes it difficult to give conclusive reports about the supply chain studied. This suggests that although data on losses along the supply chain is very useful, it is also difficult to generate.

Postharvest losses of fruits along the supply chain in Asia

Asian countries lose most of their fruits at retail level (8.28%), (Table 2.15). Average fruit loss throughout the supply chain was calculated to be 18.21%. The major causes of mango losses along the supply chain were fungal diseases and injuries (Murthy *et al*, 2009). Marketing systems portrayed different handling procedures therefore resulting in variable losses as seen for the case of banana in India in which postharvest losses were higher in the wholesale channel (28.84%) than co-operative channel (18.31%) (Murthy *et al*, 2009). Careful loading, better transportation, less number of handling and acceptance of the good quality produce at the time of procurement restricted the losses at the later stage of marketing in co-operative channel.

As the distance between producing areas and consumers increases postharvest losses also increase. This is evident in the case of grapes marketing in India where losses are higher in distant marketing (21.33%) than in local marketing (14.4%) (Murthy *et al*, 2009). Transit losses were due to injuries as a result of vibrations and impact forces. When transfer time becomes long the product will be ripening on transit thereby softening and become more prone to physical damage and pathological attack. Packaging and means of transportation contributed to variation of losses along the supply chain as no systematic packing was practiced in the reported fruits rather for example mango fruits were heaped into the lorries/trucks/tractors during transportation (Murthy *et al*, 2009).

Maturity stage of fruit at harvest also determines transfer and storage quality of the fruit which are directly linked to postharvest losses. Most of the bananas are lost at wholesale and retail due to softening as they ripening thereby becoming more susceptible to mechanical damage and deterioration. Pomegranate losses were reported to be caused by diseases, insect injury, mechanical damage (press and friction injury) and over ripening (Murthy *et al*, 2009).

Table 2.15 Postharvest losses of fruits along the supply chain in Asia

Country	Fruit type	Supply Chain Level			Total	Reference
		Farm	Wholesale	Retail		
India	Orange	5.50	1.20	7.50	14.20	Jorhat, 2003
	Pineapple	2.70	2.66	2.70	8.06	Jorhat, 2003
	Banana	n/a	5.00	7.00	12.00	Jorhat, 2003
	Banana [a]	5.53	6.65	16.66	28.84	Murthy *et al*., 2007
	Banana [b]	7.72	1.22	8.72	17.66	Murthy *et al*., 2007
	Mandarin [a]	2.51	2.30	10.08	15.61	Gangwar *et al*., 2005
	Mandarin [b]	2.51	5.70	13.70	21.91	Gangwar *et al*., 2005
	Mango	15.59	8.89	5.25	29.73	Murthy *et al*., 2009
	Grapes [a]	7.31	4.24	2.85	14.4	Murthy *et al*., 2009
	Grapes [b]	7.31	10.80	3.22	21.33	Murthy *et al*., 2009
	Pomegranate	9.86	10.10	15.48	35.44	Murthy *et al*., 2009
Taiwan	Papaya	2.00	7.00	14.00	23.00	Liu & Ma, 1983
	Banana	n/a	3.00	7.00	10.00	Liu & Ma, 1983
	Carambola	2.00	6.00	7.00	15.00	Liu & Ma,1983
	Apple	2.00	1.00	3.00	6.00	Liu & Ma, 1983
Mean		**5.58**	**5.05**	**3.00**	**6.00**	

Banana a: losses recorded in the wholesale channel marketing system in Karnataka

Banana b: losses recorded in the cooperative channel marketing system in Karnataka

Kinnow Mandarin a: Losses recorded in Delhi

Kinnow Mandarin b: Losses recorded in Bangalore

Grape a: Local marketing

Grape [b]: Distance marketing

n/a: not available

Conclusion and future prospects

This review has shown that the problem of postharvest losses remains a major obstacle in addressing sustainable food and nutritional security as well as reducing the profitability of agribusiness through lost income. Consequently, reducing postharvest losses provides a plausible and additional instrument in the global fight against food and nutritional insecurity, especially in developing and transition countries. The complexity and urgency of three grand challenges facing humanity in the 21st Century (climate change, sustainable energy supply, and sustainable food supply) require a multidisciplinary and integrated approach. The huge impact of agriculture and the global food system on each of these grand challenges assures a future for postharvest food losses as the often neglected dimension in addressing these challenges. To guide both policy and development of interventions to reduce food losses, there is a need for reliable and accurate data on the incidence and amount of losses under specific conditions. Methodologies for studying postharvest losses need to be refined and standardised so that different studies can give comparable data. Further studies are also needed to quantify the cost-benefits and wider economic impacts of technological interventions to reduce postharvest food losses.

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CHAPTER 3

Postharvest losses and changes in physico-chemical properties of fruit at retail and post-purchase storage: case study of 'yellow clingstone' peach *(Prunus persica)*

Summary

Yellow clingstone peaches were purchased from three different retail outlets in Stellenbosch (South Africa) and assessed for incidence of physical losses, downgrading, and changes in physico-chemical properties during storage in ambient (23 – 26 C, 55% RH) and optimum (0 C, 95% RH) conditions to simulate consumer post-purchase practices. Physical damage due to abrasion and compression injuries was identified as the primary cause of physical losses at retail and consumer storage. The average physical loss of 18.09% at retail level was equivalent to a loss of 7240 tons worth R96.87 million per annum at national level. About 37.43% of fruit was downgraded at retail due to minor physical damages, uneven skin colour and shrivel. The average physical loss after two days of storage was 57.85% and 18.91% at ambient and optimum storage conditions, respectively. Furthermore, the average cumulative weight loss under ambient and refrigerated conditions after two days was 6.44% and 0.85% respectively. There was no significant difference in ascorbic acid of peaches from different retail stored while there was a decrease by 22.5% and 10.42% under ambient and refrigerated conditions respectively, after two days. Extending the storage period to seven days led to 53.13% and 16.67% loss in ascorbic acid under ambient and refrigerated conditions, respectively. Maturity indices increased by 98% under ambient condition and 36% under refrigeration after seven days. The energy wasted to produce lost fruits at retail was 27.35 x 10^6 MJ. GHG emission of lost peaches at retail was 2.41 tons CO_{2eq} while emissions due to losses during storage under ambient and refrigerated conditions were 7.69 tons and 2.51 tons CO_{2eq} respectively. The environmental and resource impacts of postharvest fruit losses differed among the three retails outlets.

Introduction

Peach *(Prunus persica)* is the third most important crop after apple and pear grown in the temperate zone of the world (Gupta *et al*., 2011). Global annual peach production is about 10 million tonnes, and South Africa is ranked number 15 in the world in terms of production and export (Fideghelii *et al*., 1998; DAFF, 2008). Peaches contributed 11% of the total deciduous fruit grown in South Africa in 2008 in which between 70% and 80% was absorbed by processing market while the rest went to local market sales and dried market segment. Only a small percentage of peaches (3-5%) are being exported from South Africa as fresh fruit (DAFF, 2008). The main producing areas are in Western Cape Province which includes Little Karoo, Wolseley and Ceres. Approximately 40 000 tons of peaches were sold at local market in 2008 with an average price of 6 000 Rand.Ton^{-1}. Direct employment within the industry was estimated at 110 217 people with 40 886 dependents (DAFF, 2008). The total peach production area in 2008 was 8 490 ha yielding 175 000 tons in which the Western Cape Province contributed more than half of the output (DAFF, 2008).

The average green, blue and grey water foot print of peach production in South Africa is 512, 460 and 57 cubic meters per ton, respectively (Mekonnen & Hoekstra, 2011). Gonzalez *et al* (2011) estimated the average GHG emission and energy for fruit production and transporting the fruit to the market to be 0.33 $KgCO_{2eq.}Kg^{-1}$ and 3.88 $MJ.kg^{-1}$ fruit, respectively. Incidence of fruit losses, therefore, implies wastage of resources and environmental damage proportional to amount of losses.

The main problems linked to peach industry are: low fruit quality, high production costs, international competition and overproduction (Fideghelii *et al*., 1998). South African peaches are harvested in summer when the temperature is high and atmospheric humidity is low, therefore losses are expected to occur. Under these conditions, fruit cannot be stored longer under ambient temperatures which are associated with high levels of water loss and rapid respiration (Gupta *et al*., 2011). High temperatures are associated with biological damage from the action of parasites, enzymatic effects (Khan & Singh, 2007) and microbes such as *Monilinia fruticola* and *Penicillium expansum,* causing brown rot, blue or grey mould (Guijarro *et al*., 2007). The soft thin skin of peaches makes them susceptible to mechanical damage which affects the physico-chemical quality of the fruit, market value and shelf life (Rodriguez *et al*., 1999; Gupta *et al*., 2011). The optimal storage temperature for peaches ranges from -1 ºC to 2 ºC and the mean life expected under these conditions ranges from two to four weeks (ISO, 1980; Rodriguez *et al*., 1999, PNP, 2010).

The peach is climacteric fruit which has its ripening controlled by ethylene, a hormone which produces physico-chemical modifications (Grierson, 1987; Cascales et al., 2005) that govern the sensory changes in colour, odour, flavour and texture related to consumer acceptance (Biale & Young, 1981; Cascales *et al*., 2005). Producers usually harvest the fruit at lower maturity to withstand the rigors of postharvest handling and distribution (Crisosto, 1992; Cascales *et al*., 2011), however, the result has often been negative because such fruit are more susceptible to shrivel and development of browning disorders. Lack of flavour and firmness due to early harvesting (Bruhn *et al*., 2007; Cascales *et al*., 2005) along with the presence of off-flavours and flesh browning (Von Mollendorff *et al*., 1992) have been identified as main consumer complaints.

Peaches are low in calories and a good source of potassium, vitamin A (yellow flesh type) and ascorbic acid (Adams, 1975; Bruhn *et al*., 2007). Considering this composition, peaches can play a vital role in addressing the problem of micronutrient deficiencies. However, losses of micronutrients due to improper postharvest procedures will have a negative impact on the role of peaches in nutrition security. It was reported that fresh peaches contain 87.7% moisture, 0.7% protein, 0.1% lipids, 11% carbohydrates and 0.6% fibre (Romani & Jennings, 1971; USDA, 1982).

Loss assessment together with studies in physico-chemical properties are essential in adaptation and design of various handling, packaging, storage and transportation systems (Singh *et al*., 2005) to reduce the losses and preserve fruit quality. Therefore, the objective of this study was to assess postharvest losses of peaches at the retail level and during post-purchase storage. The specific aims were to; (i) estimate the incidence of fruit postharvest physical losses and downgrading, (ii) quantify the changes in physico-chemical properties related to quality during storage, and (iii) estimate the economic and environmental impacts of the losses.

Materials and methods

Plant material

Three different major retail outlets were selected based on volume of fruit sales and observed difference in handling procedures. The outlets represented different handling systems and supply chains in Stellenbosch South Africa. Outlet 1 and outlet 2 were supermarkets where ambient shelf temperature was controlled by air conditioners. However, both outlets had a refrigerated facility to store fruit off the shelf before display. Retail outlet 3 was an open market where the fruit was displayed cartons under a shaded area and unsold fruit carried back to the vendors' home for non-refrigerated storage. 'Yellow Clingstone' peaches were purchased from the 3 retail outlets during summer season (February 2011). A total of 360 fruits was randomly selected from each store and transported inside a truck to the Postharvest Technology Research Laboratory at Stellenbosch University, about 2 kilometres from the market.

Experimental design

Fruit from each outlet were randomly distributed among three lots each consisting of three sub-lots of 40 fruits as replicates. The first lot was analysed for external quality and physico-chemical properties on the day of arrival at the laboratory (day zero) representing retail quality and losses (Fig 3.1). The remaining two lots were each stored at ambient condition (23 – 26 ºC, 55% RH) and optimum cold storage (0 ºC, 95% RH) for seven days simulating the post-purchase storage practices of consumers. Fruit was assessed for external quality and physico-chemical changes during storage (Fig 3.1). Samples of 10 fruits free from defects were selected from each treatment (storage condition) for physico-chemical analysis. Each fruit was measured for colour and flesh firmness. Samples were divided into two replicates of five fruits each and blended to determine the following parameters; total soluble solids (TSS), titratable acidity (TA), carotenoids content and ascorbic acid. Homogenate from each replicate was freeze dried and stored at -80°C until required for proximate analysis. A sample of 10 fruits from each shop was used to determine weight loss in each storage condition.

Environmental conditions

The environmental conditions inside and outside retail outlets were captured using Tinytag Explorer temperature (-25 – 50 °C) and relative humidity (0 - 100%) loggers (Gemini data loggers, UK).

Postharvest losses and environmental impact

The number of fruit found to be defective in each sub-lot (40 fruits) was expressed as a percentage. The average percentage defective fruits of the three sub-lots were used to represent the whole lot. National physical loss was estimated by expressing the percentage physical loss as a fraction of amount of fruit supplied to the local fresh market while economic loss was the monetary value of the computed losses according to respective retail prices. Physical loss was used to compute the impact of losses on environment and resources (Mekonnen & Hoekstra, 2011; Gonzalez *et al*, 2011).

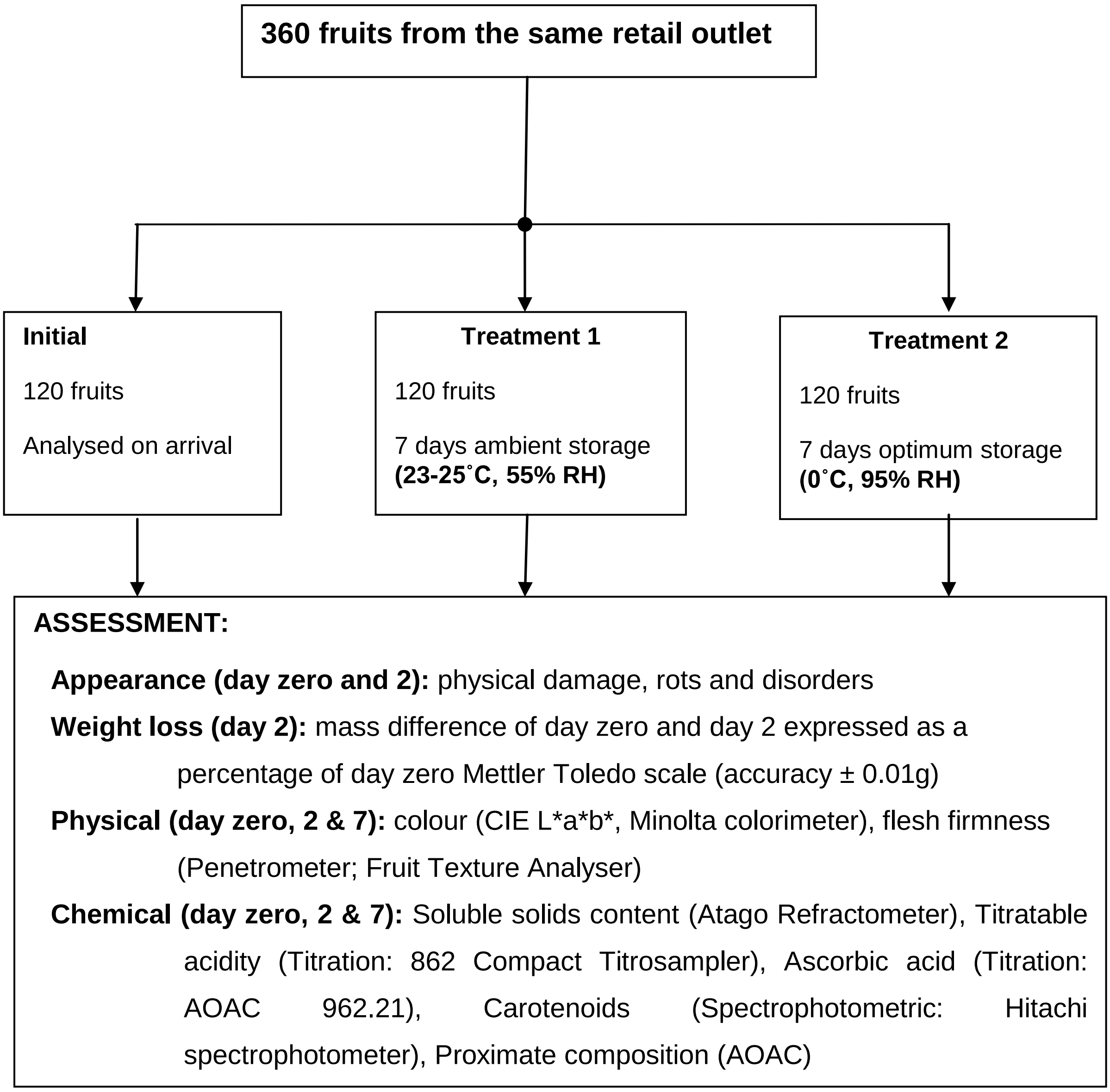

Figure 3.1 Experimental design for quality assessment and physico-chemical assessment of Yellow clingstone peaches

Proximate composition analysis

Freeze dried samples were used for analysis. Moisture was determined by desiccation at 105 C to constant mass (James, 1996). Ashing was performed at 520 C in a muffle furnace (AOAC, 2000). Nitrogen content was obtained by applying the Kjeldahl method 960.52 (AOAC, 2000) and protein concentration calculated using a nitrogen factor of 6.25. Total dietary fibre was determined using Non-enzymatic-Gravimetric method 993.21 (AOAC, 2005). Crude fat content was determined by extraction using petroleum ether in a Soxhlet Extractor at 90 C and carbohydrates calculated by difference (James, 1996). Energy was calculated using Atwater factors: fat 37 $kJ.g^{-1}$ (9 $kcal.g^{-1}$), protein and carbohydrates 17 $kJ.g^{-1}$ (4 $kcal.g^{-1}$) (Uusitalo *et al*., 2011).

Chemical analysis

Ascorbic acid content was measured using the titration method involving 2, 6-dichloroindophenol (AOAC method 967.21, 2000). Carotenoids were extracted from the homogenate using hexane-acetone mixture (3:2) and measurements of the absorbance of the extract at 450 nm and 520 nm were done using in Hitachi spectrophotometer (Helios Omega UV-Vis, Thermo Scientific, USA). Results were expressed in microgram total carotenoids and lycopene per gram fresh weight (Opiyo & Ying, 2005). Acidity was determined by titration of 2 ml of the fruit juice with 0.1M sodium hydroxide solution up to pH 8.2 using 862 Compact Titrosampler (Metrohm, Herisau, Switzerland). Results were expressed as percentage of malic acid in fresh material. Total soluble solids results were expressed in ^{0}Brix (%), measured using a digital refractometer (Atago, Tokyo, Japan). The maturity index (MI) was calculated as TSS to TA ratio.

Colour and flesh firmness

Fruit colour was measured twice on both sides of the fruit using a Minolta colorimeter (model CR-200; Minolta Co. Ltd, Osaka, Japan) after standardising the sensor with a white and black tile (Y=94; *x*= 0.13; *y*= 0.321). The measured colour was expressed as L* (lightness and darkness), a* (redness and greenness), b* (yellowness and blueness). Hunter colour parameters C (chroma) and hue angle were calculated from a* and b* values according to McGuire's suggestion (1992). Fruit firmness was determined using Fruit Texture Analysers (Guss, Strand, Western Cape, South Africa) on both sides of the fruit, after skin removal, and penetrating the pulp to depth of 8 mm, with a standard 0.5 cm^2 cylindrical probe recommended for use with peaches (Planton, 1996).

Statistical analysis

One way analysis of variance (ANOVA) was applied to data using SAS version 9.1 (SAS Institute, 2006). Means were separated using the Fishers test (α=0.05).

Results and discussion

Environmental conditions

The captured data on environmental conditions (Table 3.1) indicated that all three retail outlets displayed fruit under ambient conditions (21 – 32 ºC, 42 – 75% RH). However, a temperature range of 20 – 26 ºC and 60 – 75 % (PNP, 2010) relative humidity is recommended for ambient shelf conditions for peaches. Furthermore, optimum refrigeration temperature for peaches is -1 to 2 ºC and 95% relative humidity (ISO, 1980; Rodriguez *et al*., 1999, PNP, 2010). Shelf temperature within outlet 1 (Table 3.1) was falls within normal ripening temperature (15 – 27 ºC) (Mitchell *et al*., 1991) while shelf temperature within outlet 2 and 3 was within abnormal ripening temperature range (28 – 36 ºC) (Mitchell *et al*., 1991).

Table 3.1 Air temperature and relative humidity outside and inside the retail outlets

Retail outlet	Temperature (ºC)		Relative Humidity (%)	
	Inside	Outside	Inside	Outside
Outlet 1	21	28	75	50
Outlet 2	29	38	49	37
Outlet 3	32	32	42	40

Physical loss at retail

Physical losses among outlets (Table 3.2) ranged from 10.83% to 29.16% with an average of 18.09%. Losses were due to rots and physical damage. Fruit classified as rotten showed early stages of microbial attack which made them not safe for human consumption. Fruit damage observed were associated with compression and abrasion injuries which could be attributed to poor packaging, rough handling or vibration forces during transportation. The incidence of physical damage of fruit among Retail outlets ranged from 6.15% to 8.33%. In comparison, Amorim *et al* (2008) reported incidences of peaches collected from wholesale market with postharvest and pre-harvest mechanical injuries of 12.6% and 14.5%, respectively. In the USA, the incidence of postharvest injuries in peaches ranged from 2.3% at the New York wholesale market (Ceponis & Butterfield, 1973) to 12.3% in Chicago wholesale market (Cappellin & Ceponis, 1984). However, postharvest damage is a cumulative process therefore the number of injuries is expected to be smaller at wholesale market than at retail or consumer due to shorter time at wholesale market than at retail and consumer (Thompson & Crisosto, 2002). Visual appearance of the fruit indicated that fruit from retail outlet 3 were riper than fruit from other outlets. The differences in ripeness could have contributed to variations in losses. Ripe fruit are softer than unripe or partially ripe fruit thereby being more prone to physical damage and fungal infection.

The incidence of rot fruit among outlets ranged from 1.67 % to 18.78 %. Fruit from outlet 3 had the highest physical losses recorded mainly due to microbial spoilage. Decay is related to physical damage that exposes the fruit to fungal invasion which is more prevalent under high temperatures. However, rots incidences depend on the inoculums of the spoilage microbes which are closely related to sanitation procedure and cold chain management. Amorim *et al.* (2008) reported a correlation between postharvest mechanical injuries and disease incidence in which they recorded 2.5% and 4.5% of diseased peaches from Sao Paulo wholesale market in 2003 and 2004, respectively. Fruit from retail outlet 3 displayed on open air were more exposed to the spoilage microbes than fruit from other outlets leading to high incidence of microbial spoilage. The results indicated that the supply chain for retail outlet 3 was experiencing the most losses, while retail outlet 2 had the least.

The average physical loss of 18.09% at retail level resulted in estimated national annual loss in fresh peaches of 7 240 tons in South Africa. Considering the recommended 146 kg per capita consumption of fruit and vegetables per year (WHO, 2004), the magnitude of postharvest losses of peach at retail alone is sufficient to meet the annual fruit intake of approximately 50 000 people.

Table 3.2 Mean percentage downgrade and physical losses of peach fruit at retail level and post-purchase storage

CLASS	DEFECT	DAY ZERO			DAY 2 (Ambient)			DAY 2 (Optimum)		
		Outlet 1	**Outlet 2**	**Outlet 3**	**Outlet 1**	**Outlet 2**	**Outlet 3**	**Outlet 1**	**Outlet 2**	**Outlet 3**
DOWNGRADE	Minor physical damage	22.76	25.00	17.07	14.17	13.33	4.17	20.31	11.10	21.53
	Uneven Skin Colour	10.06	13.33	24.05	0.00	11.67	0.00	0.00	0.00	0.00
	Shrivelled	0.00	0.00	0.00	4.17	0.00	1.69	3.33	5.83	1.08
PHYSICAL LOSS	Rots/ Decay	6.10	1.67	18.78	39.17	21.67	82.34	6.67	1.67	10.32
	Severe Physical Damage	9.19	8.33	6.15	6.67	3.33	0.00	9.30	9.43	8.06
	Shrivelled not edible	0.00	0.83	0.00	0.00	0.00	0.00	0.00	0.00	6.80
	Weight loss	0.00	0.00	0.00	3.93	6.37	9.02	1.11	0.59	0.86
DOWNGRADE		**32.82**	**38.33**	**41.13**	**18.33**	**25.00**	**5.86**	**23.64**	**16.93**	**22.60**
PHYSICAL LOSS		**14.27**	**10.83**	**29.16**	**49.59**	**30.01**	**93.97**	**17.38**	**13.53**	**25.85**

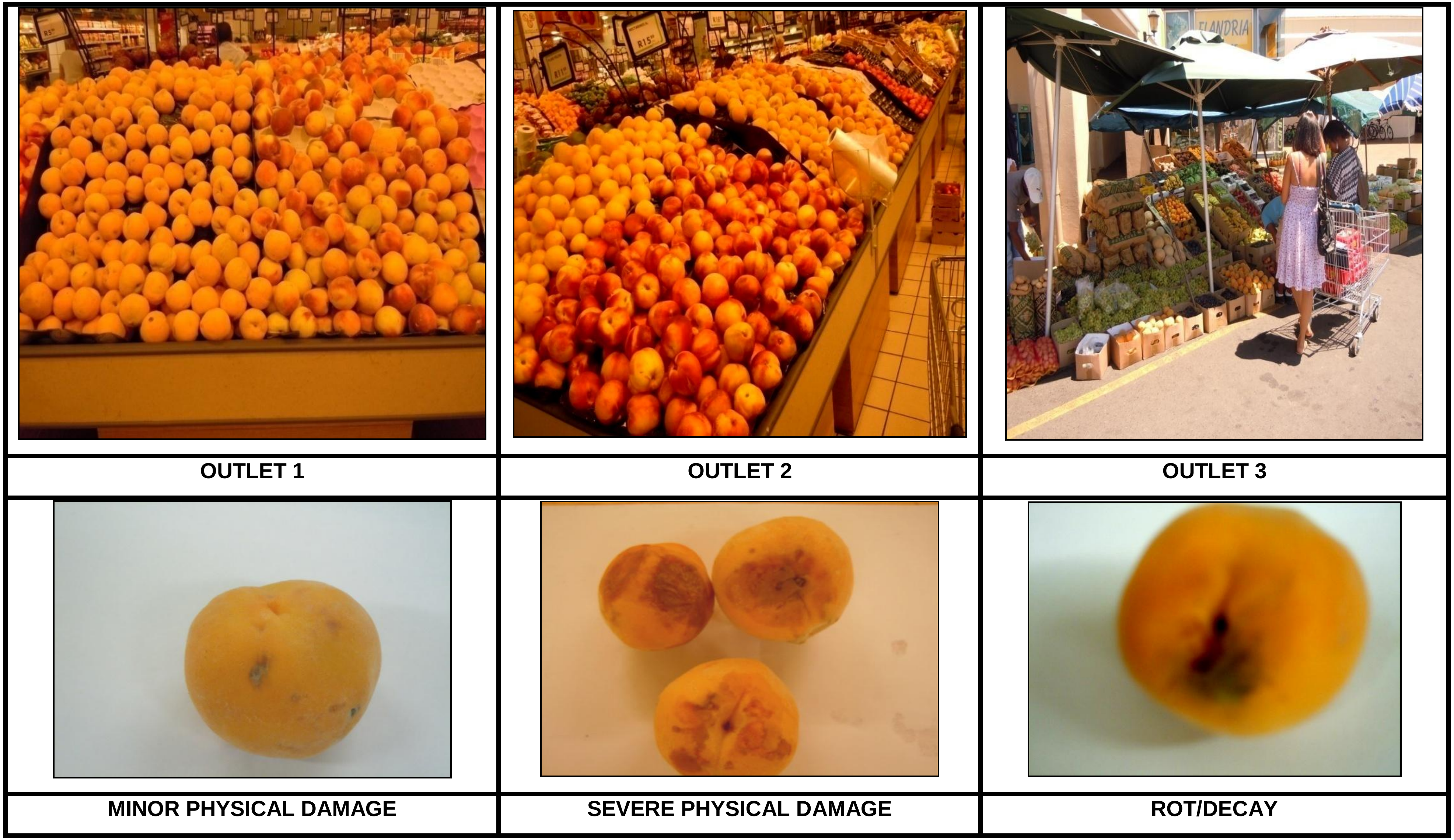

Figure 3.2 Photographs of representatives of retail outlets and peach defects used to categorise fruit into physical loss and downgrade

Physical loss during consumer storage

Physical losses (Table 3.2) during post purchase storage were related to fruit quality at retail level. Fruit from retail outlet 3 with the highest physical losses at retail level had the highest losses recorded during storage. Losses increased more than three times under ambient conditions in relation to initial losses at retail level. Contrastingly, there was a slight increase in physical losses under refrigerated condition due to weight loss. Losses under ambient condition after two days ranged from 30.01% to 93.97% with an average of 57.85%, while under refrigeration ranged from 13.53% to 25.85% with an average of 18.92%. Additionally, losses under ambient condition were almost three times more than under refrigeration. Physical losses under ambient condition were mainly due to rots while under refrigeration severe physical damage contributed to most of the losses. The increase in the percentage of rots under ambient conditions implies that the conditions promoted proliferation of spoilage microbes in which injured fruit were invaded (LaRue & Johnson, 1989). Furthermore, ambient temperature accelerates the ripening process making the fruit soft and more susceptible to microbial invasion (LaRue & Johnson, 1989) while low temperatures are associated with low ethylene and carbon dioxide production and climacteric respiration is delayed (Rodriguez *et al*., 1999). Ethylene from injured fruit can initiate ripening and flesh softening of surrounding healthy fruit, making them more susceptible to microbial attack (LaRue & Johnson, 1989). Further deterioration of fruit with minor injuries stored under ambient condition made them classified as severely injured and not fit for consumption.

Downgrade at retail and consumer level

The common downgrading defects (Table 3.2) at retail and consumers storage were minor physical damage and uneven skin colour while shrivelling was only identified during post-purchase storage. Minor injuries observed were scratches, small punctures and bruises. These injuries could have been caused by poor packaging, rough handling by fruit handlers or friction as fruit brush against each other and the walls of cartoons. Downgraded fruit at retail level ranged from 32.82% to 41.13% with an average of 37.43%. Downgraded fruit at retail level stay on the shelf longer due to discrimination by customers. Most of the injured fruit under ambient conditions deteriorated and become not fit for human consumption. Contrastingly, a few injured fruit deteriorated under optimum conditions. The presence of more downgraded fruit under refrigeration than ambient storage condition suggests that optimum conditions retards further deterioration of injured fruit while ambient condition accelerates the rate of deterioration. Downgrade under ambient condition ranged from 5.86% to 25% with an average of 16.4%, while under refrigeration ranged from 16.93% to 23.64% with an average of 35.18%.

Chemical changes

The number of defect free fruits from retail outlet 3 stored at ambient condition after two days could not make a representative sample to be used due to rots and decay. No chemical analysis was done for fruit from retail outlet 3 stored under ambient condition.

There were no significant differences (P>0.05) in ascorbic acid between fruit from all retail outlets at retail level (day zero) (Table 3.3). The measured ascorbic acid ranged from 13.75 mg to 20 mg with an average of 16.67 mg.100g^{-1} edible portion. With the average ascorbic acid of 16.67 mg.100g^{-1} edible portion it can be estimated that 7 240 tons of physical loss contained 1 236 kg of ascorbic acid which could benefit a significant number of people (about 69 000 people) with recommended 50 mg per day for a year.

There was no significant change (P>0.05) in ascorbic acid of fruit stored under optimum conditions after seven days. Fruit from retail outlet 3 stored under ambient conditions showed a decrease in ascorbic acid after two days while fruit from outlet 1 and 2 had a decrease in ascorbic acid observed after seven days. Decrease in ascorbic acid under ambient condition ranged from 2.17% to 52.63% with an average of 22.5% after two days while under refrigerated condition ranged from 7.61% to 14.47% with an average of 10.42% after two days. Extending the storage period to seven days led to a decrease in ascorbic acid ranging from 51.08% to 58.33% with an average of 53.13% under ambient condition and13.04% to 21.05% with an average of 16.67% under refrigeration. The decrease in ascorbic acid could be due to senescence and deterioration of fruit (Rodriguez *et al*., 1999). Fruit from retail outlet 3 had the highest percentage decrease in ascorbic acid under all storage conditions.

There was a significant difference in both TSS and TA of fruit from different retail outlets (Table 3.3). TSS of peaches at retail level ranged from 12.3% to 15.74% while TA ranged from 0.43% to 0.53% and MI ranged from 27.14 to 30.85. There was a significant decrease in TSS and TA of all fruits under all storage conditions. However, no significant (P>0.05) change in MI of fruit from retail outlet 1

Table 3.4 Chemical parameters of yellow clingstone peaches at retail and during consumer storage (mean ± standard deviation)

Sample	Temperature (^{0}C)	Time (Days)	Ascorbic acid (mg.100g^{-1})	Total Carotenoids (µg.g^{-1})	Lycopene (µg.g^{-1})	TSS (%)	TA (% Malic)	MI (TSS:TA)
Outlet 1		0	13.75 ± 3.23 ^{ab}	401.73 ± 47.82 ^{e}	225.58 ± 34.36 ^{abc}	15.74 ± 0.15 ^{ab}	0.58 ± 0.04 ^{a}	27.14 ± 2.19^{gh}
	0	2	11.25 ± 4.81 ^{abc}	482.00 ± 109.13 ^{de}	260.62 ± 82.18 ^{abc}	14.70 ± 0.00 ^{cd}	0.45 ± 0.01 ^{bc}	32.67 ± 0.73^{fg}
		7	10.00 ± 5.00^{abcd}	583.60 ± 234.6^{bcde}	246.39 ± 96.84 ^{ab}	14.73 ± 0.06 ^{c}	0.47 ± 0.02 ^{b}	31.35 ± .34^{fgh}
	23-26	2	10.55 ± 4.67^{abcd}	465.10 ± 171.71 ^{cde}	221.60 ± 135.14^{abc}	15.50 ± 0.10 ^{b}	0.36 ± 0.05 ^{de}	43.46 ± 6.97 ^{cd}
		7	6.25 ± 3.13 ^{d}	788.23 ± 281.28 ^{ab}	310.04 ± 110.10^{abc}	16.10 ± 0.10 ^{a}	0.25 ± 0.01^{gh}	63.55 ± 3.00 ^{a}
Outlet 2		0	20.00 ± 10.72 ^{a}	355.60 ± 106.85 ^{e}	151.74 ± 73.41 ^{c}	12.30 ± 0.95 ^{f}	0.45 ± 0.01 ^{bc}	27.33 ± 1.58^{gh}
	0	2	18.75 ± 6.25 ^{a}	419.10 ± 193.44 ^{de}	221.13 ± 149.39 ^{abc}	14.27 ± 0.06 ^{d}	0.53 ± 0.04 ^{a}	26.92 ± 1.78^{h}
		7	16.67 ± 1.80 ^{a}	514.53 ± 72.13 ^{de}	276.22 ± 62.15^{abc}	13.47 ± 0.06 ^{e}	0.44 ± 0.07 ^{bc}	30.84 ± 4.91^{fgh}
	23-26	2	17.71 ± 3.61 ^{a}	512.73 ± 152.69^{bcde}	153.04 ± 79.99 ^{bc}	12.20 ± 0.00 ^{f}	0.40 ± 0.01 ^{cd}	30.76 ± 0.88^{fgh}
		7	9.38 ± 3.13^{bcd}	694.20 ± 272.85^{abcd}	286.73 ± 125.85^{abc}	13.43 ± 0.06 ^{e}	0.27 ± 0.04^{fgh}	49.15 ± 6.14^{bc}
Outlet 3		0	19.17 ± 9.17 ^{ab}	697.60 ± 244.36 ^{cde}	243.75 ± 96.36 ^{abc}	13.27 ± 0.06 ^{e}	0.43 ± 0.03 ^{bc}	30.85 ± 1.98^{fgh}
	0	2	19.17 ± 9.17 ^{abc}	707.26 ± 195.83 ^{de}	282.94 ± 99.61 ^{abc}	11.67 ± 0.06 ^{g}	0.30 ± 0.01^{fg}	38.89 ± 1.13 ^{de}
		7	12.50 ± 3.13^{abcd}	895.77 ± 265.48 ^{a}	315.39 ± 112.90 ^{abc}	12.63 ± 0.06 ^{f}	0.24 ± 0.02 ^{h}	53.38 ± 3.77 ^{b}
	23-26	2	13.54 ± 4.77 ^{cd}	817.47 ± 118.26 ^{abc}	347.36 ± 91.39 ^{abc}	11.23 ± 0.06 ^{g}	0.31 ± 0.01 ^{ef}	35.85 ± 1.27^{ef}

Means of parameters in the same column followed by different letter are significantly different ($P<0.05$)

and 2 stored under refrigeration while the rest of the fruits showed an increase in MI. Furthermore, the average increase in MI after seven days was 98.8% and 36.05% under ambient and refrigeration, respectively. MI is an important quality factor which explains the balance between sour and sweetness in which higher values are associated with preferred palate (Mitchell *et al*., 1991; Chen *et al*., 2007). The average measured total carotenoids content (Table 3.3) of peaches at retail level was 484.33 µg per 100g fresh weight of edible portion. The average measured lycopene content at retail level was 207.02 µg.100g^{-1}. Fruit from all outlets did not differ (P>0.05) in total carotenoid and lycopene content at retail level.

There was no significant change (P>0.05) in total carotenoid and lycopene content of all fruit from retail outlet 1 and 2 stored under optimum conditions. There was significant increase in total carotenoid of fruit from outlet 3 stored under ambient conditions after 2 days which did not change after 7 days. However, fruit from outlet 1 stored under ambient conditions showed an increase in total carotenoid only after 7days while there was no significant change for fruit from outlet 2. Carotenoids were reported to be very stable and remain intact in fruit tissues even when extensive senescence has occurred (LaRue & Johnson, 1989). However, total carotenoid content increase as the fruit matures (Cascales *et al*., 2005) therefore; the increase observed could imply further maturing of the fruit during storage.

Proximate composition

There was a significant difference (P<0.05) in protein content (Table 3.4) between fruit from all 3 retail outlets at retail level (day zero). However, no significant difference (P>0.05) was observed in the rest of the measured proximate composition parameters of the fruits. The average approximate composition of Yellow Clingstone at retail level was; 85% moisture, 2.5 g protein, 0.05 g crude fat, 1.5 g ash, 1.13g dietary fibre, 10.95g carbohydrates and 202.33 kJ energy per 100 gram edible portion. The significant decrease in moisture content of fruits from all shops could have led to the increase in energy, dietary fibre and carbohydrates content of the fruit due to concentration. Rodriguez *et al* (1999) reported some changes in protein and dietary fibre of peaches stored at 10-12 ºC which were considered not significant. Physical loss of peaches implies loss of the nutrients that could have benefited consumers. For example, the estimated physical loss of 7 240 tons would have provided with 1.5 x10^{10} KJ which could have benefited over 4 700 adults with at least 8400 KJ per day for one year.

Table 3.4 Proximate composition of yellow clingstone peach fruit at retail (day zero) and after storage at 0 C (mean ± standard deviation).

	DAY 0			DAY 7		
	Outlet 1	Outlet 2	Outlet 3	Outlet 1	Outlet 2	Outlet 3
Energy ($kJ.100g^{-1}$)	222.94 ± 14.29 ^{c}	192.55 ± 0.29 ^{c}	191.49 ± 6.08 ^{c}	342.57 ± 11.54^{b}	330.10 ± 42.29^{b}	436.97 ± 14.28^{a}
Energy ($kcal.100g^{-1}$)	53.15 ± 3.41^{c}	45.90 ± 0.07^{c}	45.65 ± 1.45 ^{c}	81.67 ± 2.75 ^{b}	78.70 ± 10.08 ^{b}	104.18 ± 3.41 ^{a}
Water ($g.100g^{-1}$)	83.75 ± 0.81 ^{a}	85.63 ± 0.01 ^{a}	85.63 ± 0.18 ^{a}	76.48 ± 0.81 ^{b}	77.08 ± 2.7^{b}	69.22 ± 0.68 ^{c}
Protein ($g.100g^{-1}$)	1.87 ± 0.09 ^{c}	1.69 ± 0.08^{b}	1.94 ± 0.11 ^{a}	1.64 ± 0.07 ^{d}	1.66 ± 0.04 ^{b}	1.93 ± 0.10 ^{a}
Crude Fat ($g.100g^{-1}$)	0.06 ± 0.02 ^{a}	0.03 ± 0.02 ^{b}	0.05 ± 0.01^{ab}	0.07 ± 0.02 ^{a}	0.04 ± 0.01^{ab}	0.05 ± 0.02^{ab}
Ash ($g.100g^{-1}$)	9.66 ± 0.99^{abc}	9.83 ± 0.37^{abc}	10.56 ± 3.99^{ab}	5.43 ± 0.53 ^{c}	6.67 ± 0.82^{bc}	12.02 ± 1.86 ^{a}
Dietary Fibre ($g.100g^{-1}$)	1.02 ± 0.06 ^{c}	1.01 ± 0.16^{c}	1.08 ± 0.08 ^{c}	2.34 ± 0.50 ^{a}	2.22 ± 0.26^{c}	1.57 ± 0.17 ^{c}
Carbohydrates ($g.100g^{-1}$)	12.87 ± 1.06 ^{c}	10.16 ± 0.14 ^{c}	9.83 ± 0.30 ^{c}	20.99 ± 0.79 ^{b}	20.22 ± 2.80 ^{b}	27.03 ± 0.86 ^{a}

Means of parameters in the same column followed by different letter are significantly different ($P<0.05$)

Colour changes

Colour is one of the most important parameter used by consumers to judge fruit quality therefore; fruit with less appealing colour will stay longer on shelf before being bought increasing the chances of losses (Cascales *et al.,* 2005). Based on the colour parameters measured, fruit from retail outlet 2 had a significantly lighter (L*), more yellow (b*) and intense (C*) colour than fruit from outlet 1 and 3 which did not differ. However, there was no significant difference (P>0.05) in a* values (redness) and hue angle of peaches from all outlets at retail level (Table 3.5).

There was no significant change (P>0.05) in colour intensity of fruit from retail outlet 1 under all conditions after 7 days while yellowness and hue angle decreased after 7 days. However, redness decreased under optimum conditions while increasing under ambient conditions (Table 3.5). Although there was no significant change in lightness of fruit under optimum conditions, there was a decrease under ambient conditions. The decrease in yellowness of the fruit under optimum condition was observed after 2 days which did not change as storage period was extended to 7 days while under ambient condition no change was observed after 2 days and the decrease was only noticed after 7 days. There was a slight increase in lightness of the fruit under optimum condition after 2 days which later decreased after 7 days to be the same as the initial measurement.

Fruit from retail outlet 2 showed a significant decrease in yellowness, intensity and hue angle under all conditions after 7 days (Table 3.5). However, redness decreased under optimum conditions while increasing under ambient conditions after 7 days. There was no significant change in lightness observed for fruit under optimum condition while there was a decrease under ambient condition after 7 days. Although there was no significant change in redness of the fruit under all conditions after 2 days, the decrease was noticed only after 7 days. The decrease in yellowness of the fruit under ambient conditions and intensity under all conditions was only noticed after 2 days but did not change as storage period was extended to 7 days.

There was no sample for fruit from retail outlet 3 available for colour measurements after 2 days under ambient condition. Fruit stored under optimum condition showed no significant change in redness, yellowness, intensity and hue angle while lightness increased after 7 days. The change in lightness was only observed after 2 days which remained constant as storage period was extended to 7 days. The decrease in hue angle suggests evolution of colour towards orangey colour associated with synthesis of new carotenoids (Kader *et al*., 1982).

Table 3.5 Colour parameters of yellow clingstone peaches at retail and during post purchase storage (mean ± standard deviation)

Source	Temperature (°C)	Time (Days)	L^*	a^*	b^*	C	h^o
Outlet 1		0	$63.02{\pm}1.45^{de}$	$15.59{\pm}2.53^{c}$	$54.79{\pm}2.45^{b}$	$57.00{\pm}2.77^{b}$	$74.17{\pm}2.19^{c}$
	0	2	$65.08{\pm}3.30^{bc}$	$9.37{\pm}2.54^{f}$	$50.74{\pm}4.39^{ed}$	$51.64{\pm}4.52^{d}$	$79.59{\pm}2.61^{a}$
		7	$63.41{\pm}2.68^{cd}$	$13.55{\pm}2.65^{d}$	$49.85{\pm}5.10^{e}$	$51.70{\pm}5.33^{d}$	$74.80{\pm}2.31^{c}$
	23-26	2	$63.35{\pm}1.92^{cd}$	$18.06{\pm}1.26^{b}$	$52.89{\pm}2.62^{bcd}$	$55.90{\pm}2.66^{bc}$	$71.14{\pm}1.20^{e}$
		7	$60.78{\pm}4.46^{f}$	$20.09{\pm}1.64^{a}$	$51.61{\pm}6.97^{cde}$	$55.43{\pm}6.74^{bc}$	$68.50{\pm}2.71^{f}$
Outlet 2		0	$66.12{\pm}1.67^{ab}$	$16.05{\pm}2.37^{c}$	$58.76{\pm}4.10^{a}$	$60.94{\pm}4.36^{a}$	$74.76{\pm}1.75^{c}$
	0	2	$63.40{\pm}1.85^{cd}$	$15.03{\pm}1.47^{c}$	$53.72{\pm}2.72^{bc}$	$55.81{\pm}2.54^{bc}$	$74.33{\pm}1.83^{c}$
		7	$67.04{\pm}1.57^{a}$	$11.84{\pm}1.96^{e}$	$50.19{\pm}2.96^{ed}$	$51.61{\pm}2.90^{b}$	$76.70{\pm}2.33^{b}$
	23-26	2	$63.69{\pm}1.80^{cd}$	$15.90{\pm}2.45^{c}$	$50.78{\pm}3.40^{ed}$	$53.26{\pm}3.46^{cd}$	$72.61{\pm}2.53^{d}$
		7	$61.53{\pm}5.41^{ef}$	$19.21{\pm}1.79^{ab}$	$51.78{\pm}6.24^{cde}$	$55.26{\pm}6.18^{bc}$	$69.47{\pm}2.28^{f}$
Outlet 3		0	$63.36{\pm}3.19^{cd}$	$16.11{\pm}3.04^{c}$	$54.86{\pm}5.05^{b}$	$57.22{\pm}5.45^{b}$	$73.70{\pm}2.24^{cd}$
	0	2	$67.38{\pm}2.45^{a}$	$16.17{\pm}1.78^{c}$	$52.01{\pm}4.64^{cde}$	$54.49{\pm}4.73^{bc}$	$72.70{\pm}1.61^{d}$
		7	$67.40{\pm}1.97^{a}$	$15.73{\pm}2.30^{c}$	$53.62{\pm}3.24^{bc}$	$55.91{\pm}3.50^{bc}$	$73.68{\pm}1.94^{cd}$

Means of parameters in the same column followed by different letter are significantly different ($P<0.05$)

Flesh firmness

Flesh firmness (Table 3.6) of peaches at retail level ranged from 53.63 N to 86.18 N among the retail outlets. Fruit from retail outlet 2 had significantly higher ($P<0.05$) flesh firmness than fruit from outlet 1 and 3 which did not differ. The recommended flesh firmness of peaches at harvest ranges from 62 N to 71 N, arrival at pack house 45 N to 63 N and 44 N to 54 N as transporting firmness (Mitchell *et al*., 1991; PNP California, 2010). The average flesh firmness (65.51 N) at retail level was within harvesting firmness range which could imply that the peaches were brought to the outlets straight from the producers. However, consumers prefer peaches at transporting firmness (PNP California, 2010). There was a significant decrease in flesh firmness of fruit from retail outlet 1 and 2 under ambient conditions while fruit from all outlets under optimum conditions showed a decrease only after 7 days.

Table 3.6 Flesh firmness of yellow clingstone peaches at retail level and consumer storage (mean ± standard deviation)

Sample	Temp (^{0}C)	Time (Days)	Firmness (N)
Outlet 1		0	56.71 ± 15.93 ^{c}
	0	2	51.71 ± 21.25^{cd}
		7	33.94 ± 10.76^{ef}
	23-26	2	50.06 ± 17.18^{cd}
		7	26.11 ± 14.91^{fg}
Outlet 2		0	86.18 ± 16.01 ^{a}
	0	2	71.01 ± 15.89 ^{b}
		7	35.84 ± 9.52 ^{e}
	23-26	2	46.31 ± 27.35^{d}
		7	20.06 ± 9.86 ^{g}
Outlet 3		0	53.63 ± 13.13^{cd}
	0	2	52.88 ± 13.41^{cd}
		7	28.73 ± 16.97^{ef}

Means of firmness in the same column followed by different letter are significantly different ($P<0.05$)

The decrease in flesh firmness of peaches during maturation is associated with increase in juiciness and pulpiness while chewiness decreases (Cascales *et al.*, 2005). Crisosto (1999) proposed that the texture of unripe peaches is very high and such fruit need to mature at retail conditions 20-25 ºC and 90-95% relative humidity.

Economic loss and environmental impact

The estimated annual national physical loss at retail ranged from 4 330 to 11 660 tons with an average of 7 240 tons, with market value of approximately R97 million (Table 3.7). Land used to grow lost peaches which could have been used for other productive economic activities amounts to about 2 480 ha considering the supply chain with highest incidence of losses while the average energy wastage was estimated at 27.35 x 10^6 MJ.

The average GHG emission of the fruit losses at retail level was 2 410 tons $CO_{2eq,}$ while total water footprint was 7 410 m^3. Water wasted due to lost fruit can meet recommended basic water requirement (50 $L.dy^{-1}$) of 400 people for one year (Peter & Gleik, 1996) while it will require planting of over 61 000 trees on open space to sink the GHG emissions (0.039 metric ton per urban tree planted) (U.S. DOE, 1998). Fruit from shop three had the highest resource wastage and environmental impact due to high losses recorded. However, the economic loss and environmental impact of the losses under ambient storage was almost three times to those at retail level. Storing fruit at recommended optimal refrigerated conditions resulted in similar environmental impacts to the time of purchase at retail, highlighting the importance of maintaining the cold chain to reduce postharvest losses (Table 3.8).

Table 3.7 Losses and environmental impact of yellow clingstone peaches at retail level

PARAMETER	**Outlet 1**	**Outlet 2**	**Outlet 3**	**MEAN**
Production Area(ha)	8490	8490	8490	8490
Production ($x10^3$MT)	175.00	175.00	175.00	175.00
Fresh domestic Supply ($x10^3$)	40000	40000	40000	40000
Price at retail $R.kg^{-1}$	15.00	15.00	12.00	14.00
Physical Loss (%)	14.27	10.83	29.16	18.09
Estimated National Physical loss (MT)	5710	4330	11660	7240
Estimated National Economic Loss($x10^6$ ZAR)	85.64	65.00	0.14	96.87
Estimated Land Wasted (ha)	1210	920	2480	1540
Estimated GHG emission(tons CO_2eq)	1800	1440	3880	2410
Energy ($x10^6$ MJ)	21.58	16.38	44.09	27.35
Green water footprint (m^3)	2920	2220	5970	3700
Blue water footprint (m^3)	2630	1990	5360	3330
Grey water footprint (m^3)	330	250	660	410

MT=metric-ton, ha = hectare, ZAR=South Africa Rand, MJ=Mega-Joules

Table 3.8 Losses and environmental impact of yellow clingstone peaches during consumer storage

PARAMETER	DAY 2 (Ambient)			DAY 2 (Optimum)		
	Outlet 1	Outlet 2	Outlet 3	Outlet 1	Outlet 2	Outlet 3
Physical Loss (%)	49.59	30.01	93.97	17.38	13.53	25.85
Estimated National Physical loss ($x10^3$ MT)	19.84	12.00	37.59	6.95	5.41	10.34
Estimated National Economic Loss($x10^6$ ZAR)	297.54	180.03	451.05	104.28	81.16	124.06
Estimated Land Wasted($x10^3$ ha)	4.21	2.55	7.98	1.48	1.15	2.19
Estimated GHG emission(t CO_2eq)	6.60	3.99	12.50	2.31	1.80	3.44
Energy wasted($x10^6$ MJ)	74.98	45.37	142.08	26.28	20.45	39.08
Green water footprint ($x10^3$ m^3)	1.02	6.15	1.92	3.56	2.77	5.29
Blue water footprint ($x10^3$ m^3)	9.12	5.52	1.73	3.20	2.49	4.76
Grey water footprint ($x10^3$ m^3)	1.13	0.68	2.14	0.40	0.31	0.59

MT=metric-ton, ha = hectare, ZAR=South Africa Rand, MJ=Mega-Joules

Conclusions

The significant amount of losses of peaches (18.08%) occurring at Stellenbosch retail market was primarily caused by physical damage and rots. It was found that the estimated lost fruits (7 240 tons) could have benefited a significant number of people nutritionally. High incidence of postharvest fruit losses and waste contribute to negative environmental impacts and economic loss. The estimated losses at retail level were worth R96.87 million while the GHG emissions of fruit lost was estimated to be 2 410 tons CO_{2eq} and 7 410 m^3 water footprint.

High temperatures during the time of the study when peaches are in season are associated with high moisture losses, increased climacteric respiration and proliferation of spoilage microorganisms. This accompanied with poor cold chain management, rough handling and poor sanitation could have led to high losses recorded, especially in fruit handled and sold in outdoor market (outlet 3). The losses obtained at retail level are as a result of cumulative effects along the supply chain in which losses recorded for each shop could indicate the nature of previous handling.

Highest losses recorded for fruit from shop three at retail and post-purchase storage suggests that storage life of the fruit was related to fruit quality at retail level. Variations in physico-chemical properties of peaches at retail level could also indicate differences in sources and handling procedures. However fruit quality is consumer centred in which good quality is associated with repeated buying and sales therefore consumer sensory evaluation at each assessment level could have given more data in relation to the eating quality of peaches.

The results of physico-chemical changes obtained indicated that 51.13% of ascorbic acid could be lost during ambient storage of peaches for 7 days while 16.67% could be lost under optimum conditions after 7 days. Maturity index was found to increase by 98% and 36% after 7days storage under ambient and optimum conditions, respectively. Although there was loss of firmness under ambient conditions, there was better evolution of colour than under optimum conditions.

Further studies are needed to track peaches from harvest to provide detailed information on handling procedures and to identify the origin of defects associated with losses and downgrading.

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CHAPTER 4

Postharvest losses and changes in physico-chemical properties of fruit at retail and post-purchase storage: case study of Packham's Triumph pear (*Pyrus communis L.*)

Abstract

Packham's Triumph pears were purchased from three different retail outlets in Stellenbosch (South Africa) and assessed for incidences of physical losses, downgrading and changes in physico-chemical properties during storage in ambient (23 – 26 C, 55% RH) and optimum (0 C, 95% RH) conditions to simulate consumer post-purchase practice. Physical damage due to puncture and compression injuries was identified as the primary cause of physical losses at retail and consumer storage. The average physical loss of 3.61% at retail level was equivalent to a loss of 418 tons worth R2.2 million at national level. About 11% of fruit was downgraded at retail due to minor physical damages. The average physical loss after four days of storage was 12.45% and 2.39% at ambient and optimum storage conditions, respectively. Furthermore, the average cumulative weight loss under ambient and optimum conditions after four days was 1.9% and 0.17%, respectively while after 14 days was 6.21% and 0.54%, respectively. Although there were no significant differences in ascorbic acid of pears at retail level, there was a decrease by 4.93% and 11.91% under ambient and optimum conditions respectively, after four days. Extending the storage period to 14 days led to 59.04% and 46.4% decrease in ascorbic acid under ambient and optimum condition, respectively. There was no significant change in TSS and TA of the fruit stored at 0 C after 14 days. Flesh firmness of green and yellow pears at retail ranged from 33.01 N to 60.24 N and 24.39 N to 31.31 N respectively. The energy wasted to produce lost fruits at retail was 1.6×10^6 MJ while during post purchase storage was 5.52×10^6 MJ under ambient condition and 1.07×10^6 MJ under optimum condition after four days. Greenhouse gas (GHG) emission of lost pears at retail was 139 tons CO_{2eq} while emissions for losses during storage under ambient and refrigerated conditions were 473.77 tons and 91.93 tons CO_{2eq} respectively.

Introduction

Pears (*Pyrus communis L.*) are one of the most important deciduous fruits grown in South Africa in terms of their foreign exchange earnings, employment creation and linkages with support institutions (DAFF, 2010). Majority of South African pears are available in many northern hemisphere countries during their winter and spring seasons. South Africa's total pear production area in 2009 was 11 435 ha where Packham's triumph cultivar accounted for 29% of the total planted area, followed by Forelle (25%), Williams Bon Chretien (17%) and Early Bon Chretien (10%) (DAFF, 2010). Pear production in South Africa is primarily focused at both export and processing and to a lesser extent, local markets. The total annual production of pears in 2009 was 300 000 tons in which 40 000 tons were supplied to the local market. Direct employment within the industry was estimated at 14 588 people with 58 352 dependents (DAFF, 2010).

Pears are climacteric usually harvested at commercial maturity (lower maturity) to withstand the rigors of postharvest handling and distribution (Crisosto, 1992). Unripe pears are usually destined for long-term storage and controlled atmosphere while ripe pears are selected for short-term storage and immediate transfer to fresh market or processing (Bai *et al*., 2009). Significant pear losses occur during harvesting, handling, transportation and storage. Studies in Tunisia on pears revealed 0.8% losses in the field, 9% losses in storage and 10 to 15% losses during marketing (Bechir, 1993) in which the overall cause was inefficiency in cold chain management within the supply chains.

Harvested pears are susceptible to physical damage which can lead to moisture loss and infection, adversely affect fruit appearance (Slaughter *et al*., 1998). Moreover, phenyl-propanoid metabolism and subsequent tissue browning of pears have been shown to be induced by visible and invisible injuries (Amiri & Bompeix, 2004). Wang and Mellenthin (1973) suggested that exposure of cell contents to the atmosphere caused by mechanical damage was probably the reason for friction discolouration of pears. Additionally, vibration treatment can lead to changes in respiration and cell membrane composition of fruit (Ying *et al*., 1998). Browning disorder of pear fruit can result in considerable economic losses as the symptoms are internal and cannot be observed visually without cutting the fruit in half (Franck *et al*., 2007). Therefore studies in physico- chemical properties are essential in adaptation and design of various handling, packaging, storage and transportation systems to maintain fruit quality throughout the supply chain (Singh & Reddy, 2005).

Many studies have highlighted the importance of fruits in solving micronutrient deficiency problem (Haddad *et al*., 2002; Ali *et al*., 2002; Monde, 2003; Ganry, 2009). However, poor quality and high incidence of postharvest losses are some of the major constraints to consumption of fruits. Although the majority of pear consumers does not know the nutritional importance of pears (Mahammad *et al*., 2010), pears are good sources of vitamin C, less allergenic than many other fruits and their juice sometimes used as the first juice introduced to infants (Vadivel & Janardhanam, 2005). It has been found that the pulp of pears contain 78.0 ± 0.57% moisture, 12.4% sugars, 0.4-3% protein, 15.5-20% carbohydrates, 0.1-0.35% lipids, 0.95-5.6% fibre and 2.2 ± 0.4% ash depending on cultivar (Senser *et al*., 1999; Lukmanj *el at*., 2008; Muhammad *et al*., 2010). Furthermore, pears possess other nutritional components, such as minerals, antioxidants and bioactive elements that are important sources of health-beneficial compounds (Silos-Espino *et al*., 2003).

Information on the nature and extent of losses in fruit reaching the South African local fresh fruit markets could help in identifying factors responsible for the losses and provide guidelines in developing proper measures required to prevent or reduce such losses. Therefore, the aim of this study was to assess postharvest losses of pears at the retail level and during post-purchase storage. The specific objectives were to; (i) estimate the incidence of fruit postharvest physical losses and downgrading, (ii) quantity the changes in physico-chemical properties related to quality during storage, and (iii) estimate the economic and environmental impacts of the losses.

Materials and methods

Plant material

Packham pear fruits were purchased from the three retail outlets during summer season (March 2011). A total of 360 fruits was randomly selected from each outlet and transported to the Postharvest Technology Research Laboratory at Stellenbosch University, about 2 kilometres from the market. The retail outlets selected represented different handling systems and supply chains in Stellenbosch (South Africa). Outlet 1 and 2 were supermarkets where ambient shelf temperature was controlled by air conditioners. However, both outlets had refrigerated facility to store fruit off the shelf awaiting display. Outlet 3 was an open market where the fruit was displayed in cartons under shaded area and unsold fruit carried back to the vendor's home for ambient storage.

Experimental Design

Fruit from each outlet (360 fruits) were randomly distributed among three samples (120 fruits/sample), each consisting three sub-samples (40 fruits/sub-sample). The sub-samples represented three replicates. One out of three samples was analysed on the day of arrival at the laboratory (day zero) representing retail quality and losses (Fig 4.1). The remaining two samples were each stored at ambient condition (23-26 ºC, 55% RH) and optimum cold storage (0ºC, 95% RH) simulating the post-purchase practices of consumers. Stored fruit was analysed after four days and 14 days (Fig 4.1). Fruit was inspected for external physical damage, physiological disorders and decay. Fruit not fit for consumption was classified as physical loss and consumable defective fruit as downgrade. Samples of 10 fruits free from defects were selected from each treatment for physico-chemical analysis. Each fruit was measured for colour and flesh firmness. Samples were divided into two replicates of five fruits each and blended to determine the following parameters; total soluble solids (TSS), titratable acidity (TA), carotenoids content and ascorbic acid. Homogenate from each replicate was freeze dried and stored at -80°C until required for proximate analysis.

Postharvest loss assessment

The three percentages of defective fruit for the sub-samples were averaged to represent the whole sample. National physical loss was estimated by expressing the percentage physical loss as a fraction of amount of fruit supplied to the local fresh market while economic loss was the monetary value of the computed losses according to respective retail prices. Physical loss was used to compute the impact of losses on environment and resources (Mekonnen & Hoekstra, 2011; Gonzalez *et al*, 2011).

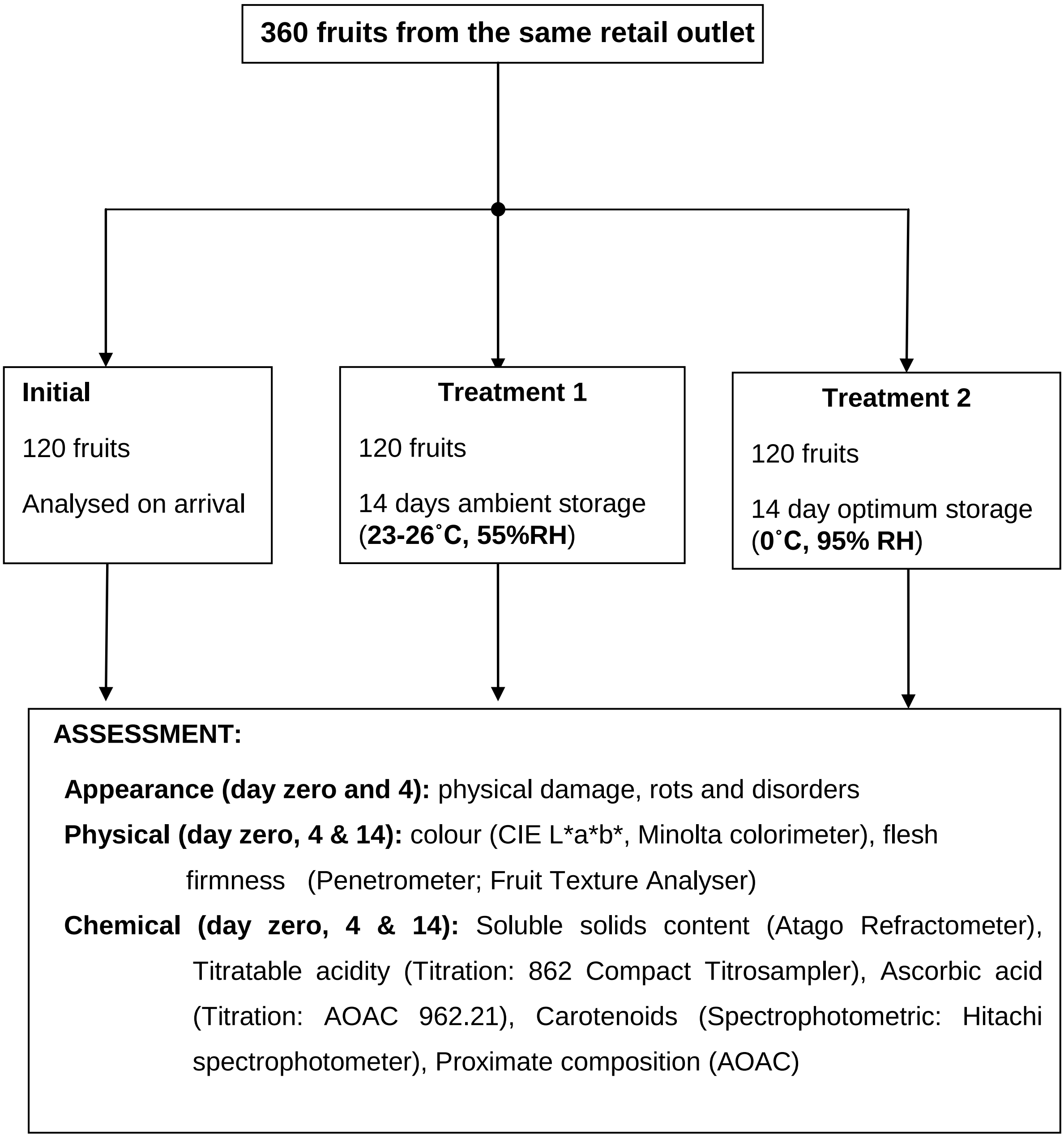

Figure 4.1 Experimental design for quality assessment and physico-chemical assessment of Packham's Triumph pear

Environmental conditions

Tinytag Explorer temperature (-25 – 50°C) and relative humidity (0 - 100%) loggers (Gemini data loggers, UK) were used to capture the environmental conditions inside and outside the retail outlets.

Weight loss

A sample of 10 fruits from each shop for each storage condition were labelled and weighed using Mettler Toledo scale at day zero, after 4 and 14 days in storage (Singh & Reddy, 2005). The average data of 10 fruits was used for each treatment.

Proximate composition analysis

Freeze dried samples were used for analysis. Moisture was determined by desiccation at 105 C to constant mass (James, 1996). Ashing was performed at 520 C in a muffle furnace (AOAC, 2000). Nitrogen content was obtained by applying the Kjeldahl method 960.52 (AOAC, 2000) and protein concentration calculated using a nitrogen factor of 6.25. Total dietary fibre was determined using Non-enzymatic-Gravimetric method 993.21 (AOAC, 2005). Crude fat content was determined by extraction using petroleum ether in a Soxhlet Extractor at 90 C and carbohydrates calculated by difference (James, 1996). Energy was calculated using Atwater factors: fat 37 $kJ.g^{-1}$ (9 $kcal.g^{-1}$), protein and carbohydrates 17 $kJ.g^{-1}$ (4 $kcal.g^{-1}$) (Uusitalo *et al*., 2011).

Chemical analysis

Ascorbic acid content was measured using the titration method involving 2, 6-dichloroindophenol (AOAC method 967.21, 2000). Carotenoids were extracted from the homogenate using hexane-acetone mixture (3:2) and measurements of the absorbance of the extract at 450 nm and 520 nm were done using in Hitachi spectrophotometer (Helios Omega UV-Vis Thermo Scientific, USA). Results were expressed in microgram total carotenoids and lycopene per gram fresh weight (Opiyo & Ying, 2005). Acidity was determined by titration of 2 ml of the fruit juice with 0.1M sodium hydroxide solution up to pH 8.2 using 862 Compact Titrosampler (Metrohm, Herisau, Switzerland). Results were expressed as percentage of malic acid in fresh material. Total soluble solids results were expressed in ^{0}Brix (%), measured using a digital Refractometer (Atago, Tokyo, Japan). The maturity index (MI) was calculated as TSS to TA ratio.

Colour and flesh firmness evaluation

Fruit colour was measured twice on both sides of the fruit using a Minolta colorimeter (model CR-200; Minolta Co. Ltd, Osaka, Japan) after standardising the sensor with a white and black tile (Y=94.00; *x*= 0.13; *y*= 0.321). The measured colour was expressed as L* (lightness and darkness), a* (redness and greenness), b* (yellowness and blueness). Hunter colour parameters C (chroma) and hue angle were calculated from a* and b* values according to McGuire's suggestion (1992). Fruit firmness was determined using Fruit Texture Analyser (Guss, Strand, Western Cape, South Africa) on both sides of the fruit, after skin removal, and penetrating the pulp to depth of 8 mm, with a standard 0.5 cm^2 cylindrical probe recommended for use with peaches (Planton, 1996).

Statistical Analysis

One way analysis of variance (ANOVA) was applied to data using SAS version 9.1 (SAS Institute, 2006). Means were separated using the Fishers test (α=0.05)

Results and discussion

Environmental conditions

The three retail outlets displayed fruit under ambient temperature (22 - 29 ºC) (Table 4.1). However, a temperature range of 0 - 2 ºC and 90 - 95 % (Yu *et al*., 2006; Kaur *et al*., 2011; OHIO State University, 2011) relative humidity is recommended for storage of pears. Open market had the highest shelf temperature and lowest relative humidity. Relative humidity within open market was the same as outside. Shelf temperature within outlets (22 - 29 ºC) promotes fruit ripening and softening (Murayama *et al*., 2002; Predieri & Gatti, 2009).

Physical loss at retail

Fruits from retail outlet 1 were all green while retail outlet 2 and 3 had 33.33% and 24.17% yellow fruit, respectively. The observed differences in ripeness could be attributed to loss control procedure to minimise losses since unripe fruit are more resistant to physical damage than ripe fruit. However, the presence of yellow ripe fruit could also indicate that the fruit was harvested ripe or had longer time on market than green fruit.

Table 4.1 Average air temperature and relative humidity on the day of fruit procurement

Retail outlet	Temperature (ºC)		Relative Humidity (%)	
	Inside	Outside	Inside	Outside
Outlet 1	24	27	69	53
Outlet 2	22	30	79	43
Outlet 3	29	34	35	35

Most of the physically damaged fruit from retail outlet 3 were yellow. Although there were ripe fruit from retail outlet 2, there were no rotten or damaged fruit indicating proper fruit handling. Physical losses among retail outlets (Table 4.2) ranged from 0 - 10% with an average of 3.61% mainly due to rots, mechanical and insect damage. There were no physical losses recorded for outlet 2 while outlet 1 and 3 had 0.84% and 10%, respectively mainly due to mechanical damage. Mechanical damage was observed as puncture injuries which could be due to the harvesting methods while compression damage could be related to rough handling and poor packaging along the supply chain. Furthermore, stacking of fruit on top of another on shelf could have led to compression physical damage to fruits at the bottom especially soft ripe fruit. High incidence of physical damage in fruit from outlet 3 could have made the fruit more prone to infection. Furthermore, increased ethylene production in injured tissue accelerates physiological activity and deterioration rate of fruit (LaRue & Johnson, 1989).

There were no rots observed in fruit from retail outlet 1 and 2 while fruit from retail outlet 3 had 0.83% rots. Fruit on display in retail outlet 3 were more exposed to weather and infecting microbes than fruit from retail out let 1 and 2 therefore having higher chances of being infected.

The average physical loss of 3.61% at retail resulted in estimated national annual loss in fresh pears of 418 tons in South Africa. Considering the recommended 146 kg per capita consumption of fruit and vegetables per year (WHO, 2004), the magnitude of postharvest losses in pears at retail alone is sufficient to meet the annual fruit intake of approximately 3 000 people for the whole year.

Table 4.2 Means of percentage downgrade and physical losses of pears at retail level and consumer storage

CLASS	DEFECT	DAY ZERO			DAY 4 (Ambient conditions)			DAY 4 (Optimum condition)		
		Outlet 1	Outlet 2	Outlet 3	Outlet 1	Outlet 2	Outlet 3	Outlet 1	Outlet 2	Outlet 3
DOWNGRADE	Minor physical damage	4.17	1.67	16.67	6.67	1.67	16.67	6.67	4.17	11.67
	Stem end injury	5.00	2.50	0.00	0.83	0.00	0.00	1.67	0.00	6.67
PHYSICAL LOSS	Rots/ Decay	0.00	0.00	0.83	0.00	0.00	5.83	0.00	0.00	0.00
	Severe Physical Damage	0.83	0.00	9.16	0.00	6.67	19.17	0.00	0.00	6.67
	Insect damage	0.00	0.00	3.33	0.00	0.83	1.67	0.00	0.00	0.00
	Weight loss	0.00	0.00	0.00	2.41	1.74	1.55	0.20	0.10	0.20
DOWNGRADE		**9.17**	**4.17**	**20.00**	**7.50**	**2.47**	**18.34**	**8.33**	**4.17**	**11.65**
PHYSICAL LOSS		**0.84**	**0.00**	**10**	**2.41**	**7.89**	**26.55**	**0.20**	**0.10**	**6.85**

	
MINOR PHYSICAL DAMAGE	**INSECT DAMAGE**
	
SEVERE PHYSICAL DAMAGE AND DECAY	**STEM END INJURY**

Figure 4.2 Photographs of representatives of each pear defect used to categorise fruit into physical loss and downgrade

Physical losses during consumer storage

Physical losses during storage were related to fruit quality at retail level as the highest loss was recorded for fruit from retail outlet 3 with the highest damage incidences (Table 4.2). Losses ranged from 2.41% to 25% with an average of 12.29% under ambient condition and 0.1% to 6.85% with average 2.38% at 0 ºC after four days. Ambient conditions promoted proliferation of spoilage microbes in which injured fruit were invaded and rot thereby increasing the percentage physical losses in fruit from retail outlet 3. Decay incidence of 5% was recorded for fruit from retail outlet 3 under ambient condition while no incidences were observed at 0 ºC. Ambient temperature accelerates the ripening process making the fruit soft and more susceptible to microbial invasion (LaRue & Johnson, 1989). However, lower temperatures promote fruit healing reducing losses (LaRue & Johnson, 1989). Furthermore, ethylene from injured fruit can initiate ripening and flesh softening of surrounding healthy fruit, making them more susceptible to microbial attack (LaRue & Johnson, 1989).

Downgrading at retail and consumer level

Downgrading was due to minor physical damage (small punctures, scratches and friction bruises) and stem end injuries. Downgraded fruit (Table 4.2) among retail outlets ranged from 4.17 - 20% with an average of 11.11%. Retail outlet 3 had the highest per- cent downgraded fruit while outlet 2 had the least. Downgrading during storage ranged from 2.47 - 18.34% with an average of 9.43% under ambient condition while the range of 4.17 - 11.65% with average 8.05% was recorded at 0 C after four days. Retail outlet 3 had the highest per-cent downgraded fruit while fruit from retail outlet 3 had the least downgrade during consumer storage. There was a decrease in downgraded fruits from day zero to day four in all storage conditions. The reduction in downgrade of fruit under ambient conditions could be due to deterioration of less damaged fruit that made them classified as physical loss. However, less damage fruit at 0 ºC could have healed and led to reduced percentage downgrade (LaRue & Johnson, 1989).

Weight loss

The average cumulative weight loss under ambient and optimum conditions after four days was 1.9% and 0.17% respectively. The average cumulative weight loss under ambient and refrigerated conditions after 14 days was 6.21% and 0.54% respectively. This indicated that weight loss under ambient condition was more than 10 times under refrigeration. The highest weight loss was recorded for fruit from retail outlet 1 under all temperature levels (Table 4.3). However, there was no significant difference (P>0.05) in weight loss between fruit from all shops under optimum condition after four days. Weight loss can be due to respiration and transpiration of which the rate of these processes is higher at higher temperatures than lower temperatures (Martinez-Javega *et al*., 1989). Weight loss increased about three times from day 4 to day 14 under all temperature levels implying that longer post purchase storage could lead to reduced consumable fruit weight.

Table 4.3 Percentage weight loss of pears during storage (mean ± standard deviation)

Temperature (ºC)	Time (Days)	Outlet 1	Outlet 2	Outlet 3
0˚C	4	0.20 ± 0.05^{h}	0.10 ± 0.02^{i}	0.20 ± 0.05^{h}
	14	0.67 ± 0.13^{f}	0.36 ± 0.09^{gh}	0.57 ± 0.04^{fg}
23-26	4	2.41 ± 0.03^{d}	1.74 ± 0.03^{e}	1.55 ± 0.05^{e}
	14	7.10 ± 0.42^{a}	6.43 ± 4.13^{b}	5.11 ± 0.21^{c}

Means of percentage weight loss followed by the same letter are significantly different (P<0.05)

Proximate composition

Fruit from Retail outlet 1had significantly (P<0.05) lower moisture content, higher protein and carbohydrate content than fruit from other outlets, that did not differ (P>0.05) in all measured proximate composition parameters (Table 4.4). The average proximate composition of Packham's Triumph pears at retail level was; 85.24 g moisture, 2.45 g protein, 0.05 g fat, 1.49 g ash, 0.95 g dietary fibre and 9.82 g carbohydrates. In comparison with the values from other studies (Senser *et al*., 1999; Lukmanj *el at*., 2008; Muhammad *et al*., 2010), the studied pears had higher moisture content, less fat, ash and carbohydrates, while proteins and dietary fibre content was within the range found in the literature. The average energy content of pears was 111.67 $kJ.100g^{-1}$ of edible portion. The estimated physical loss of 418 tons would have provided with 7.68×10^{9} kJ which could have benefited 2 500 adults with at least 8400 kJ per day for one year.

Table 4.4 Proximate composition at retail (day zero) and after seven day storage at 0 ºC (mean ± standard deviation)

PARAMETER	DAY 0			DAY 7		
	Outlet 1	Outlet 2	Outlet 3	Outlet 1	Outlet 2	Outlet 3
Energy (kJ.100g^{-1})	467.49 ± 7.78^{a}	433.71 ± 27.42^{a}	413.64 ± 16.83^{a}	453.78 ± 28.59^{a}	457.46 ± 4.13^{a}	448.32 ± 55.69^{a}
Energy (kcal.100g^{-1})	117.24 ± 1.22^{a}	111.3 ± 6.42	107.41 ± 3.41	108.19 ± 6.82	109.07 ± 0.98	106.92 ± 13.33
Water (g.100g^{-1})	68.88 ± 0.48^{c}	71.13 ± 1.78^{abc}	72.49 ± 1.04^{a}	69.86 ± 1.84^{abc}	69.47 ± 0.18^{abc}	71.97 ± 1.01^{ab}
Protein (g.100g^{-1})	0.92 ± 0.06^{a}	0.76 ± 0.01^{bc}	0.60 ± 0.0^{c}	0.85 ± 0.02^{ab}	0.60 ± 0.05^{c}	0.78 ± 0.13^{ab}
Crude Fat (g.100g^{-1})	0.09 ± 0.04^{a}	0.08 ± 0.05^{a}	0.09 ± 0.03^{a}	0.11 ± 0.04^{a}	0.09 ± 0.03^{a}	1.56 ± 2.05^{a}
Ash (g.100g^{-1})	1.49 ± 0.01^{abc}	1.35 ± 0.20^{bc}	1.32 ± 0.23^{bc}	1.17 ± 0.01^{c}	2.07 ± 0.82^{ab}	2.34 ± 0.01^{a}
Dietary Fibre (g.100g^{-1})	5.61 ± 0.56^{a}	4.48 ± 1.26^{a}	5.01 ± 0.47^{a}	4.40 ± 1.64^{a}	5.16 ± 0.19^{a}	3.67 ± 0.32^{a}
Carbohydrates (g.100g^{-1})	29.88 ± 0.37^{a}	27.82± 1.72^{abc}	26.63 ± 1.07^{bc}	29.00 ± 1.81^{ab}	29.52 ± 0.38^{ab}	25.35 ± 1.18^{c}

Means of parameters in the same row followed by different letter are significantly different (P<0.05)

Chemical changes

There were no significant differences (P>0.05) in ascorbic acid of fruit from all retail outlets at retail level (Table 4.5). The studied pears were found to contain ascorbic acid ranging from 3.68 mg to 4.11 $mg.100g^{-1}$ edible portions which was close to the average content of 4.2 $mg.100g^{-1}$ edible portions (Lukmanj *et al*., 2008). With the average ascorbic acid of 3.38 $mg.100g^{-1}$ edible portion it can be estimated that 418 tons of estimated physical losses contained 14 kg of ascorbic which could meet recommended daily intake (50 $mg.day^{-1}$) of about 774 people for one year.

Although there was no significant change (P>0.05) in ascorbic acid content of fruit from retail outlet 2 and 3 after four days under all storage temperature levels, fruit from retail outlet 1showed a decrease in ascorbic acid after four and 14 days. A significant decrease (P<0.05) in ascorbic acid was noticed after 14 days under all conditions except for fruit from retail outlet 3 at 0 ˚C. This means that fruit from retail outlet 3 had best storage quality in terms of ascorbic acid retention as they had significantly higher ascorbic acid than fruit from other shops under all temperature levels after 14 days. A consumer that would have purchased from retail outlet 3 could have the least losses in ascorbic acid under all simulated storage conditions. However, an average of 4.93% and 11.91% of ascorbic acid was lost under ambient and optimum conditions respectively, after four days. Extending the storage period to 14 days led to 59.04% and 46.4% loss in ascorbic acid under ambient and refrigerated condition respectively. Fruit from retail outlet 2 showed an increase in ascorbic acid by 6.25% and 18.75% under ambient and refrigerated conditions respectively after four days.

TSS and TA are important parameters that influence flavour, sweetness, sour taste and astringency of pears (Manning, 2009). MI explains the balance between sour and sweetness of pears in which higher values are associated with preferred palate (Chen *et al*., 2007). The measured TSS at retail (Table 4.5) ranged from 13 to 15.07 ºBrix, while TA ranged from 0.21% to 0.30% and MI from 44.05 to 72.9. In comparison, Manning (2009) reported 15 ºBrix TSS, 0.29% TA, and 55.3 MI for South African Packham Triumph pears used for consumer sensory analysis. The TSS of fruit from retail outlet 3 was significantly higher (P<0.05) than fruit from other outlets while fruit from retail outlet 2 had the lowest at retail level.

Table 4.5 Chemical parameters of Packham pears at retail and during consumer storage (mean ± standard deviation)

Sample	Temperature (^{0}C)	Time (Days)	Ascorbic acid ($mg.100g^{-1}$)	Total Carotenoids ($\mu g.g^{-1}$)	Lycopene ($\mu g.g^{-1}$)	TSS	TA	MI (TSS/TA)
Outlet 1		0	4.11 ± 0.99^{a}	100.27 ± 4.81^{g}	15.70 ± 3.64^{h}	13.00 ± 0.69^{e}	0.21 ± 0.01^{bcde}	61.12 ± 5.78^{bcd}
	0	4	2.60 ± 0.65^{c}	109.33 ± 24.83^{g}	36.50 ± 18.38^{hg}	13.20 ± 0.10^{e}	0.17 ± 0.01^{def}	76.20 ± 2.02^{bcd}
		14	1.30 ± 0.32^{d}	141.60 ± 3.82^{gef}	55.64 ± 2.69^{fg}	12.50 ± 0.10^{e}	0.19 ± 0.01^{cdef}	65.92 ± 3.79^{bcd}
	23-26	4	3.25 ± 0.00^{bc}	193.73 ± 51.37^{bcd}	77.58 ± 33.09^{def}	14.03 ± 0.06^{c}	0.17 ± 0.01^{def}	82.75 ± 5.19^{cb}
		14	1.19 ± 0.19^{d}	191.20 ± 21.04^{bcde}	111.07 ± 15.52^{bcd}	13.77 ± 0.59^{cd}	0.16 ± 0.00^{efg}	86.04 ± 3.66^{cb}
Outlet 2		0	3.46 ± 0.37^{ab}	121.87 ± 46.61^{g}	60.53 ± 32.30^{efg}	13.07 ± 0.12^{e}	0.30 ± 0.0^{a}	44.05 ± 0.75^{d}
	0	4	4.11 ± 0.37^{a}	127.33 ± 13.54^{gf}	52.94 ± 8.35^{fg}	13.13 ± 0.29^{e}	0.24 ± 0.02^{abc}	55.78 ± 4.48^{cd}
		14	1.62 ± 0.32^{d}	230.13 ± 25.85^{b}	124.70 ± 19.17^{bc}	13.33 ± 0.06^{de}	0.22 ± 0.01^{bcd}	59.72 ± 1.27^{bcd}
	23-26	4	3.68 ± 0.37^{ab}	176.00 ± 15.83^{cdef}	72.18 ± 12.33^{fg}	14.60 ± 0.10^{b}	0.13 ± 0.07^{g}	125.74 ± 49.0^{a}
		14	1.62 ± 0.32^{d}	148.00 ± 2.80^{defg}	77.38 ± 2.72^{def}	12.43 ± 0.06^{f}	0.14 ± 0.00^{fg}	88.81 ± 0.41^{b}
Outlet 3		0	3.68 ± 0.37^{ab}	215.73 ± 62.91^{bc}	142.58 ± 42.50^{b}	15.07 ± 0.21^{a}	0.21 ± 0.12^{abc}	72.90 ±1.75^{bc}
	0	4	3.03 ± 0.37^{bc}	194.93 ± 22.02^{bcd}	114.19 ± 15.30^{bc}	14.50 ± 0.10^{b}	0.20 ± 0.01^{bcdef}	72.61 ± 3.44^{bcd}
		14	3.03 ± 0.37^{bc}	311.20 ± 32.40^{a}	193.86 ± 22.31^{a}	14.57 ± 0.06^{b}	0.26 ± 0.01^{ab}	56.08 ± 2.18^{bcd}
	23-26	4	3.68 ± 0.37^{ab}	176.13 ± 37.80^{cdef}	95.78 ± 26.55^{cde}	15.13 ± 0.15^{a}	0.19 ± 0.02^{cdef}	80.08 ± 7.08^{bc}
		14	1.73 ± 0.37^{d}	221.07 ± 24.21^{bc}	144.98 ± 17.16^{b}	15.07 ± 0.12^{a}	0.21 ± 0.01^{bcde}	70.66 ± 2.20^{bcd}

Means of parameters in the same column followed by different letter are significantly different ($P<0.05$)

There was no significant change (P>0.05) in TSS and TA of the fruit stored at 0 ºC after 14 days. TSS of fruit from retail outlet 1 and 2 under ambient condition increased significantly (P<0.05) after four days and decreased as the storage period was extended to 14 days. However, there was no significant change (P>0.05) in both TSS and TA of fruit from retail outlet 3 under ambient condition. There was no significant change in TA of fruit from all outlets during storage except for fruit from retail outlet 2 which decreased after four days.

The average measured carotenoid content of pears from the entire three outlets was 145.96 $\mu g.100g^{-1}$. There was no significant difference (P>0.05) in carotenoid content between fruit from outlet 1 and 2 that differ from outlet 3 fruit. Fruit from outlet 3 had the highest total carotenoid content (Table 4.5). There was a significant increase (P<0.05) in total carotenoid content of fruit from retail outlet 1 and 2 under ambient condition after 4 days while there was no significant change for fruit from outlet 3 under the same conditions. However, there was no significant change (P>0.05) in total carotenoid of all fruit stored at 0˚C after four days while an increase was noticed only after 14 days. The changes in lycopene content followed the same trend as changes in total carotenoid.

Colour attributes

There were no significant differences (P>0.05) in a* values (greenness) and hue angle of pears from all outlets at retail level (Table 4.6). However, fruit from retail outlet 3 had a lighter, more yellow and intense colour than fruit from other outlets. The colour parameters measured in this study were almost similar to those reported by Manning (2009) for Packham's Triumph pears used for consumer preference research in South Africa where the L* value was 62.8, Chroma 44.7 and hue angle 106.7º. Colour is one of the most important parameter used by consumers to judge fruit quality therefore; fruit with less appealing colour will stay longer on shelf before being bought increasing the chances of losses.

There were no significant changes (P>0.05) in colour of fruit stored at 0˚C after 14 days. Fruit from retail outlet 1 and 2 under ambient condition showed a significant increase (P<0.05) in lightness, yellowness and colour intensity while hue angle decreased. Furthermore, fruit from retail outlet 3 under ambient condition showed colour change only after 14 days.

Table 4.6 Colour parameters of Packham pears at retail and during post purchase storage (mean ± standard deviation)

Source	Temperature (°C)	Time(Days)	L^*	a^*	b^*	C	h^0
Outlet 1		0	60.00 ± 2.13^{g}	-15.00 ± 1.13^{g}	40.81±1.49^{fg}	43.48±1.61^{fgh}	110.17±1.26^{a}
	0	4	60.81 ± 2.75^{efg}	-13.57 ±1.87^{efg}	40.66±2.87^{fg}	42.90±2.90^{gh}	108.46±2.47^{ab}
		14	60.64 ± 4.23^{gf}	-14.07 ±3.97^{fg}	40.99±2.72^{efg}	43.37±2.33^{fgh}	108.94±5.09^{ab}
	23-26	4	62.74 ± 4.83^{de}	-10.17 ± 5.42^{cd}	43.58±4.39^{cd}	45.02±4.82^{def}	102.84±6.54^{cd}
		14	65.81 ± 2.76^{ab}	-7.26 ±1.83^{c}	46.90±2.78^{b}	47.64±2.89^{bc}	98.93±2.23^{d}
Outlet 2		0	62.67 ± 2.44^{def}	-13.55 ± 2.24^{efg}	40.03±2.25^{g}	42.30±2.61^{h}	108.62±2.52^{ab}
	0	4	63.18 ± 3.10^{cd}	-10.82 ± 11.15^{de}	40.31±4.51^{g}	43.01±5.60^{gh}	103.54±15.21^{c}
		14	63.11 ± 2.76^{cd}	-11.05 ± 4.02^{de}	40.48±2.22^{g}	42.11±2.78^{h}	105.05±5.10^{bc}
	23-26	4	62.61 ± 2.10^{def}	-12.42 ± 2.30^{defg}	42.66±1.85^{cde}	44.48±2.17^{efg}	106.17±2.59^{bc}
		14	64.87 ± 4.71^{bc}	1.22 ± 1.83^{a}	48.33±3.62^{ab}	48.49±3.60^{bc}	88.44±4.53^{f}
Outlet 3		0	67.07 ± 2.48^{a}	-14.06 ± 2.7^{fg}	42.35±2.77^{def}	44.67±3.13^{defg}	108.26±3.14^{ab}
	0	4	66.39 ± 4.04^{ab}	-11.38 ± 9.08^{def}	43.38±3.99^{cd}	45.81±2.39^{cde}	103.77±13.73^{c}
		14	66.72 ± 2.95^{ab}	-13.35 ± 2.2^{efg}	44.41±1.32^{c}	46.42±1.24^{cd}	106.73±2.78^{abc}
	23-26	4	67.40 ± 2.89^{a}	-12.59 ± 3.27^{defg}	43.67±3.43^{cd}	45.56±3.49^{de}	106.07±4.07^{bc}
		14	66.23 ± 3.80^{ab}	-2.72 ± 2.01^{b}	49.62±1.77^{a}	49.74±1.75^{a}	93.15±2.32^{e}

Means parameters in the same column followed by different letter are significantly different (P<0.05)

The instrumental colour measurements showed similar trends to that reported by Predieri and Gatti (2009) in which the colour of 'Abate Fetel' pears stored at 20˚C changed from green to yellow, with the hue angle showing the most consistent significant variation with ripening. Although ambient condition was associated with change in colour to yellowness and no significant change under refrigeration, it is important to consider consumer colour preference for the cultivar. Therefore ambient conditions can be used to improved colour while refrigeration can be used to preserve the colour of pears (Predieri & Gatti, 2009).

Flesh firmness

Flesh firmness of green and yellow pears at retail ranged from 37 N to 60.24 N and 24.39 N to 31.31 N, respectively (Table 4.7). The optimum commercial harvesting flesh firmness of pears ranges from 60 N to 80 N (Manning, 2009) which was reported to decrease by 2-4 N per week and warm wet weather increases softening. However, unripe pears have a flesh firmness of over 50 N while full ripe is below 20 N (Bai *et al.*, 2009).

There were significant differences ($P<0.05$) in flesh firmness between pears from all outlets. Pears from retail outlet 2 were the hardest while fruit from outlet 1 the softest. This means that fruit from outlet 2 were more resistant to physical damage due to compression and impact forces than fruit from other outlets. However, flesh firmness is related to eating quality parameters like soft texture, juiciness and melt character preferred by South African consumers (Manning, 2009). It was reported that at crisp stage of ripeness, the flavour of pears is flat and the texture of unripe pears is usually rough and lacks juiciness (Bai *et al*., 2009).

Fruit from retail outlet 1 and 2 under ambient optimum conditions showed a significant decrease in firmness only after 14 days while there was no significant change for fruit from outlet 3 under the same conditions. There was a significant decrease ($P<0.05$) in flesh firmness of fruit from retail outlet 1 and 2 under ambient condition after 4 days while fruit from outlet 3 showed a decrease only after 14 days under same condition. There was no significant difference ($P>0.05$) in flesh firmness between fruit from all shops under ambient storage after 14 days. Fruit from outlet 3 had the best storage quality in terms of firmness retention at 0˚C. The decrease in flesh firmness could be attributed to solubilisation and depolymerisation of pectin (Fisher & Bennett, 1991) and hemicelluloses (Wakabayashi, 2000) that are thought to contribute to cell wall loosening and disintegrating.

Table 4.7 Flesh firmness of pears at retail level and consumer storage (mean ± standard deviation)

Sample	Temperature (°C)	Time (Days)	Flesh Firmness
Outlet 1		0	37.00 ± 17.34[c]
	0	4	33.01 ± 13.01[c]
		14	11.60 ± 4.27 [d]
	23-26	4	25.35 ± 11.48[ef]
		14	7.27 ± 2.86[f]
Outlet 2		0	60.24 ± 18.55[a]
	0	4	58.74 ± 13.68[a]
		14	47.68 ± 19.06[b]
	23-26	4	16.12 ± 10.10 [e]
		14	5.04 ± 1.92[f]
Outlet 3		0	48.60 ± 5.57[b]
	0	4	49.91 ± 5.90[b]
		14	45.89 ± 5.77[b]
	23-26	4	44.38 ± 7.27[b]
		14	6.14 ± 4.64[f]

Means of firmness in the same column followed by different letter are significantly different ($P<0.05$)

Economic loss and environmental impact

The estimated annual physical loss (Table4.8) at retail ranged from zero to 1160 tons with an average of 419 tons valued at approximately R2.26 million. Land used to produce lost and wasted pears which could have been used for other activities amounts to about 120 ha while the average energy wasted was estimated at 1.62 x 10^6 MJ. The average GHG emission of fruit lost at retail level was 139 tons CO_{2eq}, while total water footprint was 211 000 m^3. Water wasted due to lost fruit at retail can meet the recommended basic water requirement (50 litres / day) of 11 500 people for one year (Peter & Gleik, 1996) while it will require planting of about 3500 trees on open space to sink the GHG emissions of the fruit losses(0.039 metric ton per urban tree planted) (U.S. DOE, 1998).

Table 4.8 Estimated Packham pear retail losses at national level and environmental impact

PARAMETER	Outlet 1	Outlet 2	Outlet 3	MEAN
Production Area(ha)	3320	3320	3320	3320
Production (x10^3MT)	87.00	87.00	87.00	87.00
Fresh domestic Supply (x10^3)	11.6	11.6	11.6	11.6
Price at retail R/kg	10.00	7.33	5.50	7.63
Physical Loss (%)	0.84	0.00	10.00	3.61
Estimated National Physical loss (MT)	96.86	0.00	1160.00	418.95
Estimated National Economic Loss(x10^6 ZAR)	0.97	0.00	5.80	2.26
Estimated Land Wasted(ha)	27.85	0.00	331.62	119.76
Estimated GHG emission(t CO_2eq)	32.21	0.00	385.7	139.30
Energy (x10^6 MJ)	0.38	0.00	4.50	1.62
Green water footprint (x10^3 m^3)	27.22	0.00	325.96	117.73
Blue water footprint (x10^3 m^3)	21.60	0.00	258.68	93.43
Grey water footprint (x10^3 m^3)	2.71	0.00	32.48	0.12

MT=metric ton, ha = hectare, ZAR=South Africa Rand, MJ=Mega-Joules

Table 4.9 Packham pear losses at national level and environmental impact during consumer storage

PARAMETER	DAY 4 (Ambient conditions)			DAY 4 (Optimum conditions)		
	Outlet 1	Outlet 2	Outlet 3	Outlet 1	Outlet 2	Outlet 3
Physical Loss (%)	2.41	7.89	26.55	0.20	0.10	6.85
Estimated National Physical loss (MT)	279.56	915.24	3079.8	23.2	11.60	794.6
Estimated National Economic Loss(x10^6 ZAR)	2.80	6.71	15.40	0.23	0.085	3.97
Estimated Land Wasted(ha)	79.92	261.64	880.44	6.63	3.32	227.16
Estimated GHG emission(t CO_2eq)	92.95	304.32	1024.03	7.71	3.86	254.20
Energy (x10^6 MJ)	1.08	3.55	11.93	0.09	0.045	3.08
Green water footprint (x10^3 m^3)	78.56	257.18	865.42	6.52	3.26	223.28
Blue water footprint (x10^3 m^3)	62.34	204.10	686.80	5.17	2.59	177.20
Grey water footprint (x10^3 m^3)	7.83	25.63	86.23	0.65	0.32	22.25

MT=metric ton, ha = hectare, ZAR=South Africa Rand, MJ=Mega-Joules

Conclusions

The results obtained in this study demonstrated that postharvest losses of pears at retail level and consumer storage have an impact on food security, agribusiness profitability, sustainable resource management and environment conservation. Physical damage was observed as the primary cause mainly due puncture and compression injuries that could be attributed to harvesting procedures and poor handling along the supply chain. However, losses during consumer storage were related to the quality of fruit at retail level. Furthermore, losses under ambient conditions were five times more than under refrigeration. This indicated that proper cold chain management can help in reducing losses. Although ambient storage conditions are conducive for improvement of organoleptic properties of pears, it is however advisable to be used over a short period to reduce losses whereas refrigeration could be used to preserve the quality. The measured physico-chemical properties indicated variation in quality of pear fruit at retail market leading to differences in quality retention during storage. Fruit quality is consumer cantered in which good quality is associated with repeated buying and sales therefore consumer sensory evaluation at each assessment level could have given more data in relation to the eating quality of pears. However, studies to track pears from harvest are needed to provide more information on handling procedures and origin of defects associated with losses and downgrading.

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CHAPTER 5

Postharvest losses and changes in physico-chemical properties of fruit at retail and post-purchase storage: case study of soft citrus 'Minneola Tangelo' (*Citrus reticulate*)

Abstract

Postharvest losses are some of the challenges in addressing food security and profitability in agribusiness. They also serve as indicators of wastage of resources and have an environmental impact in terms of greenhouse gases (GHG) emissions. Minneola orange fruits were purchased from three different retail outlets in Stellenbosch (South Africa) assessed for incidence of physical losses, downgrading, and changes in physico-chemical properties during storage in ambient (17 – 20 ºC , 65% RH) and optimum (5ºC, 95% RH) conditions to simulate consumer post-purchase practices. Physical damage and puffiness were the major causes of physical losses at retail and consumer storage. Insect damage, pitting and staining were the major factors contributing to downgrading. The average physical loss of 11.11% at retail level was equivalent to a loss of 1000 tons worth R8.19 million at national level. The average physical loss after seven days of storage was 13.72% and 5.29% under ambient and optimum conditions, respectively. The average physical loss after 14 days was 16.25% under ambient condition and 11.88% under optimum condition. About 50% of fruit was downgraded at retail. The average cumulative weight loss after 14 days under ambient and optimum conditions was 4.81% and 0.54%, respectively. There was a significant difference in ascorbic acid of fruit from different retail stores with fruit from shop three having the highest. However, there was a decrease in ascorbic acid by 22.88% and 23.47% under ambient and optimum conditions, respectively. There was no significant change in TSS of all stored fruits while a significant decrease in TA and MI was observed in fruit from shop three only. The juice content increased after seven days in both storage conditions while colour index (CI) values were increased in ambient conditions corresponding to the variety's typical colour, making the fruit more attractive to the consumer. The energy wasted to produce lost fruits at retail was 3.8 x 10^6 MJ while GHG emission was 2.41 tons $CO_{2eq.}$

Introduction

South Africa is ranked 14^{th} in world citrus production and the world's second largest exporter of fresh citrus. Minneola tangelo a hybrid of Duncan grapefruit (*Citrus paradisi*) and Dancy tangerine *(Citrus reticulata*) is one of the soft citrus grown and consumed fresh in South Africa which is available during winter in June and July. 'Minneola' belong to a group of citrus fruits called tangerines which is a subgroup of mandarins. The primary difference between other mandarins and tangerines is the colour of the peel, where tangerines have a darker reddish-orange peel and other mandarins have a lighter orange colour (Burns, 2004). However, other mandarins are easier to peel and sweeter than tangerines (Muramatsu *et al*., 1999; Campbell *et al*., 2004; Ebel *et al*., 2004)

There was an increase in soft citrus production, processing and export while domestic fresh consumption remained stable from 2009 to 2011(Siphugu, 2011). This progress in the citrus industry can be significant and sustainable by minimising the losses within supply chains. South Africa's total soft citrus production area in 2011was 5 100 ha while harvested area was 4 800 ha yielding 180 000 tons in which 145 00 tons were exported, 26 000 tons processed and 9 000 tons supplied to fresh domestic consumption (DAFF, 2011). However there were no imports of soft citrus fruit in South Africa from 2009 to 2011 (Siphugu, 2011).

The average green, blue and grey water footprint of soft citrus production in South Africa is 262, 170 and 29 cubic meters per ton (Mekonnen & Hoekstra, 2011). Gonzalez *et al* (2011) estimated the average GHG emission and energy for orange production to be 0.32 Kg $CO_{2eq}.kg^{-1}$ and 3.8 $MJ.kg^{-1}$ fruit. Incidence of fruit losses, therefore, implies wastage of resources and environmental damage proportional to amount of losses.

Postharvest practices such as methods of harvesting, handling, treatments, packaging and marketing greatly influence citrus fruit losses. Preharvest factors which influence losses include climatic conditions, especially relative humidity, rainfall, temperature, cultivation practices, tree health, and stage of maturity (Ladaniya, 2008). Appearance is a criterion used by most consumers while purchasing fruit. Consumers dislike fruit that is shrivelled, lustreless and soft. These conditions arise from water loss and lead to reduction in price. Fruit that is infected in the field or injured during harvesting is sure to rot within two to three days while marketing (Ladaniya, 2008). Losses from physical damage, physiological disorders and decay occur throughout the supply chain, despite effective control measures (Kitagawa & Kawada, 1984).

Various studies presented different estimates of soft citrus losses in different countries depending on the methodology adopted for the study, sample size, fruit type, the way fruit is handled, and conditions of packing, transport, season and duration of marketing. Studies in India on soft citrus mandarins indicated that 5% of the fruits are lost at farm, 8% at wholesale, and 10% at retail level (Ladaniya, 2004). Losses at farm were reported to be caused by harvesting injury, insect damage and culls while 49% of the 8% losses at wholesale were due to small size and deformation, 23.5% due to insect- damaged, 20% as result of pressing, 5.5% rotted and 2% sunburn injury. The losses at retail level were mostly due to rotting, pressing and insect damage (Ladaniya, 2004). Additionally, in developing and under-developed countries, mostly in tropics, high losses result from inadequate storage facilities and improper transport and handling as compared to lower losses reported in developed countries were technological advancement, adequate facilities and awareness among growers and marketing personnel (Ladaniya, 2008).

Mandarins are excellent source of vitamins and minerals and supply an array of colour, flavour and texture to the pleasure of eating. Mandarins contain between 14 and 54 $mg.100g^{-1}$ of fresh fruit depending on cultivar, maturity stage, orchard management and postharvest handling (Nagy, 1980; USDA, 2006. Considering this composition, mandarins can supply 28% to 108% of recommended daily intake of vitamin C per 100g (Mbogo *et al*., 2010). Because of the importance of fruits as valuable food resources and in income generation, many studies are being undertaken to establish the quality, physico-chemical properties and postharvest losses of fruits. The fragile ring of Minneola fruit makes it prone to physical damage and infections leading to losses during sorting and transportation. Cold chain management in the supply chain also influences the physico-chemical properties that are related to nutritional and cosmetic quality.

Physico-chemical properties data of fruits are important in adaptation and design of various handling, packaging, storage and transportation systems (Sigh & Reddy, 2005). The properties such as colour and firmness of orange that differentiate units of a product are important to determine the degree of acceptability of product to the buyer (Guzzel *et al*., 1994). Fruit softening is often used as a criterion for estimating the feasibility of their storage or shelf life (Kader, 1992). Studies on the relationship between colour and level of maturation in citrus proposed the use of the formula $1000a^*/(L^*b^*)$ as a colour index for recording the process of degreening (Jimenez-Cuesta *et al*, 1981). Proximate and micro-nutrient analysis is essential for nutritional assessment of fruits to tally the compositions with the dietary intake requirements. Nutritional quality in fruit is determined by physico-chemical changes taking place throughout the supply chain. Evaluation of these changes may be established by the modifications in sensory and chemical characteristics indicating alterations in nutritive value (Biolatto, *et al*., 2005).

There is scarce information on the nature and extent of losses in fruit reaching the South African local fresh markets. The nature and magnitude of these losses could help in identifying factors responsible and provide guidelines in developing proper measures required to prevent or reduce such losses. Therefore, the aim of this study was to assess postharvest losses of Minneola orange at the retail level and during post-purchase storage. The specific objectives were to; (i) estimate the incidence of fruit postharvest physical losses and downgrading, (ii) quantity the changes in physico-chemical properties related to quality during storage, and (iii) estimate the economic and environmental impacts of the losses

Materials and methods

Plant material

Minneola orange fruits were purchased from three retail outlets at Stellenbosch fresh fruit markets in South Africa during winter season (July 2011). A total of 600 fruits were randomly selected from each outlet and transported inside a truck to the Postharvest Technology Research Laboratory at Stellenbosch University, about 2 kilometres from the market. The retail outlets were selected based on volume of fruit sales and handling procedures. Outlet 1 and 2 were supermarkets where ambient shelf temperature was controlled by air conditioners. However, both outlets had a refrigerated facility to store fruit before display. Outlet 3 was an open market where the fruit was displayed in cartons under a shaded area and unsold fruit carried back to the vendors’ home for non-refrigerated storage.

Experimental Design

Fruit from each outlet were randomly distributed among five lots each consisting of three quantities of 40 fruits. The first lot was assessed for external quality and physico-chemical properties on the day of arrival at the laboratory (day zero)

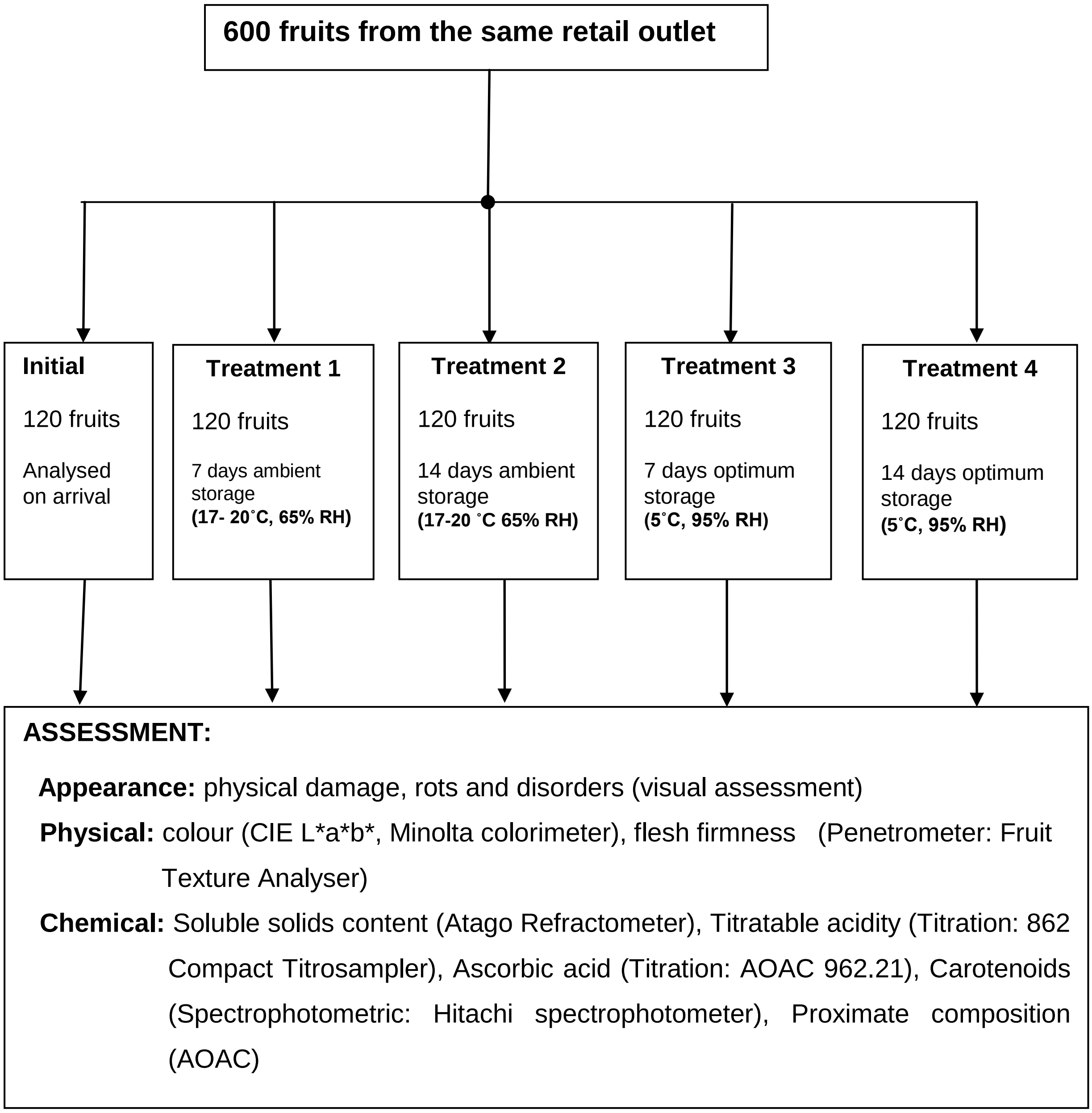


Figure 5.1 Experimental design for quality assessment and physico-chemical assessment of Minneola orange

representing retail quality and losses (Fig 5.1). The remaining four lots had, two lots stored at ambient conditions (17-20 ºC, 65 % RH) and the other two at optimum cold storage (5 ºC, 95% RH). Different storage conditions with variable storage temperature, relative humidity and time were referred to as treatments. One lot from each storage condition was used for external quality and physico-chemical properties analysis after 7 days while the remaining lot was analysed after 14 days. Fruit was inspected for external physical damage, physiological disorders and decay. Fruit not fit for consumption was classified as physical loss and consumable defective fruit as downgrade. The criteria used for external quality assessment was almost similar to what was done at retail outlets. Samples of 10 fruits free from defects were selected from each treatment for physico-chemical analysis. Each fruit was measured for colour and flesh firmness. Samples were divided into two replicates of five fruits each and blended to determine the following parameters; total soluble solids (TSS), titratable acidity (TA), carotenoids content and ascorbic acid. Homogenate from each replicate was freeze dried and stored at -80°C until required for proximate analysis.

Environmental conditions

The environmental conditions inside and outside retail outlets were captured using Tinytag Explorer temperature (-25 – 50 °C) and relative humidity (0 - 100%) loggers (Gemini data loggers, UK).

Postharvest loss assessment

The number of fruit found to be defective for each quantity (40 fruits) of the lot (120 fruits) was expressed as a percentage. The percentages of defects in the three quantities were averaged to represent the whole lot. National physical loss was estimated by expressing the percentage physical loss as a fraction of amount of fruit supplied to the local fresh market while economic loss was the monetary value of the computed losses according to respective retail prices. Physical loss was used to compute the impact of losses on environment and resources (Mekonnen & Hoekstra, 2011; Gonzalez *et al*, 2011).

Weight loss assessment

A sample of 10 fruits from each shop for each storage condition were labelled and weighed at day zero. Individual fruits were weighed after four days and thereafter at two day intervals for the rest of storage period (Singh & Reddy, 2005).The average data of 10 fruits was used for each storage condition.

Proximate composition analysis

Freeze dried samples were used for analysis. Moisture was determined by desiccation at 105 C to constant mass (James, 1996). Ashing was performed at 520 C in a muffle furnace (AOAC, 2000). Nitrogen content was obtained by applying the Kjeldahl method 960.52 (AOAC, 2000) and protein concentration calculated using a nitrogen factor of 6.25. Total dietary fibre was determined using Non-enzymatic-Gravimetric method 993.21 (AOAC, 2005). Crude fat content was determined by extraction using petroleum ether in a Soxhlet Extractor at 90 C and carbohydrates calculated by difference (James, 1996). Energy was calculated using Atwater factors: fat 37 $kJ.g^{-1}$ (9 $kcal.g^{-1}$), protein and carbohydrates 17 $kJ.g^{-1}$ (4 $kcal.g^{-1}$) (Uusitalo *et al*., 2011).

Chemical analysis

Ascorbic acid content was measured using the titration method involving 2,6-dichloroindophenol (AOAC method 967.21, 2000). Carotenoids were extracted from the homogenate using hexane-acetone mixture (3:2) and measurements of the absorbance of the extract at 450 nm and 520 nm were done using in Hitachi spectrophotometer (Helios Omega UV-Vis Thermo Scientific, USA). Results were expressed in microgram total carotenoids and lycopene per gram fresh weight (Opiyo & Ying, 2005). Acidity was determined by titration of 2 ml of the fruit juice with 0.1M sodium hydroxide solution up to pH 8.2 using 862 Compact Titrosampler (Metrohm, Herisau, Switzerland). Results were expressed as percentage of citric acid in fresh material. Total soluble solids results were expressed in ^{0}Brix (%), measured using a digital Refractometer (Atago, Tokyo, Japan). The maturity index (MI) was calculated as TSS to TA ratio.

Colour evaluation

A sample of10 fruits from each shop was used to assess colour changes in each storage condition. Each fruit was numbered for identification and marked equatorially on two positions. The colour was measured twice on both sides of the fruit (marked positions) using a Minolta colorimeter (model CR-200; Minolta Co. Ltd, Osaka, Japan) after standardising the sensor with a white tile and black tile. The measured colour was expressed in L* (lightness), a* (redness and greenness), b* (yellowness and blueness), C (chroma) Hunter parameters and colour index (CI) calculated (Jimenez-Cuesta *et al*., 1981):

$$CI=100a^*/L^*b^* \quad (1)$$

Fruit firmness and juice content

Fruit was set upon a flat base plate of Texture Analyser (TA.XT plus, Stable Microsystems, England). The probe carrier fixed with a 35 mm diameter flat plate was brought in contact with the fruit and a 250 N load cell at a speed of 1 $mm.s^{-1}$ was used to compress the fruit for 10 mm from the contact point. Fruit firmness was expressed as the force that compressed the fruit for 10 mm (Singh & Reddy, 2005). The average values of 10 replications for day zero, day seven and day 14 in both storage conditions are reported. A random sample of six non defective fruit from each treatment was used to determine the juice content. Each fruit was weighed, peeled and pressed using a juice press. The juice was strained and weighed. Juice content was expressed as a percentage of the fruit mass and the average of six fruits used for each treatment (DAFF, 1990)

Statistical analysis

One way analysis of variance (ANOVA) was applied to data using SAS version 9.1 (SAS Institute, 2006). Means were separated using the Fishers test (α=0.05).

Results and discussion

Environmental conditions

All three retail outlets displayed fruit under ambient conditions (Table 5.1). Minneola oranges are should be stored at recommended temperature of 4.5- 6 ºC and relative humidity 90-95% (Ladaniya, 2004; OHIO State University, 2011). Outlet 1 and 2 had almost the same shelf conditions while outlet 3 had higher temperature and lower relative humidity than the later.

Table 5.1 Average temperature and relative humidity on the day of fruit procurement

Retail outlet	Temperature (ºC)		Relative Humidity (%)	
	Inside	Outside	Inside	Outside
Outlet 1	19	21	83	53
Outlet 2	18	23	83	39
Outlet 3	25	25	39	39

Physical loss at retail

Physical losses at retail level ranged from 7.67 - 13% among outlets (Table 5.2). Similarly, Ladaniya (2004) reported 10% loss at retail for mandarins in India while higher losses in Kinnow mandarins at retail were reported in Delhi (10.06%) and Bangalore (13.7%) (Gangwar *et al*., 2007). However, the physical damage and rots were a common cause of losses for Kinnow mandarin and studied Minneola oranges.

The major contributing factors for physical losses in Minneola fruit were physical damage (compression and puncture injury) and puffiness (Fig 5.2). Puffiness is a condition whereby the rind becomes thick and separates from the pulp creating an air gap between the peel and the pulp. This condition is caused by high humidity associated with long storage period (Ladaniya, 2004). The incidences of puffiness observed can be an indication of long storage periods of the fruit associated with high humidity in the supply chain represented by the retail outlets.

Physical damage (0.83-6.67%) and puffiness (3.33-5%) was identified in fruit from all outlets. Gangwar *et al* (2007) reported lower incidences of Kinnow mandarin physical damage in Delhi (2.46%) and Bangalore (2.36%) indicating differences in handling systems. Higher incidence of physical damage in fruit from outlet 2 and 3 highlights rough handling or poor packaging.

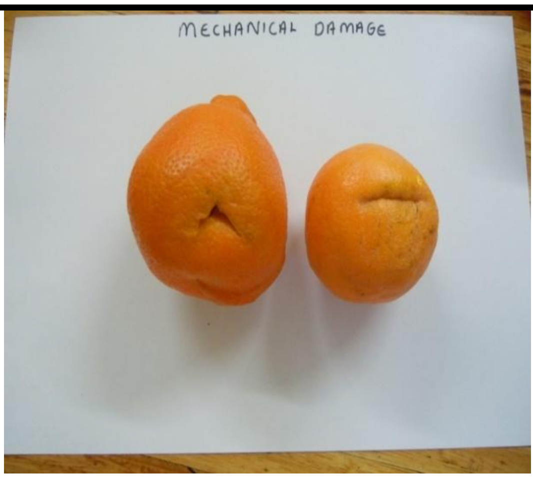
Microbial spoilage ranged from 0.83% to 3.33% in which green mould was identified (Fig 5.2). In comparison, higher incidences of rots in Kinnow mandarin were reported in Delhi (7.60%) and Bangalore (11.34%) (Gangwar *et al*., 2007). The variation in rot incidence of the supply chain systems can be attributed to differences in cold chain management. The identified green mould (*P.digitatum*) infects wounded fruit slowly at lower temperatures and at higher temperatures (20-30 ^{0}C) it grows very rapidly.

Table 5.2 Means of percentage downgrade and physical loss of Minneola orange at retail (day zero)

CLASS	DEFECT	Outlet 1	Outlet 2	Outlet 3
DOWNGRADE	Bollworm damage	0.00	5.00	20.00
	Thrip damage	8.33	0.00	3.33
	Wind/mechanical injury (scars)	32.50	5.83	14.17
	Chemical burn (scars)	7.50	0.00	6.67
	Red scale	5.83	0.00	2.50
	Staining	5.00	2.50	1.67
	Pitting	12.50	10.00	9.17
	Sunburn	3.33	0.00	2.50
PHYSICAL LOSS	Green Mould	3.33	0.00	0.00
	White Rot	0.00	1.67	0.83
	Physical damage	0.83	5.83	6.67
	Puffiness	3.33	5.00	5.00
DOWNGRADE		**75.00**	**23.33**	**60.00**
PHYSICAL LOSS		**7.67**	**13.00**	**12.67**

It is associated with poor orchard and packinghouse sanitation which promotes sporulation (Ladaniya, 2004).The microbes from orchards and packinghouses make inoculums which affects fruit down the supply chain to the consumer. Green mould incidence on fruits from retail outlet 1 indicates poor sanitation and cold chain management within the represented supply chain. The incidence on shelf could also be attributed to lack of shelf inspection, high shelf temperatures and fruit wounding at retail level.

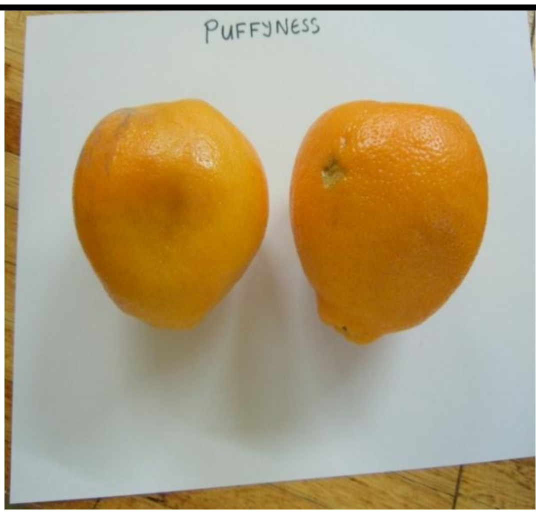
The average physical loss of 11.11% at retail level resulted in estimated national annual loss in soft citrus of 1 000 tons in South Africa. Considering the recommended 146 kg per capita consumption of fruit and vegetables per year (WHO, 2004), the magnitude of postharvest loss of ‘Minneola’ at retail alone is sufficient to meet the annual fruit intake of approximately 7 000 people.



MECHANICAL DAMAGE

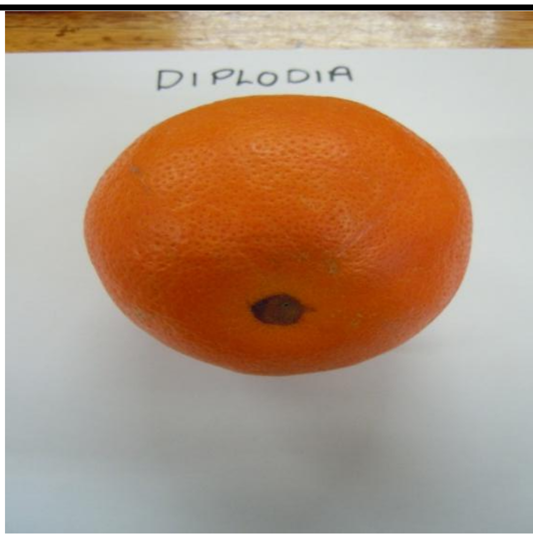
WHITE MOLD

GREEN MOLD



PUFFINESS

PITTING



DIPLODIA

Figure 5.2 Photographs of representatives of each Minneola orange defect used to categorise fruit into physical loss and downgrade

Physical losses during consumer storage

The average physical loss after seven days storage was 13.72% under ambient condition and 5.29% at 5 ºC. The average physical loss after 14 days was 16.25% under ambient condition and 11.88% at 5 ºC. Duo *et al* (2004) reported 16% decay incidences in Minneola stored at 22 ºC after 14 days while Nules mandarins stored at ambient temperature (18-20 ºC) had 100% decay after seven days (Perez el al, 2005). This indicates that higher losses than recorded in this study can occur during storage of soft citrus depending on the cultivar and previous handling.

Consumers prefer mandarins with a relatively long post-purchase life of at least 31 days (Campbell *et al*., 2006). There were higher incidences of rots in ambient condition in comparison to refrigerated fruit after 7 and 14 days of storage. Green mould and diploida (*Botryodiplodia theobromae)* (Fig 5.2) were observed on fruit from retail outlet 3 only under refrigeration after seven days. *Botryodiplodia* is a waterborne bacterium which invades the fruit through scars at the stem-end (Ladaniya, 2008).Puffiness increased in ambient condition for fruit from outlet 1 and 2 after seven day storage. Fruits stored at 5 ºC showed a decrease in puffiness after seven days but later increased after 14 day storage. This showed puffiness is a problem for long storage of Minneola fruit. The high humidity of 95% under refrigerated conditions might also have contributed to puffiness. Diploida rot*)* was observed in fruit from outlet 2 under ambient conditions and fruit from outlet 3 stored at 5 ºC after seven days (Table 5.3). However, it later increased in both storage conditions after 14 days with fruit from Retail outlet 3 having the highest incidence of 5% (Table 4).

Downgrading at retail and consumer storage

The amount of fruit downgraded at retail level ranged from 23.33% to 75% among outlets. In comparison, 38% of 'Goorg' mandarins were downgraded and sold at 80% reduced price in India (ICAR, 1991). Downgrading after seven day storage ranged from 27.50% to 61.67% under ambient condition and 20% to 50.83% under refrigeration (Table 5.3) while after 14 day (Table 5.4) storage ranged from 22.5% to73.33% in ambient condition and 22.5% to 42.55% at 5 ºC. Fruit from retail outlet 3 had the highest amount of downgrade in all storage conditions after 14 day storage.

Fruit from retail outlet 2 had the least amount of downgraded fruits at retail level and during consumer storage. Down grading was due to cosmetic defects (Table 5.2) which include insect damage (bollworm, thrip and red scale), chemical burn scars, staining, pitting and sunburn. The major downgrading defects were pitting, insect damage, mechanical injury scars and chemical burns. However, insect damage, mechanical injury scars and chemical burns were due to pre-harvest practices only affecting the rind of the fruit and have no effect on the chemical composition of the edible pulp during storage. Pitting and staining conditions can be increased by high temperature. It was reported that for fruit stored at 20 ºC, with a 2 hour exposure to low humidity (30%) was sufficient to induce peel pitting in tangerines after transfer to high humidity of 90% (Alferez *et al*., 2005). Furthermore, damage of the epicuticular wax structure may result in increased flavedo water permeability and water loss and influence the development of peel pitting during storage (Sala, 2000).

The identified defects were among those not permitted for export fruit which indicates that the fruit at the local retail outlets could have failed for export (PPECB, 2011). The maximum permitted percentage cosmetic defects (blemishes, wilt, shrivelling, skin defects, and minor bruises) of fruit intended for sell in South Africa is 5% for Class 1, Class 2 (15%) and Lowest Class (20%) (DAFF, 1990).There were higher incidences of pitting and staining for fruit stored under ambient condition than at 5 ºC (Table 5.3).

Table 5.3 Means of percentage downgrade and physical loss of Minneola orange during storage after seven days

CLASS	DEFECT	AMBIENT (17-20 °C)			OPTIMUM (5°C)		
		Outlet 1	Outlet 2	Outlet 3	Outlet 1	Outlet 2	Outlet 3
DOWNGRADE	Bollworm damage	0.00	0.00	6.67	2.50	0.83	6.67
	Thrip damage	8.33	0.83	0.83	4.17	0.00	2.50
	Wind/mechanical injury (scars)	18.33	6.67	6.67	10.00	2.50	7.50
	Chemical burn (scars)	5.83	0.00	0.00	6.67	0.00	7.50
	Red scale	2.50	0.00	6.67	3.33	0.00	3.33
	Staining	9.17	6.67	2.50	5.83	1.67	5.83
	Pitting	12.50	13.33	12.50	9.17	15.00	10.83
	Sunburn	5.00	0.00	0.83	9.17	0.00	3.33
PHYSICAL LOSS	Green Mould	2.50	1.67	1.67	0.00	0.00	0.83
	White Rot	0.00	1.67	0.83	0.00	0.00	0.83
	Physical damage	0.83	2.50	1.67	0.83	0.83	0.00
	Puffiness	7.50	8.33	4.17	2.50	1.67	5.83
	Diploida	0.00	0.83	0.00	0.00	0.00	0.83
	Weight loss	2.30	2.40	1.80	0.28	0.34	0.26
DOWNGRADE		**61.67**	**27.50**	**30.83**	**50.83**	**20.00**	**47.50**
PHYSICAL LOSS		**13.31**	**17.73**	**10.13**	**3.94**	**3.01**	**8.93**

Table 5.4 Means of percentage downgrade and physical loss of Minneola orange during storage after 14 days

CLASS	DEFECT	AMBIENT (17-20 °C)			OPTIMUM (5°C)		
		Outlet 1	Outlet 2	Outlet 3	Outlet 1	Outlet 2	Outlet 3
DOWNGRADE	Bollworm damage	0.00	1.67	5.83	0.00	0.00	14.17
	Thrip damage	5.83	0.00	1.67	5.83	0.00	1.67
	Wind/mechanical injury (scars)	12.5	5.00	1.67	11.67	10.00	15.00
	Chemical burn (scars)	3.33	0.00	5.83	3.33	0.83	4.17
	Red scale	8.33	0.00	3.33	5.83	0.00	0.00
	Staining	0.83	0.00	4.17	1.67	0.83	2.50
	Pitting	10.83	15.83	38.33	3.33	10.83	3.33
	Sunburn	5.83	0.00	2.50	4.17	0.00	1.67
PHYSICAL LOSS	Green Mould	0.83	1.67	0.00	1.67	0.00	0.00
	White Rot	0.00	0.00	0.00	0.00	0.00	1.67
	Physical damage	0.00	6.67	3.33	1.67	3.33	0.83
	Puffiness	3.33	6.67	5.00	1.67	5.00	4.17
	Diploida	2.50	3.33	2.50	0.83	0.00	5.00
	Weight loss	5.08	5.54	3.81	0.55	0.56	0.53
DOWNGRADE		**47.50**	**22.50**	**73.33**	**35.83**	**22.50**	**42.50**
PHYSICAL LOSS		**12.08**	**24.21**	**12.48**	**6.55**	**16.56**	**12.53**

Weight Loss

The average weight loss was about 10 times more under ambient condition (4.81%) than optimum condition (0.54%) after 14 days. Fruit from retail outlet 2 stored under ambient condition lost weight faster than fruit from other outlets reaching 5.54% at day 14. In comparison, weight loss of 19.4% under ambient (28 ºC) and 7.3% at 7 ºC after seven days was reported for in Nagpur mandarins (Sigh & Reddy, 2006) while Nules' mandarins stored at ambient temperature (18-20 ºC) showed a 0.97% weight loss after two days and 4.75% after one week (Perez *et al*., 2005).

Increase in temperature has been reported to accelerate respiration and transpiration rate leading to increase weight loss in fruit (Kader, 2002). Higher weight loss in fruit stored under ambient condition may be attributed to the high rate of change in soluble sugar concentration due to the monosaccharide utilisation in the respiration (Martinez-Javega *et al*., 1989). Weight loss of Minneola oranges increased with time in all storage conditions (Table 5.2 & 5.3) implying that longer post-purchase storage could lead to reduced consumable fruit weight.

Table 5.5 Cumulative percentage weight loss of Minneola oranges stored under ambient conditions (mean ± standard deviation)

Storage Time (Days)	Outlet 1	Outlet 2	Outlet 3
4	1.37 ± 0.25^{c}	1.43 ± 0.23^{c}	1.23 ± 0.51^{b}
6	2.15 ± 0.38^{d}	2.20 ± 0.39^{c}	1.83 ± 0.38^{b}
8	2.75 ± 0.48^{c}	2.30 ± 0.30^{c}	2.24 ± 0.34^{b}
10	4.14 ± 0.70^{b}	4.48 ± 0.80^{b}	3.15 ± 0.42^{b}
12	4.53 ± 0.76^{b}	4.89 ± 0.89^{b}	3.39 ± 0.48^{b}
14	5.44 ± 0.95^{a}	5.88 ± 1.14^{a}	3.81 ± 0.74^{a}

Means of parameters in the same column followed by different letter are significantly different ($P<0.05$)

Table 5.5 Cumulative percentage weight loss of Minneola oranges stored under optimum conditions (mean ± standard deviation)

Storage Time (Days)	Outlet 1	Outlet 2	Outlet 3
4	0.22 ± 0.05[b]	0.27 ± 0.05[c]	0.21 ± 0.04[c]
6	0.29 ± 0.08[b]	0.32 ± 0.06[bc]	0.26 ± 0.05[c]
8	0.29 ± 0.09[b]	0.37 ± 0.07[b]	0.25 ± 0.06[c]
10	0.48 ± 0.13[a]	0.51 ± 0.09[a]	0.42 ± 0.08[b]
12	0.52 ± 0.14[a]	0.55 ± 0.10[a]	0.44 ± 0.09[b]
14	0.55 ± 0.16[a]	0.56 ± 0.10[a]	0.53 ± 0.11[a]

Means of parameters in the same column followed by different letter are significantly different (P<0.05)

Proximate Composition

There was no significant difference in nutrients between fruits from all retail outlets (Table 5.5), however ash content of fruit from retail outlet 2 was significantly higher (P<0.05) than fruit from other outlets. Variation in ash content could be due to differences in soil types and different rates of absorption of minerals by plants which in turn is influenced by, among other factors, pH of soil and organic matter content (Vogel, 1978; Ifon & Bassir, 1979). However, determination of individual mineral elements in the ash could have given better nutritional data as it is estimated that tangerines contain 25 - 47 mg calcium, 11.7- 23 mg, phosphorous and 0.17 - 0.6 mg iron per 100 g edible portion (USDA, 2011). The average nutrient composition of fruit at retail level was; moisture 72.46%, proteins 3.21%, ash 0.44%, crude fat 0.07%, dietary fibre 2.43% and carbohydrates 23.83%. In comparison, mandarins fruits are reported to contain an average of 85% water, 13% carbohydrates, 0.85% protein, (0.29-0.54)% ash, (0.05-0.32)% fat and 1.85% fibre (USDA, 2006). The dietary fibre content falls in the range (1.3g to 4.4 g.100 g^{-1} edible portion of oranges) reported by Widmer (2002). The average caloric energy value was 377.98 kJ.100 g^{-1} of edible portion. Physical loss of the fruit implies loss of measured nutrients that could have been utilised. The estimated physical loss of 1000 tons would have provided with 3.78 x 10^9 kJ which could benefit over 1200 adults with at least 8400 kJ per person per day for one year.

Table 5.5 Proximate composition at retail (day zero) and after seven day storage at 5 C (mean ± standard deviation)

PARAMETER	DAY 0			DAY 7		
	Outlet 1	Outlet 2	Outlet 3	Outlet 1	Outlet 2	Outlet 3
Mass	199.94 ± 42.74	270.91 ± 23.32	328.64 ± 38.25	188.44 ± 31.65	264.84 ± 23.86	306.28 ± 30.35
Energy ($kJ.100g^{-1}$)	373.70 ± 40.13^{a}	346.12 ± 22.65^{a}	414.13 ± 32.15^{a}	482.02± 139.41^{a}	421.45 ± 105.94^{a}	430.70 ± 29.00^{a}
Energy ($kcal.100g^{-1}$)	89.09 ± 9.57	82.52 ± 5.40	98.73 ± 7.67	114.91 ± 33.24	100.47 ± 25.26	102.68 ± 6.91
Water ($g.100g^{-1}$)	74.79 ± 2.64^{a}	76.55 ± 1.50^{a}	72.17 ± 2.10^{a}	67.4 ± 9.24^{a}	71.38 ± 7.01^{a}	71.06 ± 1.9^{a}
Protein ($g.100g^{-1}$)	2.30 ± 0.11^{c}	1.90 ± 0.08^{dc}	1.66 ± 0.01^{c}	5.22 ± 0.38^{a}	4.95 ± 0.42^{a}	3.67 ± 0.2^{b}
Crude Fat ($g.100g^{-1}$)	0.04 ± 0.01^{c}	0.05 ± 0.03^{c}	0.09 ± 0.01^{b}	0.08 ± 0.01^{b}	0.07 ± 0.004^{b}	0.17 ± 0.02^{a}
Ash ($g.100g^{-1}$)	2.51 ± 0.05^{e}	3.09 ± 0.0^{ab}	2.81 ± 0.1^{dc}	2.97 ± 0.01^{bc}	3.23 ± 0.11^{a}	2.74 ± 0.19^{de}
Dietary Fibre ($g.100g^{-1}$)	2.16 ± 0.34^{ab}	1.70 ± 0.38^{b}	1.57 ± 0.42^{b}	3.80 ± 1.81^{a}	3.04 ± 0.6^{ab}	2.73 ± 1.40^{ab}
Carbohydrates ($g.100g^{-1}$)	22.48 ± 2.74^{a}	21.03 ± 1.56^{a}	25.65 ± 2.09^{a}	26.86 ± 8.85^{a}	23.10 ± 7.42^{a}	24.70 ± 1.98^{a}

Means of parameters in the same row followed by different letter are significantly different ($P<0.05$)

Chemical changes

There was a significant difference (P<0.05) in ascorbic acid between fruit from all three retail outlets at day zero ranging from 21.79 - 30.56 $mg.100g^{-1}$ with fruit from shop three having the highest content (Table 5.6). The average ascorbic acid content of fruit at retail was 24.15 mg which was within the range of 14 to 50 $mg.100g^{-1}$ edible portion reported by Nagy (1980) and USDA (2006). However the later reported that the contents depend on cultivar, stage of maturity and environmental factors during development in the field as well as postharvest handling conditions.

Minneola fruit (average mass 248 g) was found to contain 55 mg of ascorbic acid therefore consumption of one healthy fruit will meet the recommended daily allowance (50 mg). On a consumer's perspective, mandarins should display a high vitamin C content label (Campbell *et al*, 2006). South African Minneola orange could be considered as a source of ascorbic acid for nutritional purposes. The estimated physical loss of 1000 tons could have benefited approximately 13 232 people with 50 mg of ascorbic acid per day for the whole year.

There was a significant decrease (P<0.05) in ascorbic acid in all storage conditions. Postharvest handling conditions, such as prolonged storage periods, high storage temperatures, low relative humidity, physical damage and chilling injury were reported by Kader (1988) to induce vitamin C destruction in citrus fruits. Post purchase storage of the studied Minneola fruit (Table 5.6) for one week in ambient conditions led to 22.88% loss in ascorbic acid while under refrigerated conditions 23.47% was lost. Extending storage to two weeks in refrigerated conditions of 5 ºC led to 27.56% decrease in ascorbic acid. In comparison, warmed Nules' mandarins (two cycles of 18hrs at 38 ºC) and subsequently stored at (18-20) ºC for one week showed higher ascorbic acid losses (12%) than fruit that is not warmed (10%) (Perez *et al*., 2005). Furthermore, changes in ascorbic acid depend on conditions and cultivar as it is shown that cold storage of Clemenules' mandarin led to a decrease in vitamin C while significant increase in vitamin C in Fortune mandarin after storage at low temperature was recorded (Huang *et al*., 2008; Rapisarda *et al*., 2008; Sidri *et al*., 2008).

Table 5.6 Chemical parameters of Minneola oranges during consumer storage (means ± standard deviation)

Sample	Temperature (C)	Time (Days)	Ascorbic acid (mg.100g^{-1})	Total Carotenoids (µg.g^{-1})	Lycopene (µg.g^{-1})	TSS	TA	MI (TSS:TA)
Outlet 1		0	25.43 ± 0.37^{bc}	141.60 ± 2.51^{c}	80.70 ± 1.33^{a}	11.40 ± 0.95^{a}	1.12 ± 0.13^{abcde}	10.21 ± 0.37^{bcd}
	5	7	25.48 ± 0.41^{bc}	121.00 ± 2.46^{d}	24.75 ± 1.21^{d}	10.17 ±1.01^{a}	1.06 ± 0.12^{abcde}	9.73 ± 1.90^{bcd}
		14	20.95 ± 0.41^{ed}	49.47 ± 10.06^{h}	18.10 ± 6.55^{ef}	10.87 ± 0.93^{ab}	1.38 ± 0.12^{ab}	7.92 ± 0.87^{d}
	17-20	7	19.52 ± 0.82^{g}	138.40 ± 5.54^{c}	79.77 ± 3.62^{a}	10.23 ± 0.64^{ab}	0.95 ± 0.28^{abcde}	11.53 ± 3.66^{abcd}
		14	18.33 ± 0.82^{f}	54.87 ± 3.76^{gh}	16.43 ± 2.45^{gf}	10.93 ± 0.78^{ab}	1.40 ± 0.57^{a}	8.96 ± 4.28^{dc}
Outlet 2		0	21.79 ± 0.64^{d}	135.53 ± 4.30^{c}	46.68 ± 2.89^{h}	10.67 ± 1.21^{ab}	0.91 ± 0.13^{cde}	11.73 ± 0.75^{abcd}
	5	7	17.38 ± 0.19^{hg}	102.93 ± 8.78^{e}	50.34 ± 6.10^{b}	10.57 ± 0.72^{ab}	1.03 ± 0.15^{abcde}	10.43 ± 1.52^{bcd}
		14	17.62 ± 0.41^{hg}	76.73 ± 5.22^{f}	12.79 ± 3.30^{gf}	10.57 ± 0.72^{ab}	0.96 ± 0.19^{abcde}	11.44 ± 3.05^{abcd}
	17-20	7	17.38 ± 0.41^{hg}	80.67 ± 6.38^{f}	33.38 ± 4.66^{c}	10.70 ± 0.17^{ab}	0.73 ± 0.19^{e}	15.28 ± 4.06^{a}
		14	15.00 ± 0.00^{f}	62.87 ± 6.50^{g}	11.02 ± 4.94^{gh}	9.90 ± 0.30^{b}	0.92 ± 0.25^{bcde}	11.42 ± 3.92^{abcd}
Outlet 3		0	30.56 ± 0.37^{a}	178.93 ± 4.44^{b}	26.47 ± 3.24^{d}	10.10 ± 0.17^{ab}	1.33 ± 0.60^{abc}	8.45 ± 2.95^{d}
	5	7	25.00 ±1.24^{c}	197.73 ± 0.37^{a}	49.09 ± 6.10^{b}	10.43 ± 0.78^{ab}	0.81 ± 0.02^{abcd}	8.75 ± 0.70^{d}
		14	20.00 ± 0.71^{ef}	102.53 ± 0.88^{e}	25.48 ± 2.53^{d}	10.73 ± 0.32^{ab}	0.93 ± 0.01^{ed}	13.31 ± 0.54^{ab}
	17-20	7	26.19 ± 0.41^{b}	76.27 ± 6.40^{f}	24.54 ± 5.48^{de}	10.97 ± 0.19^{ab}	0.74 ± 0.02^{ed}	6.12 ± 2.69^{a}
		14	17.15 ± 0.00^{h}	83.87 ± 4.28^{f}	10.82 ± 2.81^{gh}	10.70 ± 0.66^{ab}	0.83 ± 0.03^{ed}	12.93 ±1.28^{abc}

Means of chemical components in the same column followed by different letter are significantly different ($P<0.05$)

There was no significant difference (P>0.05) in TSS, TA and MI of Minneola oranges at retail level. TSS and TA of oranges are responsible for the organoleptic value of the fruit which includes flavour, sweetness and sourness (Palou *et al*., 2008; Tietel *et al*., 2011). TSS of Minneola oranges at retail ranged from 10.1-11.4%, while TA ranged from 0.91-1.33% with MI of 8.45-11.73. Contrastingly, TA of freshly harvested mandarin range from 0.73 to 0.85% while TSS range from 10.5 to 10.8% depending on cultivar (Perez-Lopez & Carbonell-Barrachina, 2005). United States maturity standards require that mandarin s have a minimum MI of 6.5 (Arpaia & Kader, 2006), while in South Africa the standards require a minimum of 7.0 (DAFF, 1990).

There was no significant (P>0.05) change (Table 5.6) in TSS of all fruits. However, a significant decrease in TA and increase in MI was observed in fruit from retail outlet 3 while there was no change in these parameters for fruit from other outlets. These results are, in general, in concordance with those reported in 'Or' and 'Odem' mandarins stored for four weeks at 2.5 ºC and 8 ºC followed by three days at 20 ºC (Tietel *et al*., 2011). As mandarin fruit matures TSS increases and TA decreases, resulting in an increased MI (Nunes, 2008). Duo *et al* (2004) reported an increase in TSS of Minneola fruit stored at 22 ºC for two weeks, while Satsuma mandarins stored at 30 ºC showed higher MI compared to fruit held at 18 ºC due to decrease in TA (Burdon *et al*, 2007). The increase in TSS during storage might be due to the moisture loss, hydrolysis of polysaccharides and concentration of the juice as a result of degradation (Kaur *et al*., 2011). Decrease in TA could be attributed to the use of organic acids as respiratory substrates during storage and conversion of acids into sugars (Echeverria & Valsch, 1989).

Carotenoids are anti-oxidants, free radical scavengers and provide orange yellow and red colours of the oranges (Grassmann *et al*., 2002; Britton *et al*., 1995). Lycopene intake in particular is associated with a decreased incidence of prostate cancer (Giovannucci, 1999). The total carotenoid content of Minneola fruit at retail ranged from 135.53 mg to 178.93 mg per 100g edible portion while lycopene content ranged from 26.47 mg to 80.7 mg. Fruit from retail outlet 3 had a significantly higher carotenoid content than fruit from other outlets which did not differ. Minneola fruit from retail outlet 1 had the highest lycopene content than fruit from other shops while fruit from outlet 3 had the least. There was a decrease in total carotenoid and lycopene of fruit under all storage conditions except for fruit from outlet 3 under ambient conditions which showed an increase after 7 days.

Colour attributes

Minneola oranges have a bright reddish-orange colour at peak maturity. There was a significant difference (P<0.05) in colour between the fruits from all retail outlets (Table 5.7). Although there was no significant change (P>0.05) in colour of fruit stored at 5 ºC after 14 days, fruit under ambient condition showed a significant increase in L*(brightness), a*(redness) and CI after seven days. Additionally fruit under ambient conditions showed no significant change in b*(yellowness) and chroma (intensity) after 14 days. The significant decrease in hue angle of fruit under ambient condition towards 60º zone indicates change towards the cultivars' typical reddish-orange colour. Similar trend was reported for 'Odem' mandarin stored at 8 ºC for four weeks in which the hue angle increased from 39º to 45º, thus changing towards reddish-orange colour (Tietel *et al*., 2011). Ambient condition promoted degreening leading to the variety's typical colour, making the fruit more attractive to the consumer. Post-purchase storage at ambient conditions improves the colour better than refrigerated conditions.

Juice content and fruit firmness

The minimum juice requirements for soft citrus intended for sale in republic of South Africa is 45% (DAFF, 1990). Minneola fruit had lower juice content (Table 5.8) at retail level in comparison to the minimum juice requirements. There was no significant difference in juice content between fruit from all shops (P>0.05). However, juice content increased during post-purchase storage in both ambient and refrigerated conditions meeting the agricultural products standards of South Africa (DAFF, 1990). There was a significant increase (P<0.05) in juice content of fruit from retail outlet 1 and 3 after seven days in all storage conditions. However, no significant change (P>0.05) in juice content was noticed from day 7 to day 14 in all storage conditions. Treatments used in the study had no effect on the juice content of mandarins from Stellenbosch market that season.

High quality mandarins should have a turgid and firm, deep orange-red peel, which should be easily removed from the flesh by hand. Additionally, the flesh should be juicy containing few or no seeds (Burns, 2004; DAFF, 1990). There was no significant difference (P>0.05) in firmness of Minneola fruit at retail level indicating that fruit from all shops had equal strength to resist impact and compression forces during consumer handling.

Table 5.7 Colour parameters of Minneola oranges during consumer storage (mean ± standard deviation)

Source	Temperature (°C)	Time(Days)	L^*	a^*	b^*	C	h^0	CI $(1000a^*)/L^*b^*$
Outlet 1	**5**	0	60.51 ± 2.29 ^{d}	33.92 ± 4.23^{ab}	54.86 ± 4.14^{i}	64.70 ± 2.97 ^{f}	58.21 ± 4.51 ^{ed}	10.39 ± 2.32^{a}
		7	59.84 ± 1.74 ^{ed}	34.93 ± 3.65^{a}	55.98 ± 3.37^{ghi}	66.11 ± 3.03 ^{cde}	58.00 ± 3.63^{ed}	10.53 ± 2.87^{a}
		14	59.83 ± 1.67 ^{ed}	35.47 ± 3.44^{a}	57.48 ± 4.77^{fgh}	67.69 ± 3.67 ^{bc}	58.22 ± 3.89^{ed}	10.45 ± 2.87^{a}
	17 – 20	0	60.27 ± 2.31^{d}	30.10 ± 4.87^{b}	55.71 ± 4.85^{hi}	63.54 ± 4.17 ^{f}	61.5 ± 4.87^{d}	9.13 ± 2.14^{b}
		7	58.71 ± 2.23 ^{ef}	33.82 ± 2.95^{ab}	55.24 ± 3.57^{hi}	64.89 ± 2.28 ^{def}	58.45 ± 3.52^{ed}	10.57 ±1.62^{a}
		14	57.93 ± 1.92 ^{f}	35.15 ± 2.54 ^{a}	54.52 ± 2.96^{i}	64.94 ± 2.24 ^{def}	57.15 ± 2.80^{e}	11.22 ± 1.75^{a}
Outlet 2	**5**	0	63.92 ± 2.49^{a}	21.53 ± 6.27^{de}	60.77 ± 3.26^{de}	64.77 ± 2.89^{def}	70.5 ± 45.76^{b}	5.64 ± 1.61^{e}
		7	63.38 ± 2.40 ^{c}	23.21 ± 5.88^{cde}	61.81 ± 2.85^{de}	66.29 ± 2.40^{bcde}	69.46 ± 5.29^{bc}	6.02 ± 2.49^{de}
		14	62.88 ± 2.44^{c}	24.46 ± 5.19^{dc}	66.57 ± 2.76^{ab}	71.12 ± 2.48^{a}	69.8 ± 4.30^{bc}	5.93 ± 2.84^{de}
	17 – 20	0	63.25 ± 2.00 ^{c}	19.83 ± 8.23^{ef}	59.48 ± 3.94^{ef}	63.18 ± 4.35 ^{f}	71.86 ± 7.67^{b}	5.25 ± 2.01^{e}
		7	61.14 ± 2.39 ^{d}	23.08 ± 9.44^{cde}	58.07 ± 3.89^{fg}	63.11 ± 4.74 ^{f}	68.78 ± 8.71^{bc}	6.48 ± 1.94^{cde}
		14	60.18 ± 2.07 ^{d}	25.12 ± 9.48^{c}	57.03 ± 3.39^{fgh}	62.90 ± 4.84 ^{f}	66.73 ± 8.52^{c}	7.30 ± 1.61^{c}
Outlet 3	**5**	0	68.20 ± 2.16 ^{a}	13.90 ± 5.87^{g}	65.28 ± 4.30^{ab}	66.97 ± 4.54^{bcd}	78.06 ± 4.89^{a}	3.12 ± 2.14^{f}
		7	67.83 ± 2.38^{a}	14.24 ± 6.17^{g}	66.61 ± 4.08^{a}	68.38 ± 4.03^{b}	77.99 ± 5.33^{a}	3.15 ± 1.62^{f}
		14	67.55 ± 1.61 ^{a}	15.73 ± 6.04^{g}	65.23 ± 3.17^{ab}	67.34 ± 3.43^{bc}	76.54 ± 5.09^{a}	3.57 ± 1.75^{f}
	17 – 20	0	67.04 ± 2.78 ^{a}	16.56 ± 6.64^{gf}	64.2 ± 3.91^{bc}	66.63 ± 4.34^{bcde}	75.72 ± 5.59^{a}	3.84 ± 1.32^{f}
		7	65.30 ± 2.87 ^{a}	21.27 ± 8.50^{de}	62.43 ± 4.09^{cd}	66.48 ± 3.91^{cde}	71.38 ± 7.65^{b}	5.30 ± 1.45^{e}
		14	63.54 ± 2.87^{a}	25.76 ± 8.65^{c}	61.38 ± 3.67^{de}	67.15 ± 2.43^{bcde}	67.31 ± 7.82^{c}	6.82 ± 1.40^{dc}

Means of colour parameters in the same column followed by different letter are significantly different ($P<0.05$)

Table 5.8 Juice content and firmness of Minneola oranges during consumer storage (mean ± standard deviation)

Sample	**Temperature (^oC)**	**Time (Days)**	**Juice content (%)**	**Firmness (N)**
Outlet 1		0	39.69 ± 3.62[bcd]	22.37± 6.82[bcd]
	5	7	50.19 ± 1.91[a]	18.97±3.75[cdef]
		14	48.01 ± 3.82[a]	18.15±3.66[bcdef]
	17 – 20	7	49.04 ± 3.58[a]	16.77 ± 5.24[ef]
		14	47.01 ± 6.12[abc]	13.88±3.91[f]
Outlet 2		0	39.33 ± 7.05[cd]	23.57±6.35[ab]
	5	7	46.57 ± 2.87[abcd]	20.14±3.24[edf]
		14	46.43 ± 2.49[abc]	18.99±4.94[bcdef]
	17-20	7	45.11 ± 4.18[abcd]	18.18±2.60[cdef]
		14	46.46 ± 2.77[abc]	18.00±2.23[bcde]
Outlet 3		0	38.41 ± 4.76[d]	27.79±6.40[a]
	5	7	46.91 ± 1.26[abc]	28.08±4.29[abc]
		14	44.57 ± 2.89[abcd]	23.16±4.01[a]
	17-20	7	47.33 ± 2.33[ab]	19.39±4.81[bcde]
		14	46.99 ± 1.59[abc]	15.56±3.86[ef]

Means of juice content and firmness in the same column followed by different letter are significantly different ($P<0.05$)

There was no significant change in firmness of fruit stored under optimum conditions for 14 days. Fruit from all outlets under ambient conditions showed a significant decrease in firmness after 7 days which did not change when the storage period was extended to 14 days. However, instrumental tests on flesh firmness and consumer sensory evaluation on fruit segments could have given more data on the sensory characteristics associated with the fruit handling within the supply chain and post-purchase storage.

Economic loss and environmental impact

The estimated annual physical loss of 1000 tons at retail level was worth R8.9 million (Table 5.9). In comparison, the annual economic loss of Nagpur mandarin for 10% physical loss at retail in Central India was 500 million Indian Rupees (R7.8 million) (Ladaniya, 2004). The average economic loss during post-purchase storage was

R0.91 kg^{-1} of fruit purchased and stored under ambient conditions for seven days while under refrigerated condition had an average economic loss of R0.35 kg^{-1}. Land used to grow lost and wasted Minneola orange which could have been used for other productive economic activities amounts to about 307 ha while the average energy wastage was estimated at and 3.8 x 10^6 MJ. The average GHG emission of fruit losses was 320 tons CO_{2eq}, while total water footprint 262 x 10^3 m^3. Water wasted due to fruit losses at retail level could meet the recommended basic water requirement (50 $L.day^{-1}$) of about 14 400 people (Peter & Gleik, 1999) while it will require planting of over 8 000 trees on open space to sink the GHG emission of the fruit losses (0.039 metric ton per urban tree planted) (U.S. DOE, 1998). Higher losses under ambient condition than optimum condition highlights the importance of maintaining cold chain to reduce postharvest losses associated with wastage of resources and environmental impact.

Table 5.9 Estimated national retail losses and environmental impact of Minneola oranges

PARAMETER	Outlet 1	Outlet 2	Outlet 3	MEAN
Area harvested(x10^3 ha)	4800	4800	4800	4800
Production (x10^3 MT)	180.00	180.00	180.00	180.0
Fresh domestic Consumption(x10^3 MT)	9000	9000	9000	9000
Price at retail $R.kg^{-1}$	8.99	8.89	2.00	6.63
Physical Loss (%)	7.67	13.00	12.67	11.11
Estimated National Physical loss(MT)	690	1170	1140	1000
Estimated National Economic Loss ZAR (x10^6)	6.20	10.52	10.25	8.99
Estimated Land Wasted(ha)	368	624	608	306.67
Estimated GHG emission(ton CO_2e)	220.8	374.4	364.8	320
Energy wasted (x10^6 MJ)	2.62	4.45	4.33	3.80
Green water footprint (x10^3 m^3)	180.78	306.54	298.68	262.00
Blue water footprint (x10^3 m^3)	117.3	198.9	193.8	170
Grey water footprint (x10^3 m^3)	20.01	33.93	33.06	29.00

MT=metric ton, ha = hectare, ZAR=South Africa Rand, MJ=Mega-Joules

Conclusion

Different types of losses of variable magnitudes were observed at retail and consumer storage with significant impacts on the food security, economy and environment. Physical damage and puffiness were major causes of losses in Minneola oranges at retail and consumer storage. The estimated amount of physical loss at retail was 11.11% which is 1000 tons worth R8.19 million as national annual loss in 2011. There were lower grade Minneola fruit at retail level in Stellenbosch during the time of the study with almost 50% being downgraded fruits. Pitting, insect damage and staining were major causes of downgrading at retail and consumer storage. Physical losses of Minneola oranges during consumer storage were more than double under ambient conditions than refrigerated conditions. However, extended storage period led to increased losses under both storage conditions. Fruit from retail outlet 2 had least amount of downgraded fruits but highest in physical loss at retail and consumer storage. Post-purchase storage quality of Minneola fruit depended on quality at retail.

The study showed that over 20% of ascorbic acid could be lost during post purchase storage of Minneola oranges. Ambient storage conditions were associated with improved colour and high weight loss. Storage temperature and period had no significant effect on total soluble solids, Titratable acidity, maturity indices and juice content. However, consumer sensory evaluation of the studied fruit at each assessment point could have given more information associated with changes in organoleptic properties responsible for consumer satisfaction.

The study highlights the need for improved sanitation procedures, pre and post-handling care and an efficiency of a cold chain system for Minneola oranges in order to reduce the losses and preserve nutritional value. Furthermore, short consumer storage periods are recommended for Minneola oranges to reduce physical and nutritional losses. Studies to trace the Minneola oranges from harvest are needed to provide more holistic information on handling and origin of defects which contributed to the incidences of losses and downgrading.

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Chapter 6

General discussion and conclusions

The magnitude of postharvest losses of fruit at retail and during post-purchase storage was quantified to three types of fruit. This study showed that the incidence of fruit postharvest losses at retail level is variable depending on the season, supply chain (type of retail outlet), type of fruit, maturity and post-purchase storage condition. High temperature and low relative humidity during summer (during peach harvesting) are associated with high levels of water loss and rapid respiration. Relating to harvesting season, higher losses at retail were recorded for peaches on market than Minneola oranges (in winter). Although high losses were expected for Packham's Triumph pears on market in summer presumably due to the characteristic thin skin which predisposes fruit to injury, the study showed that pears had lower incidence of losses than peaches and Minneola orange. Peaches and pears are climacteric while Minneola oranges are non-climacteric. Climacteric fruits can be harvested at lower maturity stage when they can withstand rigors of postharvest handling and distribution (Crisosto, 1992; Cascales *et al*., 2011). In contrast, non-climacteric fruit have to be harvested when they are ripe therefore more losses are expected as the fruit would be more susceptible to physical damage and spoilage. Peaches and pears are more fragile and sensitive to environmental changes than Minneola oranges due to thinner and softer skin. Considering this, more peaches and ripe pears were damaged than Minneola oranges.

Physical damage and rots were common primary causes of losses at retail. However, losses at retail are a result of cumulative effect along the supply chain in which losses recorded for each fruit from different outlets indicates the effects of previous handling. The purpose of loss assessment is to identify critical control points within the supply chain where losses can be reduced or eliminated. The results obtained on the high incidence of postharvest fruit losses indicate that appropriate packaging and maximum care in fruit handling is essential in reducing physical damages. Efficient cold chain management and fruit inspection for rots and damages could help to reduce spoilage incidences at retail and post-purchase storage (Mari *et al*., 2003; Singh & Reddy, 2005). Although ambient temperatures could be used to improve sensory quality of fruit, it is advisable to be used over a short period to reduce physical and ascorbic acid losses. Refrigeration should be used to preserve fruit quality and reduce further deterioration of injured fruits. However, maturity indices should be considered in deciding the appropriate storage temperature and period (Cascales *et al*., 2011) as cold storage of unripe fruit could lead to fruit lacking flavour and taste after storage. Consumers are advised to utilise injured fruits as fast as possible to reduce losses due to further deterioration while retailers could convert injured fruit to fresh cut, dried or other semi-processed fruit products.

The amount of peaches (40 000 tons) supplied to local fresh market in South Africa were more than four times pears (3 320 tons) and Minneola oranges (4 800 tons) supplied (DAAF, 2010). Additionally, the retail price of peaches was double that of pears and Minneola oranges. The percentage physical losses in peaches were about six times losses in pears and almost double that of Minneola oranges. However, the national physical losses in peaches were more than ten times that of pears and more than seven times Minneola oranges while economic loss was approximately 40 times pears and 10 times Minneola oranges. This suggests that percentages cannot fully reveal the magnitude of losses unless expressed in monetary and tonnage terms to show the actual physical and economic losses that could have been estimated. It was found out that estimated national fruit losses of the studied fruits over R100 million and could have benefited a significant number of people nutritionally. Considering that the availability of fruit and vegetables in South Africa is only 50% of the FAO/WHO recommendation (Ganry, 2009), reducing losses would increase availability of nutrients we benefit from fruit thereby help in solving the problem of food and micro-nutrient insecurity. Additionally, reducing the losses would contribute to sustainable management of natural resources considering the land, energy and water used to produce lost fruits (Peter & Gleik, 1996; U.S.DOE, 1998).

The variation in physico-chemical properties of fruit at retail level could be related to differences in harvest maturity, weather conditions during the marketing seasons and postharvest handling procedures along the supply chain. It is essential to adapt postharvest handling procedures that maintain or improve physico-chemical properties that are typical for different fruit type related to consumer preferences (Sigh & Reddy, 2005). Physico-chemical properties have been reported to be correlated to sensory quality thereby determining whether a consumer will purchase the fruit or consume the fruit after storage (Predieri & Gatti, 2009) therefore sensory evaluation at each assessment point of the studied fruits could have helped to relate physico-chemical properties to consumer expectations. However, fruit handling between the sampling point and the laboratory can bias the results on physico-chemical properties of fruits. The use and adaptation of mobile testing kits during product tracking along the supply chain would help in providing more accurate data on physico-chemical changes.

. The sampling method used gives more accurate data on postharvest losses than surveys and estimations. However, there are no reliable methods for evaluating postharvest losses therefore; the results obtained in this study will only refer to the supply chains where samples were drawn and the 2011 marketing seasons of the studied fruit types. Additionally, inaccurate data makes assessment of the potential cost-effectiveness of interventions to reduce losses at different stages of the supply chain virtually impossible. This may lead to misplaced interventions by governments therefore, methodologies for studying postharvest losses need to be refined and standardised so that different studies can give comparable data.

Although the study was done at micro-level, it could open windows to macro-studies which provide more holistic information on postharvest losses at national level. However, further studies are needed to track the studied fruits from harvest to consumer to provide more information on handling procedures and origin of defects associated with losses and downgrading. Incorporation of consumer sensory analysis studies at each level of the supply chain would help to relate physico-chemical properties to consumers' preferences. The use of force sensors would provide information on points were rough handing would be occurring (Newman *et al*., 2008) while environment sensors would indicate points of temperature abuse.

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