DEVELOPMENT OF AN IN-FIELD INTEGRATED PRE-PACKAGING CITRUS TREATMENT UNIT AND THE EFFECTS OF THE TREATMENTS ON FRUIT QUALITY

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ABSTRACT

Kumquat (*Fortunella* spp.) is an exotic citrus fruit currently grown and exported from South Africa. Access by small-scale kumquat farmers to the international export market is required to allow for greater income generation and for the development of the South African citrus industry. Once harvested, fruit continue to respire, which is further exacerbated by elevated temperatures in the field and during transport to packhouses. This results in the proliferation of pathogens, which is detrimental to the postharvest fruit quality and, consequentially, results in a decrease in the fruit shelf-life. Bottlenecks in South African packhouses have been identified as a challenge due to the large quantity of fruit that need to be processed. Limited research on postharvest quality issues of kumquat, particularly in South Africa, is available in literature. This warrants the need for postharvest research to be undertaken on kumquat fruit.

The aim of this document is to highlight the pre-packaging treatments of citrus fruit and the equipment involved in such treatments. Hot water, surface coatings, ultra-violet irradiation, chlorine, salt treatments and microbial antagonists have been beneficial in maintaining the citrus quality and reducing the prevalence of postharvest decay. Environmentally-friendly, electrochemically activated water has also proven to be a favourable postharvest treatment of carrots and tomatoes. However, the effect of these treatments on the postharvest quality of kumquat fruit has not been documented thus far. Integrated treatments, such as hot water treatments and chlorine disinfection, have been successfully used in the global citrus industry. The use of integrated pre-packaging treatments improved the quality and shelf-life of citrus, compared to discrete treatments. An effective combination of pre-packaging treatments should include: (1) disinfectant; (2) curative and (3) preventative treatments to control pre- and postharvest pathogens. The equipment and machinery responsible for treating citrus fruit are predominantly situated in packhouses, which require that fruit be transported a distance after harvest. This contributes to quality degradation due to pathogenic infections such as *Penicillium*. Treating fruit directly after harvest in the orchard, as opposed to at a packhouse, introduces an innovative method of addressing the current challenges in the citrus industry. Research is required to improve and optimize the postharvest handling technologies for citrus fruit, specifically kumquats in South Africa. This could, most importantly, reduce the postharvest losses and improve the quality and shelf-life of the fruit and promote the involvement of small-scale farmers.

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1. INTRODUCTION

The citrus industry is the third largest horticultural industry in South Africa, contributing 19% of the total gross value of horticultural crops (R6.9 billion) during the 2010/11 season and is largely export-based (DAFF, 2012). The aesthetic appeal of citrus fruit has a significant effect on the consumer's decision to purchase (Blasco *et al.*, 2009). The aesthetics and nutritional characteristics of citrus are negatively affected by pathogenic disorders and postharvest handling. Unsuitable fruit handling leads to hastened physiological deterioration, which can manifest in the proliferation of microbiological activity, and accelerated ripening and decay. This can have further market related consequences, resulting in low income generation by farmers and a negative perception of importers toward South African citrus fruit.

The *Penicillium* moulds have been identified as the most severe postharvest fungal infection affecting citrus fruit (Altieri *et al.*, 2013) and recently the onset of citrus black spot has led to the rejection of some citrus exports from South Africa to Europe in November 2013 (Mokomele, 2013). Fungicides have commonly been used to address these problems. However, more environmentally-friendly treatment alternatives are being sought due to the development of fungal resistance to fungicides, and the growing public demand for safer foods (Ben-Yehoshua *et al.*, 2005; Zhang and Swingle, 2005; Zhang, 2007). Some of these environmentally-friendly treatments include hot water, ultra-violet irradiation, biocontrol agents and anolyte water (Ben-Yehoshua *et al.*, 2005; Workneh *et al.*, 2011a). Therefore, much emphasis needs to be placed on research within the postharvest citrus industry to maximise the potential benefits of improved fruit quality and income via the application of effective integrated pre-packaging treatments.

Exposure to field heat and ambient conditions during transport from the orchard to the packhouse exacerbates the deterioration process by further increasing the fruit temperature, promoting microbial proliferation (Sullivan *et al.*, 1996; Brosnan and Sun, 2001). The use of pre-packaging treatments, such as hot water, surface coatings, ultra-violet irradiation, chlorine water, biocontrol agents, and carbonate and bicarbonate salts have been found to be beneficial in maintaining the postharvest quality of citrus fruit (Porat *et al.*, 2000; Njombolwana *et al.*, 2013; Youssef *et al.*, 2014). Heat treatments have been found to induce fruit tolerance against cold injury and pathogens due to the development of heat shock proteins (Ben-Yehoshua *et al.*, 2005). Surface coatings or waxes not only promote the aesthetic appeal of the fruit but also reduce the loss of moisture, thereby extending the fruit shelf-life (Johnston and Banks, 1998). Ultra-violet irradiation reduces decay in citrus fruit due to its germicidal effect and ability to induce the fruit's tolerance to decay (Ben-Yehoshua *et al*., 2005). Treatment of citrus with carbonate and bicarbonate salts can delay postharvest decay by activating the fruit's defence mechanism (Youssef *et al*., 2014). Similarly, the use of chlorine (hypochlorite) as a disinfectant has also extended the citrus fruit shelf-life and is currently used in industry (Workneh *et al*., 2003; Beghin, 2014c). Biocontrol agents have been used as an alternative to synthetic fungicides to alleviate postharvest decay (Droby *et al*., 2009; Abraham *et al*., 2010). These pre-packaging treatments have been used with success as individual treatments but more so, the combined effect of a number of these pre-packaging treatments have been beneficial in extending the shelf-life of citrus (Korf *et al*., 2001; Obagwu and Korsten, 2003; Ben-Yehoshua *et al*., 2005; Hong *et al*., 2014; Moscoso-Ramirez and Palou, 2014).

The use of equipment to perform postharvest operations at the packhouse and during harvesting is an existing practice in the citrus industry (Dodd *et al*., 2008). Many advances have been made in the use of brushes and nozzles to rinse and apply treatments, such as waxes, hot water, fungicides and hypochlorite to citrus fruit (Fallik *et al*., 1999; Fallik, 2004; Ladaniya, 2008). However, much of the postharvest processing is confined to fruit packhouses, where bottlenecks are likely due to the large quantity of produce to be processed (Ortmann *et al*., 2006). Additionally, the logistics involved can result in delays in conveying the produce from the field to the packhouse, and also delaying preventative disease control treatments (Camelo, 2004). Research can be undertaken to quantify the losses in horticultural commodities due to time delays and temperature, however, it is not included in the scope of this study. Pre-treating fruit in the orchard can be expected to eliminate the backlogs at packhouses. More importantly, citrus pre-treatment at the orchard will reduce the time lapse from harvest to pre-packaging, which will ultimately improve the fruit quality and shelf-life (Sullivan *et al*., 1996). This approach to the treatment of horticultural commodities has not been previously documented, which could be adopted by the citrus industry and extended to other horticultural crops.

Numerous studies have concentrated on the integrated effect of discrete treatments on citrus, such as orange, grapefruit and lemon. However, limited research, particularly in South Africa, has delved into the integrated effects of these discrete treatments on kumquats, an uncommon citrus cultivar (Choi, 2005; Sisquella *et al*., 2013). This problem necessitates research involving the integrated effect of suitable treatments in alleviating the need for immediate transport of kumquat fruit to packhouses. It is, therefore, essential that these techniques be developed to maintain the fruit quality all the way from the field to the final market destination. The research questions that may arise are: (1) what is the most effective combination of pre-packaging treatments on the kumquat fruit quality? (2) what are the benefits of an on-farm mobile pre-packaging unit? and (3) how can the current citrus supply chain be optimised?

Attention on small-scale citrus farmers in South Africa has been neglected due to the industry being primarily export-based and reliant on more established commercial farmers. However, the development of small-scale farmers is crucial for expanding current markets, food security and job creation. Improving the current postharvest technologies will assist small-scale farmers.

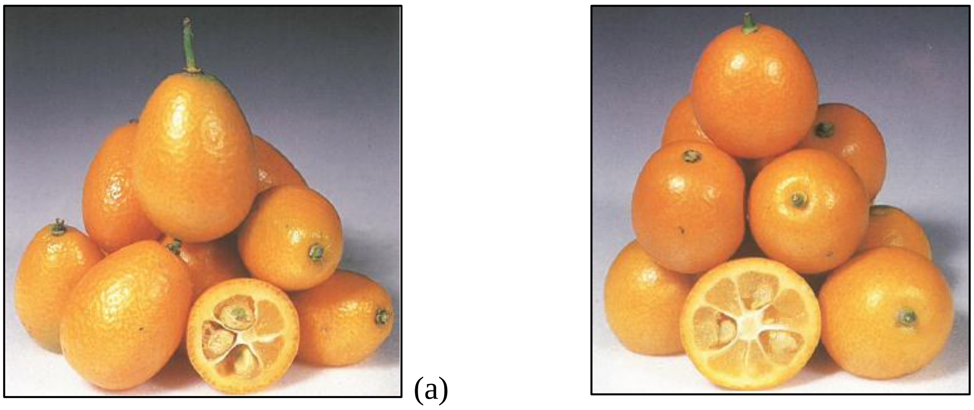
The aim of this document is to review literature on the pre-packaging treatments, technologies and equipment in order to improve the quality of horticultural commodities, with a specific focus on postharvest trends in the citrus industry (Section 5). An introduction to kumquats and the harvesting techniques are presented in Section 2. An outline of the physical, chemical, and microbiological quality parameters associated with evaluating the quality of citrus fruit are provided in Section 3. Subsequently, the effects of different pre-packaging treatments applied to citrus fruit are discussed (Section 4). The citrus supply chain and markets are explained in Section 6 followed by a discussion and conclusion in Section 7. A project proposal contextualising the findings of the literature in combining suitable pre-packaging treatments in a unit for kumquat fruit after harvest in the orchard is included in Section 8.

2. HARVESTING AND DISORDERS AFFECTING KUMQUAT QUALITY

This section introduces the kumquat fruit as well as the associated harvesting techniques. Pathogenic and physiological disorders related to citrus fruit are also discussed.

2.1 Introduction to Kumquat

The kumquat (*Fortunella* spp.) belonging to the family Rutaceae, to which citrus belongs, is the smallest citrus fruit and is believed to have originated in China (Hall, 1986; Choi, 2005; Ladaniya, 2008; Schirra *et al*., 2008; Peng *et al*., 2013). The two most common kumquat varieties are Nagami (*Fortunella margarita*) and Marumi (*Fortunella japonica*) (Young, 1986; Saunt, 1990) as indicated in Figures 2.1 (a) and 2.1 (b), respectively. Nagami are oval with a slightly wider stylar-end of approximately 39 mm in length and weigh 14 g (Jaliliantabar *et al*., 2013). Marumi are more rounded to slightly oval, and are smaller than Nagami, with a mean weight of 12 g. The juice content of kumquats is approximately 15-17% °Brix, 4-5% acid and 50-55 mg ascorbic acid.100 ml^{-1}, which may vary, depending on the variety and growing regions (Ladaniya, 2008). The optimum storage temperatures for kumquats range from 4.5°C to 11.0°C (Beghin, 2014c). Cultivation of kumquats in South Africa, aimed primarily at the export market, is concentrated in the Letsitele region, just outside Tzaneen and Levubu near the Kruger National Park.



(a) (b)

Figure 2.1 Kumquat fruit (a) Nagami (*Fortunella margarita*) and (b) Marumi (*Fortunella japonica*) (Saunt, 1990)

Citrus fruit can be classified as being non-climacteric, with low rates of respiration and ethylene evolution during the ripening stage (Porat *et al*., 2004; Ladaniya, 2008; Li *et al*., 2008). This allows for extended storage periods of six to eight weeks (variety dependant) (Porat *et al*., 2004; Li *et al*., 2008). However, Chalutz *et al*., (1989); cited by Schirra *et al*. (2011), stated that kumquat fruit are susceptible to early decay due to high respiration rates and infection caused by *Penicillium*. Similarly, Li *et al*. (2008) revealed that after harvest, under ambient conditions, kumquats can lose excessive moisture and become wrinkly. Therefore, effective postharvest handling procedures of kumquat fruit, such as pre-packaging treatments need to be identified to mitigate these detrimental effects.

2.2 Impact of Harvesting Techniques

Grierson and Ben-Yehoshua (1986) identified harvesting as being the single most critical factor influencing fruit quality during storage and transportation. The characteristics of kumquat fruit is similar to that of other citrus in that they are unable to ripen once harvested unripe and, therefore, they should be picked when fully ripe (Kader, 1999; Ladaniya, 2008). The onset of postharvest decay in citrus fruit is largely dependent on cultural practices, such as the method and time of harvest, and pre- and postharvest factors (D’hallewin *et al*., 1999; Beghin, 2014a). Once harvested, the fruit become more susceptible to microbiological infections as it is detached from the plant (D’hallewin *et al*., 1999). McGuire and Reeder (1992) found that late and early season grapefruit succumbed to greater damage (scalding) when exposed to air heated to 46°C, 48°C, and 50°C for three, five or seven hours, compared to mid-season fruit after harvest. This could be attributed to early season fruit having immature skins and late season fruit already beginning to senesce. Dessert lemons and blood oranges are most susceptible to chilling injury when harvested early in the season (Houck *et al*., 1990; Schirra *et al*., 1997).

Currently citrus harvesting is by hand because this results in the least damage to the fruit, which minimises the risk of early decay and inferior postharvest quality (Schueller *et al*., 1999, Sanders, 2005). Mechanical harvesting in the citrus industry has not been a prominent feature because it lacks the flexibility and fruit selection ability of manual harvesting (Sanders, 2005). However, more automated systems employing the desired selection criteria for individual citrus fruit have been developed by Jimenez *et al*. (2000). Harvesting of kumquats in South Africa takes place from May to September, when fruit are picked continuously because both flowers and fruit are on the trees at the same time (Beghin, 2014a; 2014b). Kumquat fruit stems are clipped rather than snapped because the latter may induce fruit injury. Fruit that are yellow to orange are ready to be picked (Beghin, 2014b). A small portion of the pedicel is still attached to the kumquat because it cannot easily be removed without injuring the fruit. However, it is this portion of the stem that regularly causes injury to adjacent fruit in containers, which hastens fruit deterioration (Beghin, 2014a; Laing, 2014a). This problem requires research to be conducted to optimise kumquat harvesting. However, this is not included in the scope of this study. Once harvested, each worker places the kumquats into bags, which are then weighed and transferred into 18-20 kg lug boxes (Beghin, 2014a). The pickers also play a pivotal role by practicing hygienic methods of harvesting to prevent *E-coli* contamination of fruit (Laing, 2014c). This can be addressed by providing pickers with portable toilets, a suitable disinfectant and water. Pickers should also avoid picking fruit from the ground.

2.3 Pathological and Physiological Disorders

Harvested commodities are required to be cleaned of any dirt, debris, insects and synthetic chemicals prior to packaging to extend the shelf-life (Fallik, 2004). Porat *et al.* (2004) identified two factors that limit the postharvest shelf-life of citrus: (1) pathological breakdown; (2) physiological breakdown. Pathological decay is ultimately caused by fungi or bacteria, whereas physiological breakdown is initially as a result of biotic factors, which weaken the fruit and affect its ability to ripen properly (Boyette *et al.*, 1993, Ladaniya, 2008). Droby *et al.* (1998), Ladaniya (2008), Gomez-Sanchis *et al.* (2012), Altieri *et al.* (2013), and Youssef *et al.* (2014) have all identified blue and green moulds as the most severe postharvest pathological infections affecting citrus fruit (Figure 2.2 (a)). Citrus fruit under cold storage are mainly susceptible to blue mould caused by *Penicillium italicum* Wehmer, while green mould, caused by *Penicillium digitatum* Sacc. may result in 60-80% of fruit decay under ambient conditions. Strict postharvest and packhouse sanitation is required to restrict fruit losses as a result of blue and green moulds (Ladaniya, 2008). Citrus black spot (CBS) has recently contaminated South African citrus exports to the European Union (EU) after the disease was detected in some of the shipments, as explained by Mokomele (2013). As of 29 November 2013, the Standing Committee on Plant Health stated that only citrus from areas free of CBS in South Africa could be exported to the EU for that particular season (Mokomele, 2013). However, according to Yanowa *et al.* (2013), the CLIMEX model, which simulates an organism's response to a particular climate worldwide, showed that CBS poses an exceedingly low risk to the citrus producing regions in Europe. Figure 2.2 (b) illustrates freckle spot caused by CBS.

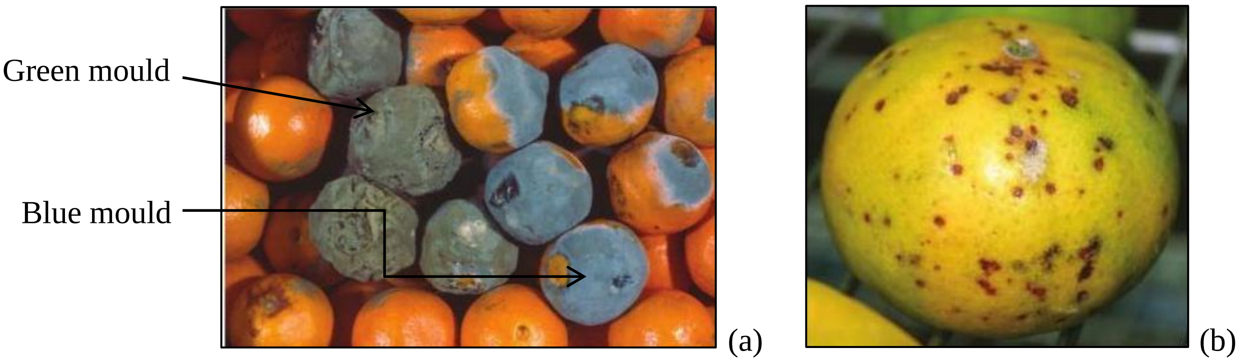


Figure 2.2 (a) Green and blue moulds and (b) freckle spot caused by CBS (Cooke *et al*., 2009)

Sour rot has also been described as a postharvest disease resulting in significant losses in citrus fruit (Merciera and Smilanick, 2005; Talibi *et al*., 2012). Losses are particularly greater during the wet season and fruit degreening (Talibi *et al*., 2012). Sour rot requires open wounds on the citrus fruit for entry and proliferation (Ladaniya, 2008; Talibi *et al*., 2012). Stem-end rind breakdown is classified as a physiological disorder, which can be attributed to an imbalance in potassium and nitrogen. However, its development is dependent on the handling procedures between picking and packaging (Grierson, 1986). This disorder results in the collapse and darkening of the epidermal tissue around the stem-end of the fruit. The loss in fruit moisture promotes stem-end rot (Grierson, 1986; Wardowski, 1988b; Ritenour *et al*., 2004). Grierson (1986) recommends that fruit be transported immediately after harvest to the packhouse and maintained at high relative humidity (>90%). Furthermore during pre-treatment, brush speeds should not exceed 100 rpm (Grierson, 1986). Table 10.1 in the Appendix lists some of the pathological and physiological diseases and disorders exhibited in citrus fruit. The scope of this study focuses primarily on improving and maintaining the quality of citrus fruit, particularly kumquats by reducing pathological disorders encountered in the citrus industry.

3. POSTHARVEST QUALITY OF CITRUS

Ladaniya (2008) defines fruit quality as the combination of fruit attributes that have a significant influence in determining consumer acceptance and willingness to purchase. It is imperative that citrus fruit for export and local markets attain both the internal and external quality standards at harvest. The physical, chemical, and microbiological properties of citrus fruit are reviewed in this section.

3.1 Physical Quality Parameters

The physical properties are associated with the appearance, aesthetics and response of the fruit to certain external stimuli such as forces (tensile and compressive) during loading and stacking and light exposure during postharvest handling (Ladaniya, 2008). The physical properties of citrus fruit discussed in this section include skin colour, weight loss, and firmness.

3.1.1 Skin colour

The colour perception of citrus fruit is an important factor in determining a customer’s willingness to purchase (Olmo *et al.*, 2000; Singh and Reddy, 2006). Colour measurement can be carried out either subjectively or objectively, as in the case of firmness (Section 3.1.3). Subjective colour measurement is determined visually by eye. Ladaniya (2008) describes a colour scale system, which divides samples into different colour categories of deep green, light green, yellowish-green, greenish-yellow, yellowish-orange, orange, and deep orange. This scale may vary depending on the citrus cultivar. Objective colour measurements make use of calibrated equipment such as colour meters (Pathare *et al.*, 2013). The parameters associated with colour include L (lightness or brightness); a* (redness or greenness) and b* (yellowness or blueness) (Pathare *et al.*, 2013).

The colour change in citrus fruit can be attributed to the conversion of chloroplasts to chromoplasts, resulting in a loss of chlorophyll and the synthesis of carotenoids (Olmo *et al.*, 2000; Ortiz, 2002; Iglesias *et al.*, 2007; Singh and Reddy, 2006). Ortiz (2002) attributed the yellow colour in citrus to carotenes and xanthophylls, and the reddish colour to anthocyanin. The application of exogenous ethylene during the process of degreening has been found to accelerate the development of carotenoids in citrus fruit and to improve colour development (Stewart and Wheaton, 1971; Rodrigo and Zacarias, 2007). Rodov *et al*. (2000) found that hot water brushing of citrus fruit at 60°C delayed the colour change from green to yellow by two weeks. This could be due to the production of heat shock proteins, which inhibit senescence. Smilanick *et al*. (2006) found that the postharvest application of sodium bicarbonate, either alone or in combination with thiabendazole fungicide, resulted in a detectable but minor delay in the colour change during the process of degreening.

3.1.2 Weight loss

Weight loss is an important factor in citrus fruit deterioration and is often accompanied by a decrease in firmness (Porat *et al*., 1999). Citrus fruit have high moisture content in both the pulp and peel (Chien *et al*., 2007; Ghanema *et al*., 2012). The loss of moisture via transpiration and respiration occur rapidly after harvest, promoting fruit decay (Purvis, 1983). Much of the moisture is lost from the peel tissue, leading to shrivelling, shrinkage, softening and deformation, affecting the fruit appearance. The weight loss in heat-treated mandarins was significantly lower than in ultra-violet (UV) irradiated fruit at 4.10 g and 5.34 g, respectively (D'hallewin *et al*., 1994). The use of waxes reduces the loss in moisture in many horticultural crops (Hall, 1981; Hagenmaier and Baker, 1994; Chien *et al*., 2007). However, over-waxing can lead to off-flavours and odours (Hall, 1981; Purvis, 1983). Cohen *et al*. (1990) found that the use of water-based polyethylene waxes on Murcott tangerines reduced the weight loss but also led to an inferior taste, compared to un-waxed fruit. According to Ben-Yehoshua *et al*. (1985), waxes block the stomatal pores, hindering gas exchange to a greater extent than moisture. It was further observed that individually wrapping oranges and grapefruit in high density polyethylene films reduced moisture loss by 90% without detrimentally restricting gas exchange, compared to waxing. Kumquat fruit dipped in hot water (53°C for 120 seconds) displayed a lower weight loss, compared to control samples (Rodov *et al*., 1995). Heat treatments have a profound effect in reducing weight loss of citrus fruit. Fruit moisture loss, due to the vapour pressure deficit at the time between harvest and packing, leads to an increase in the incidence of pitting (Citrus Growers' Association, 2013). Therefore, a shorter time between harvest and packing is required.

3.1.3 Firmness

In citrus fruit, the firmness can be defined as the resistance to puncture and can be associated with the mechanical properties of the fruit. Fruit firmness is often used as a criterion to determine the effects of storage and shelf-life (Singh and Reddy, 2006). Firmness tests include puncture resistance, compression, creep, impact and sonic tests (Abbott, 1999). Instruments commonly used to measure citrus firmness include texture analysers, and handheld penetrometers, which constitutes objective methods. Subjective techniques include hand-feel due to the viscous component of citrus fruit (Abbott, 1999; Ladaniya, 2008). The peel of the citrus fruit is composed of the flavedo (exterior coloured portion) and the albedo (white inner portion), which resists exerted forces. Beneath the peel are segments composed of juice sacs or juice vesicles, which offer minimal resistance to applied forces. With an increasing moisture loss, the peel becomes tough and leathery. Heat-treated mandarins resulted in superior fruit firmness, compared to the control and UV treated samples (D'hallewin *et al*., 1994). Similar results were obtained by Rodov *et al*. (2000), where hot water dipping (52°C for 120 seconds) and hot water brushing (60°C) resulted in firmer fruit, compared to non-treated samples. Citrus fruit coated with chitosan wax and those treated with thiabendazole fungicide were firmer, compared to control samples, after 56 days of storage at 15°C (Chien *et al*., 2007). Citrus fruit firmness primarily depends on cell turgidity, which is associated with the moisture content. Rodov *et al*. (1995; 2000) explain that heat treatments assist in redistributing the natural epicuticular wax, which seals microscopic cracks, preventing the escape of moisture, promoting cell turgidity and firmer fruit. Heat treatments may also improve fruit firmness by inhibiting enzyme activity involved in fruit softening or by cell wall strengthening (lignification).

3.2 Chemical Quality Parameters

Chemical properties primarily provide information regarding the taste, flavour, aroma and nutritive value of horticultural commodities. The chemical properties discussed in this section are total titratable acid, total soluble solids, and the maturity index.

3.2.1 Total titratable acid

Organic acids play a major role in the organoleptic characteristics of citrus fruit. Citric acid accounts for approximately 80-95% of the total titratable acids (TTA) in citrus fruit (Ladaniya, 2008). Generally, there is a decrease in the TTA of citrus fruit during ripening, depending on the cultivar (Olmo *et al*., 2000; Sadka *et al*., 2000; Ortiz, 2002; Albertini *et al*., 2006; Ladaniya, 2008). This can be attributed to the catabolism of citric acid as well as an increase in the total sugars, resulting in mature fruit having low acidity (Iglesias *et al*., 2007). Sadka *et al*. (2000) found that a high acid content in mature citrus fruit can reduce the quality and delay harvest. The method commonly used to measure TTA is titration (Lobit *et al*., 2002; Hong *et al*., 2007; Ladaniya, 2008). Other advanced methods make use of magnetic resonance (Abott, 1999). Purvis (1983) found that the acid content in grapefruit and oranges decreased during storage. Similarly, Baldwin *et al*. (1995) observed a decrease in the citric acid of oranges after four weeks of storage. The TTA in fresh cut oranges stored at 4°C was found to decrease from 0.46% to 0.29% over a 13 day storage period (Rocha *et al*., 1995). Hong *et al*. (2007) found that heat-treated mandarins did not display a significant change in the TTA.

3.2.2 Total soluble solids

The total soluble solids (TSS) of citrus fruit contribute approximately 10-20% of the fresh weight. About 70-80% of the TSS are carbohydrates (Iglesias *et al*., 2007). Other minor constituents of TSS include organic acids, proteins, lipids and minerals (Olmo *et al*., 2000; Iglesias *et al*., 2007; Ladaniya, 2008). TSS determination is based on the refractive index of the fruit juice using a refractometer. Rodov *et al*. (2000) found a gradual increase in the TSS of citrus fruit during storage. This is due to the loss in moisture resulting in an increase in the solute concentration. D’hallewin *et al*. (1994) found that the TSS in heat-treated (36°C for 72 hours) and UV-treated (24 nm) Avana mandarins were lower, compared to control samples at 7.85, 7.63 and 8.02 °Brix, respectively. Baldwin *et al*. (1995) found that coated oranges had a slightly lower TSS, compared to uncoated fruit stored at 16°C or 21°C; however, this was not significant. Purvis (1983) did not find any significant change in the TSS of waxed oranges and grapefruit. Contrary to these observations, Hong *et al*. (2007) found a decrease in the TSS, which was attributed to consumption of sugars and organic acids for plant metabolism in mandarins during storage.

3.2.3 Maturity index

The maturity index can be determined by the ratio of TSS:TTA (D’hallewin *et al*., 1994; Olmo *et al*., 2000; Ortiz, 2002; Iglesias *et al*., 2007). This serves as an indication of the legal maturity of oranges, mandarins, grapefruit, pummelos and their hybrids (Ladaniya, 2008). The maturity index is also used to determine the relative sweetness or sourness of citrus fruit. The maturity index tends to increase due the increase in the soluble solids and the decrease in the organic acids (Olmo *et al*., 2000). Higher ratios generally imply a decrease in the acidity; however, this is dependent upon the contributions of both TSS and TTA. The highest maturity index of Avana mandarins was observed for heat treatments at 36°C for 72 hours (16.77), followed by UV treatment (15.48) (D’hallewin *et al*., 1994). The maturity index for an acceptable flavour quality in grapefruit, mandarin and orange are approximately 6+, 8+ and 8+, respectively (Kader, 1999).

3.3 Microbiological Quality

Postharvest decay in citrus fruit is an important factor affecting the quality and value of citrus products. In this section, the postharvest diseases most commonly affecting citrus fruit are discussed: citrus black spot and blue and green moulds.

3.3.1 Citrus black spot

Citrus black spot (CBS) caused by *Guignardia citricarpa* Kiely, attacks the citrus fruit and foliage, resulting in unsuitable fruit for the fresh market (Bonants *et al*., 2003; Yonow *et al*., 2013). Infection occurs via both pynidia and ascospores, which may be present on infected leaves on the orchard floor (Korf *et al*., 2001). CBS has usually been controlled with copper fungicides. However, this leads to darkening of citrus blemishes and an undesirable accumulation of copper in the soil (Schutte *et al*., 1997). Agostini *et al*. (2006) found that postharvest fungicide treatments alone had minimal effects in reducing CBS symptoms. However, the application of fungicides during fruit growth and storage of harvested fruit at 8°C immediately after harvest was effective in reducing CBS symptoms.

More environmentally-friendly methods, such as heat treatments and waxing, have been used with success to alleviate CBS. The application of skin coatings to oranges was found to reduce the onset of CBS, which could be associated with reduced respiration rates (Seberry *et al*., 1967). Seberry *et al*. (1967) recommended that postharvest treatments complement orchard control methods to control CBS. Korf *et al*. (2001) found that conidial germination on CBS infected fruit was reduced to zero with postharvest treatments of hypochlorite, heat treatments, a chemical mixture, polyethylene wax or all treatments combined. This demonstrated the beneficial application of combined pre-treatments in reducing CBS. Further research is required to determine the feasibility of other combined pre-packaging treatments in citrus.

3.3.2 *Penicillium digitatum* and *Penicillium italicum*

Citrus fruit treated by hot water dipping at 52°C for 120 seconds, or thiabendazole wax, or curing at 36°C for 72 hours, all controlled the development of *Penicillium* moulds (Rodov *et al*., 2000). The incidence of citrus decay was also reduced by hot drench brushing treatments of 56 or 60°C. Similar results were obtained for kumquats in which fruit were dipped in water at 52°C for 120 seconds. This effectively reduced decay during four weeks of storage (Rodov *et al*., 2000). Hot water brushing for 20 seconds at 56°C reduced decay development due to *Penicillium digitatum* by 80% (Porat *et al*., 2000). The optimum curing temperature inhibiting *Penicillium digitatum* growth in oranges was found to be at 35°C for 48 hours. However, this resulted in an increase in the occurrence of stem-end rot after two weeks (Zhang and Swingle, 2005). The application of 500-2000 $mg.l^{-1}$ of fludioxonil fungicide reduced the presence of green mould (Zhang, 2007). Ultra-violet-C (UV-C) irradiation has also shown to significantly reduce the incidence of blue and green mould; however, the risk of over dosage may lead to the development of phytotoxins (Palou *et al*., 2008).

Based on the physical, chemical and microbiological quality parameters that have been discussed, the main question that arises is what are the effects of different pre-packaging treatments (individually and combined) on the quality of citrus? The need to quantify this is required, specifically for kumquat fruit in South Africa in order to obtain a greater understanding of the postharvest characteristics and behaviour of kumquat fruit, which can be applied in the citrus industry.

4. PRE-PACKAGING TREATMENTS

Senescence and decay are natural processes occurring in horticultural commodities and cannot be stopped but merely delayed. This can be achieved by implementing suitable postharvest strategies, such as pre-packaging treatments as outlined in this section.

4.1 Heat Treatments

Heat treatments have been used to control decay in various fruit, such as avocados (Wu *et al*., 2011; Kassim *et al*., 2013), peppers (Gonzalez-Aguilar *et al*., 2000; Fallik, 1999; 2004) and citrus (Ben-Yehoshua *et al*., 2000; Schirra *et al*., 2008). Heat treatments have the ability to inactivate surface or below surface pathogens, by inducing the fruits' resistance to inhibit pathogen development (Irtwange, 2006; Schirra *et al*., 2011). Heat treatments can therefore, provide a 'curative' treatment (Irtwange, 2006; Laing, 2014c). Contrastingly, Palou *et al*. (2002) described hot water treatments to be non-curative whose effects are only temporary, however studies by Kim *et al*. (1991), Ben-Yehoshua *et al*. (1992) and Obagwu and Korsten (2003) demonstrate the curative ability of heat treatments.

The two main protein groups activated by hot water treatments are: (1) heat shock proteins (HSP); (2) pathogenesis-related proteins (PRP) (Pavoncello *et al*., 2001). HSP's are responsible for inhibiting protein aggregation during high temperatures, thus promoting the fruit's ability to withstand these temperatures. PRP's are thought to contribute to the fruit's defence against a variety of pathogens. Water is the preferred heating medium due to it being more efficient in the heat transfer, compared to air (Fallik, 2004). The benefits associated with heat treatments include reduced chilling injury, increased gloss on the fruit exterior and reduced weight loss, resulting in an increased fruit shelf-life (Rodov *et al*., 1995; Irtwange, 2006; Schirra *et al*., 2011). However, excessive heat exposure can result in phytotoxic damage to the fruit (Ben-Yehoshua *et al*., 2000; Irtwange, 2006). This can be avoided by applying higher water temperatures with shorter exposure durations (Fallik, 2004). Contrary to this, McGuire and Reeder (1992) found that higher temperatures or extended exposure times should be avoided in order to prevent early decay. Table 10.2 in the Appendix summarises the effects of different heat treatments on citrus fruit.

Schirra *et al*. (2008) found that kumquat fruit dipped in hot water for 120 seconds at 50°C, then stored at 17°C for 21 days at approximately 80% relative humidity, did not demonstrate significant changes in their nutraceutical and health-related properties. Dipping kumquat fruit in water heated to 53°C for 120 seconds reduced decay during storage (Rodov *et al*., 1995). Similarly, kumquats dipped in hot water for 120 seconds or 30 seconds at 53°C or 56°C resulted in a reduction in incidence of *Penicillium digitatum* and *italicum* infections, while exposure to higher temperatures of 59°C and 61°C accelerated the onset of decay (Ben-Yehoshua *et al*., 2000). Hot water treatments do not involve any chemicals, making them environmentally-friendly, and are generally easy to apply, which contributes to its industrial appeal. This makes hot water treatments particularly suitable for kumquats due to the manner the fruit is consumed, which includes both the pulp and peel (Ben-Yehoshua, 2000; Schirra *et al*., 2011). Studies conducted on the effect of hot water treatments at 53°C on kumquat fruit have produced favourable results including reduced weight loss, improved appearance and reduced decay (Schirra *et al*., 1995; Ben-Yehoshua *et al*., 2000; Rodov *et al*., 2000).

4.2 Surface Wax and Coatings

Harvested horticultural commodities exhibit excessive weight loss as a result of moisture loss via transpiration and to a lesser degree the loss of carbon via respiration, reducing the shelf-life and fruit quality (Purvis, 1983; Mannheim and Soffer, 1996; Johnston and Banks, 1998). The application of surface waxes and coatings have been found to address this problem, encompassing both physiological and aesthetic effects. Surface coatings or waxes impart a gloss to the exterior of the fruit, thereby contributing to the aesthetic appeal (Nisperos-Carriedo *et al*., 1990, Maftoonazad and Ramaswamy, 2008). More importantly waxes are able to reduce the weight loss when applied to the exterior of the fruit by creating a partially permeable layer. This layer reduces the rate at which moisture is able to escape from the fruit to the surrounding environment, thus maintaining a higher moisture content (Hagenmaier and Baker, 1993). The permeability of the wax layer also contributes to a reduced rate of gas exchange between the fruit and the surrounding environment, lowering the respiration rate (Hagenmaier and Shaw, 1992; Hagenmaier and Baker, 1993; Johnston and Banks, 1998; Maftoonazad and Ramaswamy, 2008). The reduced moisture loss ensures that fruit cells remain turgid, consequentially promoting fruit firmness. Nisperos-Carriedo *et al*. (1990) found that coated oranges exhibited increased concentrations of volatile compounds (acetaldehyde, ethyl acetate, and methyl butyrate) contributing to enhanced orange juice flavour, compared to uncoated fruit. Similar findings were observed by Nisperos-Carriedo *et al*. (1991). Chitosan coatings are a form of active packaging in which deposits from the film is transferred to the fruit surface aiding in the inhibition of fungal growth (Chien *et al*., 2007). Purvis (1983) observed that waxed orange and grapefruit displayed greater loss in moisture and a reduction in the acidity, compared to individually sealed fruit. Hagenmaier and Baker (1994) found that natural carnauba wax was more effective in reducing weight loss in citrus, compared to shellac or polyethylene waxes. At present, shellac, carnauba and polyethylene waxes are commonly used for citrus (Dodd *et al*., 2008). Hagenmaier and Shaw (1992) recommended that a suitable citrus wax has high oxygen, carbon dioxide and ethylene permeabilities, while having low water vapour permeability. This will allow for a reduced transpiration rate without excessively restricting the respiration rate. Table 10.3 (Appendix) lists some of the surface coatings applied to citrus fruit. The disadvantage of wax coatings, however, are off-flavours and odours associated with impaired oxygen and carbon dioxide exchange, leading to anaerobic respiration, the release of smelly organic acids and increased ethanol and acetaldehyde concentrations (Cohen *et al*., 1990; Hagenmaier and Shaw, 1992; Hagenmaier and Baker, 1993; Mannheim and Soffer, 1996; Njombolwana *et al*., 2013). In addition, kumquat fruit are consumed with the skin. As a result, consumers may not be willing to purchase kumquat fruit with waxes or chemical residues on the surface.

4.3 Ultra-Violet Irradiation

Ultra-violet (UV) radiation from the sun can be divided into three groups, UV-C (below 280 nm), UV-B (280-320 nm) and UV-A (320-390 nm) as described by Stapleton (1992). Studies by Kim *et al*. (1991), Rodov *et al*. (1992), Rodov *et al*. (1994) and D'hallewin *et al*. (2000) have found that the release of two phytoalexins, scoparone and scopoletin, were elicited by UV light. This is related to the fruits' resistance against pathogens. Effective UV-C dosage of fruit ranges from 0.25 $kJ.m^{-2}$ to 8.0 $kJ.m^{-2}$ (Terry and Joyce, 2004; Palou *et al*., 2008). Stevens *et al*. (1996) reduced the onset of green mould in both grapefruit and tangerines, and stem-end rot and sour rot in tangerines, by hormetic exposure of the fruit to 0.84 $kJ.m^{-2}$ to 3.6 $kJ.m^{-2}$ of UV-C. Similarly, D'hallewin *et al*. (2000) found that grapefruit exposed to 0.5 $kJ.m^{-2}$ of UV-C irradiation effectively reduced decay, compared to untreated control fruit. Stevens *et al*. (1996) found the effectiveness of UV-C irradiation in reducing postharvest decay was due to its germicidal effect on the fruit surface and its ability to induce fruit resistance (Stevens *et al*., 1996). However, Rodov *et al*. (1994) attributed the fruit decay inhibition by UV irradiation to induced fruit resistance rather than to any germicidal effect because the sample citrus fruit were inoculated with the pathogens after exposure to UV light. In addition to a pathological defence, UV-irradiated fruit were shinier and firmer, possibly due to tissue lignification (Ben-Yehoshua *et al*., 1992). On the contrary, excessive amounts of UV irradiation can result in damage, as observed by Rodov *et al*. (1992) in kumquat, which appeared as peel damage. Similar observations were made by Ben-Yehoshua *et al*. (1992) on lemons. Excessive shrivelling of kumquat was also due to an overdose of UV light (Rodov *et al*., 1994). Canale *et al*. (2011) found that UV irradiation was able to inhibit CBS. Table 10.4 in the Appendix lists some of the effects of UV-C irradiation on different citrus cultivars.

4.4 Chlorinated Water

Hypochlorite has been used widely as a disinfectant for controlling postharvest pathogens in fruit and vegetables (Delaquis *et al*., 1999; Prusky *et al*., 2001; Workneh *et al*., 2003). Hypochlorite in chlorinated water is available as chlorine gas, calcium hypochlorite ($Ca(OCl)_2$), or sodium hypochlorite (NaOCl) (Boyette *et al*., 1993). A hypochlorite concentration ranging from 55-70 ppm at a temperature of 40°C and pH of 7.0 is generally recommended for treating fruit and vegetables (Boyette *et al*., 1993). Kitinoja and Kader (1994) recommend a pH of 6.5 to 7.5. Chlorination is a dynamic process and requires constant monitoring of factors, such as pH, hypochlorite concentration, temperature, organic matter, time, and the growth stage of the pathogen as explained by Boyette *et al*. (1993). Table 10.5 (Appendix) lists some of the hypochlorite treatments applied to citrus fruit.

Mango dipped in 100 $\mu g.ml^{-1}$ chlorinated water for 600 seconds resulted in a higher marketability after storage, which could be attributed to the disinfectant property of hypochlorite (Tefera *et al*., 2007). Delaquis *et al.* (1999) found that warm chlorinated water (47°C for 180 seconds) was more effective in retarding both the development of spoilage microorganisms and the onset of the brown discolouration in iceberg lettuce, compared to cold water. A 10 second wash using 200-250 ppm free chlorine of lettuce reduced the *Listeria monocytogenes* population by a factor of 10 (Simons and Sanguansri, 1997). However, Workneh *et al*. (2003) discovered a slight bleaching of carrots dipped in chlorinated water (100 $\mu g.ml^{-1}$). Korf *et al*. (2001) found that chlorine dioxide (10 $\mu g.ml^{-1}$) was more effective in reducing conidial germination in citrus fruit, compared to calcium hypochlorite (100 $\mu g.ml^{-1}$). Gil *et al*. (2009) stated that a washing time exceeding 60 or 120 seconds had no significant effect in reducing the bacterial count. However, Boyette *et al*. (1993) found that long dips were more effective than quick dips. A spray of water containing 800-1000 ppm hypochlorite was used to disinfect Nagpur mandarins and Mosambi sweet oranges with the aid of nylon brushes (6-8 seconds) (Ladaniya, 2008). Smilanick and Sorenson (2001) used chlorinated water (50 $mg.l^{-1}$) at 1350 kPa for 45 seconds and a delivery rate of 2400 $l.min^{-1}$ for washing of lemons. Research regarding the effect of chlorinated water on kumquat fruit is limited. Currently, the South African kumquat industry uses a 1% chlorine bath or chlorine dioxide (ClO_2) as a pre-treatment (Beghin, 2014c). Therefore, there exists the potential for optimising chlorine treatments for kumquat fruit in South Africa.

4.5 Anolyte Water

Electrochemically activated water (ECA) or anolyte water can generally be described as a salt water solution having an electrical charge (Buck *et al*., 2002; Bakhir, 1997; Leonov, 1997; cited by Workneh *et al*., 2003; Workneh and Osthoff, 2010; Workneh, 2014). During this process the molecular state of water is changed from stable to metastable where two ECA's are produced, anolyte and catholyte. The anolyte, which has an oxidation-reduction potential (ORP) of +1000 mV, is better suited for its antimicrobial, disinfecting effect and the catholyte, which has an ORP of -800 mV, is preferred for its cleaning and detergent ability. A comparison of the effect of anolyte water and chlorinated water on carrots revealed that the latter resulted in a greater loss of firmness and physiological weight (Workneh *et al*., 2003). However, both chlorinated and anolyte water were effective in reducing the microbial flora of carrots. Carrots dipped in the anolyte water also appeared to be shinier and smooth. Similar findings were obtained by Workneh *et al*. (2011a) when treating tomatoes on which lower counts of yeast and mould were detected. However, chlorinated water resulted in a lower coliform count than anolyte water. Guentzel *et al*. (2010) found that a dip and daily spray of electrolyzed oxidizing water at a pH of 6.3-6.5, 250 ppm and an ORP of 800-900 mV reduced the onset of gray mould and brown rot in grapes and peaches, respectively. Unpublished studies by Lesar (2002) found that Neutral Anolyte also known as ACTSOL™ was comparable to chlorine (200 ppm) in preventing green mould and sour rot spore germination. Dilutions of Neutral Anolyte at 1/5 and 1/10 and exposure times of 30, 60, 300 and 600 seconds appeared to be effective. Buck *et al*. (2002) recommend the use of anolyte water for disinfection due to it being environmentally-safe and effective. Research regarding the effect of anolyte water on citrus is limited.

4.6 Sodium Carbonate and Sodium Bicarbonate

The application of sodium carbonate (SC) or sodium bicarbonate (SB) solutions to the exterior of citrus fruit acts as a disinfectant specifically to reduce the postharvest incidence of green mould (Smilanick *et al*., 1997). The efficacy of SC and SB can be attributed to their high pH levels suppressing the action of these pathogens (Venditti *et al*., 2005), as well as promoting the host defence response (Youssef *et al*., 2014). Table 10.6 (Appendix) lists some of the salt treatments applied to citrus fruit. Smilanick *et al*. (1997) found that oranges immersed in 4% or 6% (w/v) SC solutions heated to 40.6°C or 43.3°C for 120 seconds resulted in the most effective control of green mould. Clementine mandarins dipped for 150 seconds in a 3% SC solution at 50°C displayed a significant inhibition in blue and green moulds (Palou *et al*., 2002). Mandarins dipped in 2% or 3% SC solutions at room temperature for 60 seconds or 150 seconds resulted in a 40-60% reduction in both blue and green mould. The disadvantage of SB is that heating of these solutions will result in the release of carbon dioxide and a subsequent decrease in the pH (Smilanick *et al*., 1999). In addition Obagwu and Korsten (2003) found that SB treatment (5%) of oranges resulted in salt burn on the peel.

4.7 Postharvest Biocontrol Treatments

Microbial biocontrol (microbial antagonists) has been used successfully to control the postharvest decay of many horticultural commodities as an alternative to chemical based synthetic treatments (Huanga *et al*., 1995; El-Ghaouth *et al*., 2000; Ippolito *et al*., 2000; Droby *et al*., 2009). Wisniewski and Wilson (1992) and Sharma *et al*. (2009) describe the two methods of using micro-organisms to control postharvest decay as either to use and control the already existing favorable microflora on the fruit surface or to introduce foreign antagonists to postharvest pathogens. The yeast biocontrol modes of action are based on competing for nutrients and space, inducing fruit resistance and the production of lytic enzymes (Arras, 1996; Ippolito *et al*., 2000; Bar-Shimon *et al*., 2004), while bacterial antagonists rely on the production of antibiotics (Wisniewski and Wilson, 1992). The combined use of biocontrol agents with other treatments has been found more beneficial to the fruit, compared to biocontrol as the only treatment, as seen in Table 10.7 contained in the Appendix. Some of the biocontrol products that are commercially available include BioSave-110®, Boniprotect® and BioSave-111®, (Workneh *et al*., 2003; Bar-Shimon *et al*., 2004; Abraham *et al*., 2010; Lahlali *et al*., 2011). A study by Abraham *et al*. (2010) revealed the preventative action of yeast strains B13 and Grape in controlling green mould decay in oranges and lemons in South Africa. Similar positive results were obtained by Arras (1996). However, Droby *et al.* (1998) found that biocontrol was not effective as the only mode of postharvest treatments in alleviating decay in citrus on a commercial scale. The limitation of applying biocontrol agents commercially is primarily the ‘uncontrolled’ postharvest environment, compared to laboratory applications (Wisniewski and Wilson, 1992). Research is required to determine the suitability of biocontrol agents, such as yeast B13, for commercialization (Abraham *et al.*, 2010). Furthermore, there is no research specifically on the effects of biocontrol agents on kumquat, which warrants for research to be undertaken on this topic.

4.8 Integrated Treatments

The application of combined pre-treatments, as opposed to individual treatments, have been found to be far more beneficial in maintaining citrus fruit quality and preventing decay (Obagwu and Korsten, 2003; Sen *et al.*, 2007). Hot water treatment, hypochlorite and salt treatments do not offer a permanent solution to postharvest decay but rather their effectiveness reduces with time (Hong *et al*, 2007). Other treatments need to, therefore, be applied in addition to these treatments to provide prolonged fruit protection. Table 10.8 in the Appendix presents some of the effects of integrated pre-packaging treatments applied to citrus fruit. The combination of hot water and chlorine was shown to be effective in reducing the onset of decay in citrus fruit. The addition of a biocontrol further improves the efficacy (Korf *et al.*, 2001; Sen *et al.*, 2007). Similarly, the treatment of chlorine and hot water proved to be beneficial in mandarins as indicated in Table 10.8 (Appendix) (Sen *et al.*, 2007). Ben-Yehoshua *et al.* (2005) found the treatment of oranges with hot water dipping (52°C for 120 seconds) followed by UV irradiation resulted in reduced fruit decay. It is evident from the table that biocontrol agents are more effective when used in combination with other pre-packaging treatments in reducing fruit decay. An effective combination of treatments makes use of (1) disinfection; (2) curative and (3) preventative modes of action (Laing, 2014c). Curative treatments include hot water, surface coatings or waxes, or SC or SB (Laing, 2014c). Preventative methods include biocontrol agents, such as B13, while chlorine or anolyte treatments provide a disinfecting effect. Limited studies dealt with the combined action of a disinfectant, curative and preventative modes of action on citrus fruit.

5. HARVEST AND POSTHARVEST TECHNOLOGIES AND MACHINERY

Studman (2001) refers to postharvest technology as the handling, sorting, storage, transportation, managing and marketing of horticultural products from the point of harvest until consumption. This section discusses technologies and machinery adopted during the postharvest handling of citrus fruit with a focus on pre-packaging treatments.

5.1 General Packhouse Operations

The purpose of a packhouse is for the effective and efficient application of postharvest treatments and the facilitation of transport and distribution of fruit to the required markets (Tugwell, 1988). Figure 5.1 illustrates a general packhouse processing line for citrus. The components of each processing line may vary, depending on the citrus cultivar and product end use. A U-shaped layout incorporating all the handling processes is considered to be an efficient design in a packhouse, preventing cross-contamination (Kitinoja and Kader, 1994).

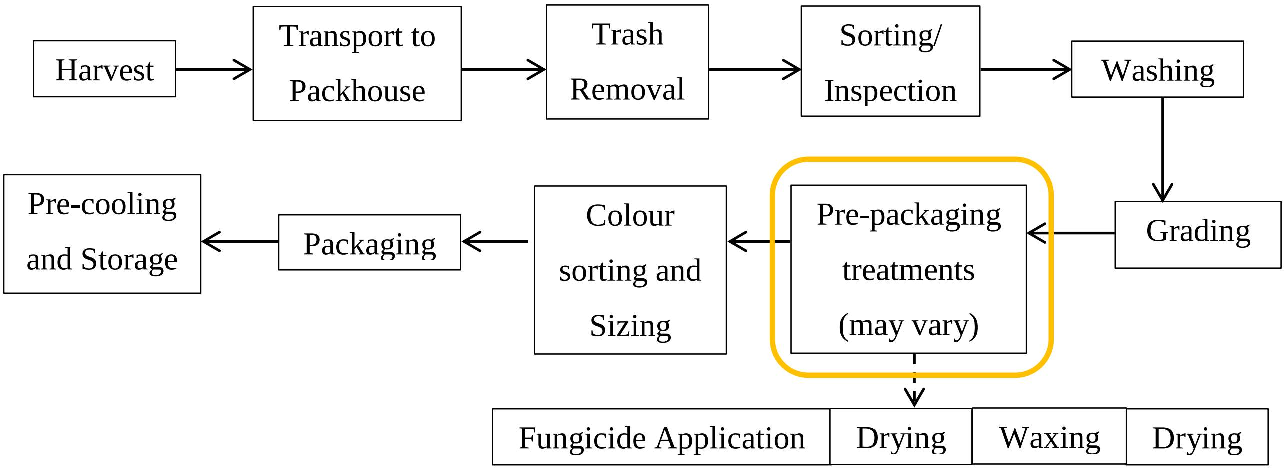


Figure 5.1 General citrus processing diagram (after Tugwell, 1988; Di Giacomo, 2002)

5.1.1 Transport to the packhouse

After harvest citrus fruit are transported by road to packhouses commonly by trucks or tractors and trailors (Ladaniya, 2008; Beghin, 2014a). Due to the smaller volume of kumquat fruit harvested in South Africa, compared to other citrus varieties, such as oranges, groupage or mixed loading is used. This method allows for different fruit to be transported in a single vehicle. TransFresh Corporation (1999) has developed a mixer guide allowing users to input specific produce to determine their transport compatibility. According to the mixer guide kumquat is suitable to be transported with oranges, mandarin and avocados but not with banana, mangoes or tomatoes. Currently kumquats are transported in non-refrigerated vehicles to packhouses that are located a distance away from the orchards (Beghin, 2014a). This time lapse and non-refrigerated transport result in increased fruit temperatures, leading to fruit deterioration (Brosnan and Sun, 2001). Sullivan *et al*. (1996) stated that every minute after harvest is vital with regard to the quality of fresh fruit, hence, the removal of field heat immediately after harvest is desirable (Dennis, 1984; Brosnan and Sun, 2001). Other sources of damage during transport include the depth to which fruit are loaded on to trucks, non-fruit inclusions such as debris, as well as rough roads. Therefore, it can be seen that delays between harvest to packhouse processing will be detrimental to the fruit quality.

5.1.2 Types of conveyors

Conveyors assist in moving produce through process lines and are, therefore, important elements in any packhouse. Kitinoja and Kader (1994) describe three types of conveyors used in the fresh fruit industry: (1) belt conveyor, (2) push-bar conveyor and (3) roller conveyors. The belt conveyor merely moves the produce in one direction without rotation, the push-bar conveyor rotates the fruit forward while moving in the forward direction, and the roller conveyor rotates the fruit backwards while moving in the forward direction. These conveyors can be modified depending on the produce and process stage. Kitinoja and Kader (1994) suggest using foam-padded ramps and shallow slopes for the transition from different conveyors. If only steep slopes are possible, then drapes or curtains should be used over the sloping sections, and slow conveyor speeds should be adopted (exact timing depends on the process). Pourdarbani *et al*. (2013) used a belt conveyor (300 × 45 mm) driven by an inverter-driven half a horsepower electro-gearbox (15 Hz) to sort date fruit, based on their maturity stage. The speed achieved was 22.6 $m.min^{-1}$. However, the belt conveyor only exposed one side of the fruit, which was not an accurate basis to determine the stage of maturity. Pourdarbani *et al*. (2013) recommended using a conveyor that exposed all sides of the fruit. Garcia-Ramos *et al*. (2003) used a chain conveyor composed of rollers with two truncated cones to hold individual fruit moving at a speed of 1 $m.s^{-1}$ powered by a variable speed electric motor. This ensured that an impact sensor could make direct contact with each fruit to determine the firmness.

5.1.3 Citrus sorters and graders

Initial inspection and sorting is essential to ensure that fruit passing through processing lines and to the customer is of an acceptable quality. This process also allows for fruit to be grouped according to their specific end use. Manual sorting, inspection and classification are subjective and may vary depending on personnel and even the time of day (Aleixos, 2002; Ladaniya, 2008). Personnel involved in sorting and grading must be adequately trained to classify fruit based on colour, size, blemishes, and shape. Commercial manual sorters are composed of aluminium rollers of varying widths (1200-1500 mm) and capacities (2-6 tons.h^{-1}), depending on the fruit being conveyed. The rollers rotate on their axis to expose the entire surface of the fruit for better inspection. The sorting area should be adequately illuminated with white light. Sorting and pre-sizing are often performed simultaneously for greater efficiency. Mechanical sorters include the drum roller, which has a series of holes of a specific diameter. The fruit are rotated inside the drum, causing fruit of a smaller diameter to exit the drum through the smaller holes. This method merely sorts citrus fruit based on size, and not on defects or internal fruit quality (Kim *et al*., 2004). This system is best suited for round fruit. A more advanced method combines visible and non-visible (near infra-red, ultra-violet and fluorescent) spectra of light to classify fruit and to detect defects (Blasco *et al*., 2009).

5.1.4 Combined washing and disinfection treatments

Washing is required to remove field dirt, superficial mould, field heat and any chemicals or fungicides from the fruit peel (Petracek *et al*., 1998). Washing may use potable water (rinsing) or the addition of disinfection chemicals (Gil *et al*., 2009). Washing systems include closed flumes, such as pipes, open flumes such as channels, baths and wash tanks (Simons and Sanguansri, 1997), or conveyors and nozzles (Fallik *et al*., 1999). Hypochlorite is the most common disinfectant used in the horticultural industry. Simons and Sanguansri (1997) recommend a chlorine solution pH within the range of 6.5-7 or between 7.0-7.2 (Laing, 2014c). Rinsing after disinfection allows for the excess disinfecting agents to be removed from the fruit surface. Smilanick and Sorenson (2001) rinsed lemons with potable water at 10 ml of water per fruit after treatment with a liquid lime sulphur solution. Batch washing can be used to clean fruit as they move along the length of the bath. However, only one side of the fruit is exposed to the water because the fruit floats with one side up. In addition the temperature of the water may vary in different zones of the tank if a powerful water circulation system is not installed (Fallik, 2004; Laing, 2014b). An efficient system will, therefore, treat the entire area of the fruit under the recommended treatment conditions, such as temperature, concentration and time. The water in batch washing becomes laden with foreign material from the fruit and loses its effectiveness to wash, which contaminates the fruit (Simons and Sanguansri, 1997).

Washer units with brushes and nozzles remove field dirt as well as some of the natural fruit wax. Soft bristle brushes are suited for fruit with a delicate skin, such as limes, lemons and mandarins (Ladaniya, 2008). It is essential that the brushes be saturated with water to reduce damage to fruit, compared to a dry brush method. Ladaniya (2008) recommended horsehair roller brushes at a speed of 100 rpm with a brushing time of 10-20 seconds to reduce bruising. Njombolwana *et al*. (2013) found that cleaning with horsehair brushes resulted in 59% green mould sporulation, compared to 64% with synthetic polyethylene brushes. Petracek *et al*. (1998) found that washing grapefruit, oranges and tangelos using a roller brush and high water pressure nozzles (1380-2760 kPa) for 10 seconds removed the epicuticular wax. However, no detrimental effects on the mass loss or moisture and gas exchange were identified. Systems implementing nozzles and brushes require a shorter operational time, compared to immersion systems (Fallik, 2004). This allows for more fruit to be processed.

5.1.5 Combined washing and hot water treatments

The benefits of hot water treatments have been discussed in Section 4.1. Fallik *et al*. (1999) combined hot water treatment with rinsing to treat sweet peppers. The fruit move along a set of brushes, while simultaneously passing under hot water applied through nozzles, thus cleaning and disinfecting the fruit. Rinsed and heat-treated sweet peppers were firmer, cleaner and displayed less decay when exported, compared to dry brush cleaning. Fallik *et al*. (1999) also found that this method sealed cracks in the fruit epidermis, promoting a longer shelf-life. Hot water rinsing and brushing offered a shorter exposure time of 10-30 seconds, compared to dipping or immersion (Irtwange, 2006). This equipment has also proven to be beneficial for citrus fruit (Porat *et al*., 2000). A minimum exposure time of 20 seconds at 56°C inhibited the germination of green mould. Fallik (2000) recommended that additional research be undertaken to explore the effects of hot water brushing technologies on horticultural commodities to reduce the reliance on pesticides.

5.1.6 Biocontrol and fungicide application

The application of microbial antagonists can be successfully achieved by postharvest dips or sprays (Sharma *et al.*, 2009). The incorporation of biocontrol agents and fungicides into waxes and coatings has also been used in commercial packing lines (Wisniewski and Wilson, 1992; Ladniya, 2008; Sharma *et al.*, 2009; Fan *et al*, 2014). Ladaniya (2008) suggested that combining fungicides with waxes reduces the antifungal action of the fungicide. Furthermore, the residue is often greater when the fungicide is included within the wax. However, the benefit of combining the wax and fungicide is to avoid having two separate operations. Brown *et al*. (1983) found that dipping treatments were more effective than spraying due to the ability of aqueous solutions to penetrate cracks in fruit, where pathogens are most prevalent. However, Ladaniya (2008) found that these dipping methods promoted disease and contamination. The preferred application method uses nozzles, which distributes the solution in a fine mist as the fruit pass on a conveyor belt. Figure 10.1 in the Appendix presents the method of applying the fungicide imazalil via an imazalil thin film treatment (Altieri *et al.*, 2013). The equipment is made of a stainless steel slide (1270 × 700 mm) that allows for the free flow of the fruit. A 30 litre tank supplies the imazalil solution via a centrifugal pump. An overflow blade controls the film thickness. A separating surface then allows excess solution to be drained and finally the fruit is dried using a centrifugal fan.

5.1.7 Surface waxing and coating methods

The choice of type, consistency, viscosity and other characteristics of waxes vary depending on the fruit and the objective of the wax (Hall, 1981). The manner in which the wax is applied to the fruit also varies. In Figure 10.2 (a) contained in the Appendix the wax is applied using wool felt while the fruit are rotated on roller brushes. The wool felt extends across the width of the belt and a polyethylene sheet prevents evaporation of the wax from the felt (Kitinoja and Kader, 1994). In Figure 10.2 (b) (Appendix) the wax is applied using a single traversing hydraulic nozzle (Ladaniya, 2008). The nozzle moves every 1-1.5 seconds. The horsehair roller brushes carrying the fruit are saturated with the wax while the metered nozzle releases a fine spray of wax over the fruit. The wax application is metered using a pump, and is atomised with compressed air to create the fine spray. Other wax applicators make use of a manifold incorporating a number of fixed nozzles mounted above roller brushes (Hall, 1981). This method does not require mechanical movement.

5.1.8 Surface drying

Surface drying is one of the main unit operations in citrus processing (Fito *et al*., 2004). The drying temperature has a profound effect on the fruit quality. Excessively high temperatures can result in dry patches and extreme moisture loss. Grierson and Smith (1986) and Ladaniya (2008) recommended that temperatures should not exceed 54°C. Air can either pass over heaters and be directed on to the fruit as they roll along conveyors, or air can be drawn through heaters located below the fruit. Centrifugal fans can also be used (Altieri *et al*., 2013). Tugwell (1988) recommended high velocity cool air flows to dry fruit because it is more efficient, compared to hot air. Drying commonly follows waxing in commercial citrus packhouses. Fito *et al*. (2004) observed that as more wax was applied to citrus fruit, higher air velocities or air temperatures resulted in a shorter drying time. This drying system is presented in Figure 10.3, in the Appendix. Oranges coated with 0.024 kg.m^{-2} of wax required a 20 second drying time at 1 m.s^{-1} (25°C), compared to a drying time of 10 seconds at 2 m.s^{-1} (25°C). Grierson and Smith (1986) recommended mechanical methods to remove excess water, compared to using heated air, to conserve energy. Mechanical methods include sponge rubber rollers or horsehair brushes with a rotation of no more than 75 rpm or 100 rpm for 10-20 seconds (Grierson and Smith, 1986; Ladaniya, 2008). Cool air is preferred as heated air, together with the rolling action of the brush, may damage the fruit. Currently in South Africa kumquats are air dried following a chlorine treatment, using ambient air as they move along a conveyor belt (Beghin, 2014c).

5.2 Energy Sources and Consumption during Operations

The current energy crisis in South Africa has placed great pressure on the fruit industry, particularly with export fruit. International markets demand that suppliers demonstrate environmentally-sustainable practices. Electricity has been identified as the main source of energy to power the various postharvest processes at the packhouse (Bouwer, 2011). Within a packhouse, processes using conveyors, water pumps, dryers, sorting tables, carton machinery, and lights are the most energy intensive operations (Bouwer, 2011). A benchmarking analysis undertaken in 2010 by Bouwer (2011) revealed that energy consumption varied among South African packhouses from 15 kW.h.ton^{-1} to 44 kW.h.ton^{-1}. Bouwer (2011) recommended that more energy efficient equipment as well as management practices be applied to conserve energy.

Miller and Singh (1986) identified the principle categories of energy to be electricity, boiler fuel (fuel oil or natural gas) and refined oils (gasoline or liquid petroleum (LP)). Electricity is primarily used for lighting and packing line machinery, transport vehicles use gasoline or LP and boilers require mainly oil or natural gas. The average energy utilisation in Florida citrus packhouses using (1) electricity, (2) fuel oil and/or natural gas and (3) gasoline and/or LP equated to 321.3 $kJ.kg^{-1}$, 313.3 $kJ.kg^{-1}$ and 40.1 $kJ.kg^{-1}$, respectively. The California study by Miller and Singh (1986) revealed that low grade heat was generally used due to air and water temperatures being limited to 70°C and 40°C, respectively. Studies by Ozkan *et al.* (2004) and Waheed *et al*. (2008) have found diesel to be one of the main fuel sources in the citrus supply chain. The use of diesel ranged from tractor operations on the field to the generation of electricity in the packhouse. The logistics involved in the fruit industry mainly consumes energy in the form of diesel for vehicles, and bunker fuel oil and marine diesel for shipment (Browne *et al*., 2008).

Recycling of materials, such as water during postharvest handling saves energy (Boyette *et al*., 1993). However, precautions need to be taken to prevent further decay in using contaminated water, by using filters or screens. Reducing the pressure on packhouses to process large volumes of fruit could reduce the energy requirements. Therefore, alternative methods of citrus processing could assist in this regard. A shift from non-renewable to renewable forms of electricity may also provide a viable research opportunity for implementation in the future.

In addition to diesel and electricity, water is a major input in the processing of citrus fruit (Thevendiraraj *et al*., 2003). The amount of water varies, depending on the end product. A water mass balance for a citrus juice plant conducted by Thevendiraraj *et al*. (2003) revealed a total fresh water consumption of 240.3 $t.h^{-1}$ and a waste water generation of 246.1 $t.h^{-1}$. Water intensive operations include rinsing, washing, disinfection and hot water treatment. Recycling the water from these operations, by installing filters, could reduce the large amount of water used, creating a more efficient system. Balls (1986) found that the water requirement for (1) a rotary barrel (deluge), (2) conveyor, (3) conveyor and pre-soak and (4) rotary barrel (immersion) ranged from 2.7-5.5 $m^3.t^{-1}$, 3.5-5.5 $m^3.t^{-1}$, 1.0-2.0 $m^3.t^{-1}$ and 0.2-0.4 $m^3.t^{-1}$, respectively.

6. THE SOUTH AFRICAN CITRUS SUPPLY CHAIN AND MARKETS

This section focuses on the South African citrus market, specifically that of export, since South Africa is a major exporter of citrus fruit. Included in this section are the key factors required to improve the South African supply chain, with the focus on kumquat fruit.

6.1 The Main Citrus Cultivars in South Africa

The four predominant categories of citrus in South Africa are oranges, soft citrus, grapefruit and lemons (van Dyke and Maspero, 2004; DAFF, 2012). Figure 10.13 contained in the Appendix illustrates the export distribution of oranges, grapefruit, lemons and soft citrus fruit, respectively, to the various international markets. According to DAFF (2012) in 2011 Valencia and Navel oranges accounted for the largest portion of the citrus cultivars planted, 42% and 24%, respectively. This was followed by grapefruit with 16%, soft citrus at 9%, and lemons with 8%. There is limited cultivation of kumquats in South Africa, with only 30 hectares dedicated to growing kumquats in the northern eastern regions.

6.2 Market Access

The South African citrus industry is primarily export-driven (Dodd *et al*., 2008; DAFF, 2012; Ntombela and Moobi, 2013). The European Union (EU) is the main recipient of the South African citrus exports with smaller export markets, such as Russia, Thailand, South Korea, China, Indonesia and Japan (DAFF, 2012; Citrus Growers' Association, 2013; DAFF, 2012). Approximately 4-5 tons of kumquats are harvested per annum with Europe (including the United Kingdom), Mauritius and United Arab Emirates being the main export destinations (Begin, 2014c). The demand for kumquats has been fairly stable over the past five years. India has been targeted as a potential market; however, high tariff charges pose a challenge. The EU-Commission Implementing Regulation (2011) contains the marketing standards for citrus fruit including, minimum quality requirements, maturity requirements, classifications, and sizing requirements among other requirements. The level of supply of citrus to the EU is possibly unsustainable due to the demands of retailers, concerning pesticide residues, and recently, due to the issue of CBS (Citrus Growers' Association, 2013). By introducing new and uncommon citrus varieties, it is possible to broaden access to other international markets. The commercial citrus industry for export is well established; however, the niche for small-scale citrus farmers regarding the export market is not yet defined. The National Agricultural Marketing Council has been focussing on small-scale farmers and rural development through the Strategic Integrated Project 11 initiative (Citrus Growers' Association, 2013).

6.3 Supply Chain Challenges

Gaining access to new markets is required to improve the revenue generated by exports, and to enhance international partnerships. However, the strict standards imposed by export markets have proved to be a challenge because this increases the quality standards that South African citrus fruit have to achieve. Due to the recent limited export supply of citrus fruit in 2013 to the EU due to black spot, there is pressure on South Africa to make up for the lost income as well as to regain their reputation for a high standard and quality of fruit. Ortmann *et al*. (2006) found that by modelling the fruit export infrastructure, the Levubu packhouse in South Africa for soft and hard citrus represented a bottleneck in terms of the volume of fruit that needed to be processed. It was recommended that more efficient management and utilisation of existing infrastructure be implemented (Ortmann *et al.,* 2006). This creates a research opportunity for other methods to be developed, such as an on-farm unit capable of treating citrus fruit, as opposed to a conventional packhouse. The following is an explanation of each stage in the kumquat supply chain:

- 1a - Harvesting: kumquats are harvested manually, as explained in Section 2.2. The daily yield harvested varies depending on the number of pickers and picking conditions. Once harvested, the kumquats are then loaded onto vehicles and transported to the packhouse.
- 1b - Transport is performed by non-refrigerated vehicles to packhouses located on the farm, approximately 5 km from the orchards or further, depending on the farm location. At the packhouse the kumquats undergo two pre-packaging treatments.
- 1c - Pre-packaging: the first treatment requires the fruit to be rinsed to remove the field heat and dirt. The kumquats are then disinfected with chlorine (1% chlorine solution or chlorine dioxide) and then air dried.
- 1d - Packaging: once treated, the kumquats are then packaged into 2 kg cardboard cartons. The kumquats are closely packed in each carton. The cartons are then stacked onto 24-ton trucks and secured in place with straps.
- 2 - Transport: due to the lower yield of kumquats, compared to other fruit, groupage transport is required, whereby kumquats are transported along with other horticultural

commodities. Transport to the airport is carried out at night when the ambient temperatures are lower, to accommodate for the absence of refrigeration. The distances from Letsitele and Levubu to the OR Tambo International Airport, in Johannesburg, are approximately 450 km and 850 km, respectively.

- 3 - Airport: once the kumquats arrive at the freight agents at the airport they are then stored temporarily in a cool store room.
- 4 - Transport: the kumquats are then exported to international markets either by air freight (overnight) or by sea (28-30 days).
- 5 - Export Market: the EU is the main export market; however, other markets, such as India, are being targeted.

Each stage is associated with challenges that have been identified in Table 6.1.

Table 6.1 Challenges and probable solutions in the South African kumquat supply chain

Stage	Challenges	Probable Solutions
1a	Both flowers and fruit appear on the tree at the same time.	Pickers need to be careful not to damage buds/ flowers, which can negatively affect subsequent fruit development and quality.
	The stem is not fully removed, resulting in a sharp protrusion, which can result in bruising of adjacent fruit.	Fruit can be collected in flat boxes in single layers rather than in bags (Laing, 2014a).
1b	Non-refrigerated transport, results in increased temperatures, which can be detrimental to the postharvest fruit quality (Workneh and Osthoff, 2010).	Implement refrigeration units in trucks. Pre-treat fruit on-site to withstand higher temperatures and reduce pathogenic infections during transit.
1c	Fruit undergo a basic wash and chlorine disinfection. Chlorine treatments are more effective when used in combination with other pre-packaging treatments, such as hot water treatments (Boyette *et al*., 1993).	Include hot water treatments as part of the pre-packaging process of kumquats.
2	Groupage requires kumquats to be transported with other horticultural commodities due to the small volumes harvested.	Make use of smaller transport vehicles. Transport kumquats with commodities that are not detrimental to the fruit.
4	Transport by sea can take up to 30 days. Extended shipping times can result in pathogenic infections, decay and quality deterioration.	Effective pre-packaging treatments need to be applied early in the supply chain to enhance the shelf-life and maintain fruit quality, such as hot water treatments (Rodov *et al*., 1995), and waxes (Hagenmaier and Baker, 1994). Effective packaging treatments need to be applied to enhance the shelf-life and maintain fruit quality.
5	There is a deficiency of small-scale farmers contributing to the export market (DAFF, 2012).	Develop resources to assist farmers to contribute to export markets, such as a mobile packhouse to reduce investments in large packhouses.

7. DISCUSSION AND CONCLUSION

Citrus fruit are susceptible to microbial infections and postharvest decay once harvested. *Penicillium digitatum* (green mould), *Penicillium italicum* (blue mould) and citrus black spot (CBS) have been identified as the major pathogens affecting citrus fruit (Obagwu and Korsten, 2003; Talibi *et al*., 2012; Mokomele, 2013; Zhang *et al*., 2014). Exposure to excessive field temperatures after harvest and during transport to the packhouse promotes the onset of decay, negatively affecting fruit quality (Dennis, 1984; Sullivan *et al*., 1996; Brosnan and Sun, 2001). In addition, non-fruit inclusions and rough roads during transport may result in further damage to the fruit. Logistical delays in conveying fruit to packhouses further extends the time between harvest and processing. In South Africa the current method of transporting kumquats to packhouses employs unrefrigerated trucks, which exposes the fruit to excessive pathogenic infections and high temperatures. This increases the rate of decay as the fruit are not pre-treated prior to transport. In addition mixed loading requires that the kumquat fruit be transported simultaneously with other horticultural commodities, which can be harmful to the commodities if they are not compatible (TransFresh Corporation, 1999). These factors have a direct influence on time and temperature after harvest, which are crucial factors affecting fruit quality and shelf-life (Brosnan and Sun, 2001).

Fruit packhouses are the hub at which majority of the postharvest handling occurs, such as pre-packaging, packaging and storage treatments. This implies that fruit are typically transported some distance from the orchards to the packhouse before any treatments can be applied. Currently, the main pre-packaging treatments identified within the citrus industry are postharvest fungicides, hypochlorite disinfection and waxing (Ladaniya, 2008). However, the relative efficacy of other treatments, such as hot water, biocontrol agents and anolyte water on citrus fruit should be further explored. Hot water treatments have a significantly positive effect on the postharvest citrus quality, particularly kumquat fruit, in terms of reduced decay as a result of the *Penicillium* pathogens, reduced weight loss and firmer fruit, (Schirra *et al*., 1995; Ben-Yehoshua *et al*., 2000; Porat *et al*., 2000; Rodov *et al*., 2000; Fallik, 2004; Sapitnitskaya *et al*., 2006; Strano *et al*., 2014). Schirra *et al*. (1995), Ben-Yehoshua *et al*. (2000) and Rodov *et al*., (2000) found 53°C for 120 or 30 seconds to be the optimum temperature and time combination for kumquat heat treatments. Hot water treatments do not contain any chemicals and are, therefore, recommended for kumquat fruit due to the manner in which the fruit is consumed (Rodov *et al*., 1995; Schirra *et al*., 1995; Ben-Yehoshua, 2000;

Schirra *et al*., 2011). Waxes were found to reduce the moisture loss and create shiny fruit surfaces; however, excessive waxing can result in the development of off-flavours due to suppressed gas exchange (Njombolwana *et al*., 2013). The use of hypochlorite as a disinfectant is common practice in the postharvest fruit industry. The current hypochlorite treatment of kumquats at packhouses in South Africa uses a 1% chlorine solution or chlorine dioxide. Biocontrol agents have been presented as an environmentally-friendly alternative to fungicides. The yeast strain B13 provided positive results in preventing green mould decay in oranges and lemons in South Africa (Abraham *et al*., 2010). Further studies are required to determine the feasibility of using B13 as a biocontrol agent for kumquat fruit. Excessive UV-C irradiation (>0.5 kJ.m^{-2}) or too high salt content (5%) resulted in damage to the citrus fruit peel (D'hallewin *et al*., 2000; Obagwu and Korsten, 2003; Canale *et al*., 2011).

Combined pre-packaging treatments have been recommended, compared to individual treatments, due to their higher overall efficacy in reducing decay and maintaining fruit quality (Obagwu and Korsten, 2003; Sen *et al*., 2007). An effective pre-packaging treatment combination should include a disinfectant (hypochlorite or anolyte water), curative (hot water) and a preventative agent (biocontrol). Many studies have focused on combined pre-packaging treatments on citrus fruit, such as oranges and mandarins (Korf *et al*., 2001; Sen *et al*., 2007). However, these treatments did not combine disinfection, curative and preventative modes of action, and were conducted under simulated conditions of packhouses (Ben-Yehoshua *et al*., 2005; Sen *et al*., 2007). Insufficient data is available on anolyte water as a pre-packaging treatment in citrus, particularly in kumquats. Therefore, a portion of this study will be dedicated to determining the efficacy of anolyte water as a disinfectant of kumquat fruit.

The equipment used in industry focussed primarily on brushes and spray nozzles to remove dirt and clean the fruit surface. Hydraulic sprayers or water baths have been used for the application of hot water and chlorine treatments. Fallik (1999) developed a hot water brushing and rinsing unit for sweet peppers. However, this equipment was aimed at operation within a packhouse. Electricity and diesel were found to be the main sources of energy in packhouses. The energy utilisation among South African packhouses varied from 15 kW.h.ton^{-1} to 44 kW.h.ton^{-1}. Efficient equipment and management practices are essential to introduce and manage energy saving.

Ideally, an in-field integrated pre-packaging unit would address these concerns by pre-treating the fruit on-site, immediately after harvest, a concept which has not been previously documented. The unit will incorporate disinfecting, curative and preventative pre-packaging treatments. This unit can be described as ‘condensing’ the packhouse processes into a mobile unit that can be operated directly on-site at the orchard. Mobile units for small-scale farmers are likely to reduce the financial investment in large packhouses. South African kumquat yields are lower than other major citrus varieties, such as oranges (Beghin, 2014c). This allows for the unit to be taken directly to the orchard, where treatment of smaller fruit volumes can be controlled. More importantly, the damaging delay between harvest and pre-packaging treatments will be greatly reduced which will improve fruit quality and reduce decay.

Innovative and convenient techniques of treating kumquat fruit after harvest are required to alleviate losses that occur when the fruit is transported untreated to packhouses. It is envisioned that by developing the South African kumquat industry, a larger export market can be created, as well as providing small-scale kumquat farmers with a niche in this export arena. The availability of literature pertaining to the pre-packaging treatment of kumquat fruit, particularly in South Africa, is limited. Therefore, postharvest kumquat research is required to improve and extend the shelf-life, by developing an in-field pre-packaging treatment unit. This concept is discussed further in the project proposal (Section 8).

8. RESEARCH PROPOSAL

A project proposal on the effects of combined pre-packaging treatments and the development of an integrated in-field pre-packaging treatment unit specific to kumquat fruit (*Fortunella margarita*) is presented in this section. The aim and objectives are stated, followed by a materials and methods section. The innovation and potential outcomes of the project are also provided, followed by a project plan outlining the proposed activities.

The overall goal of the project is to develop an integrated pre-packaging citrus treatment unit that is capable of being operated in the orchard. This addresses the challenge of having the fruit transported to a packhouse, which may be located a great distance from the point of harvest. The delay between fruit harvesting and processing will be reduced and fruit treated earlier so as to reduce decay as a result of uncontrolled pathogens. The three main pre-packaging treatments of the unit are: (1) disinfecting (hypochlorite or anolyte water); (2) curative (hot water); and (3) preventative (a yeast isolate - biocontrol agent). Anolyte water has been successfully used as a postharvest disinfectant treatment on carrots and tomatoes (Workneh *et al*., 2003; Workneh *et al*., 2011a). However, the effect of anolyte water on the quality of kumquat fruit as a potential pre-packaging treatment has not as yet been determined.

8.1 Aim and Objectives

The aim of this project is to develop an infield, integrated pre-packaging citrus treatment unit and to evaluate the effects of the pre-packaging treatments on the postharvest quality of kumquat fruit. The specific objects of the project are:

i. to develop a unit with multiple pre-packaging treatment modules: (1) weighing and initial inspection; (2) rinsing; (3) disinfection; (4) hot water; (5) surface drying and (6) a biocontrol application,
ii. to evaluate the effects of the individual and integrated pre-packaging treatments on the physical, chemical, and microbiological quality of kumquat fruit,
iii. to evaluate the overall efficiency of the pre-packaging treatment unit in terms of energy and water use, and
iv. to assess the cost benefit of the integrated pre-packaging treatment unit.

8.2 Materials and Methods

The sample fruit, pre-packaging treatments including the experimental design, data collection and data analysis are discussed in the following sections.

8.2.1 Sample fruit

Nagami (*Fortunella margarita*) has been identified as the key sample fruit due to it being the main kumquat variety exported from South Africa. Samples of kumquat fruit will be obtained from the Letsitele region, just outside Tzaneen, and Levubu near the Kruger National Park, Limpopo Province, South Africa. The kumquat orchards are registered with the Department of Agriculture Forestry and Fisheries and have been registered as clear of CBS and fruit fly. Premier Fruit Exports (Pty) Ltd will provide the necessary samples for testing. Once harvested, the kumquat fruit will be immediately couriered overnight to the UKZN laboratories for testing. A total of 1100 fruit will be required for the preliminary experiment and 850 fruit will be required for the main experiment (Section 8.2.3).

8.2.2 Integrated pre-packaging treatment unit

The concept of the unit including the pre-packaging treatments (modules 1-6) is presented in Figure 8.1.

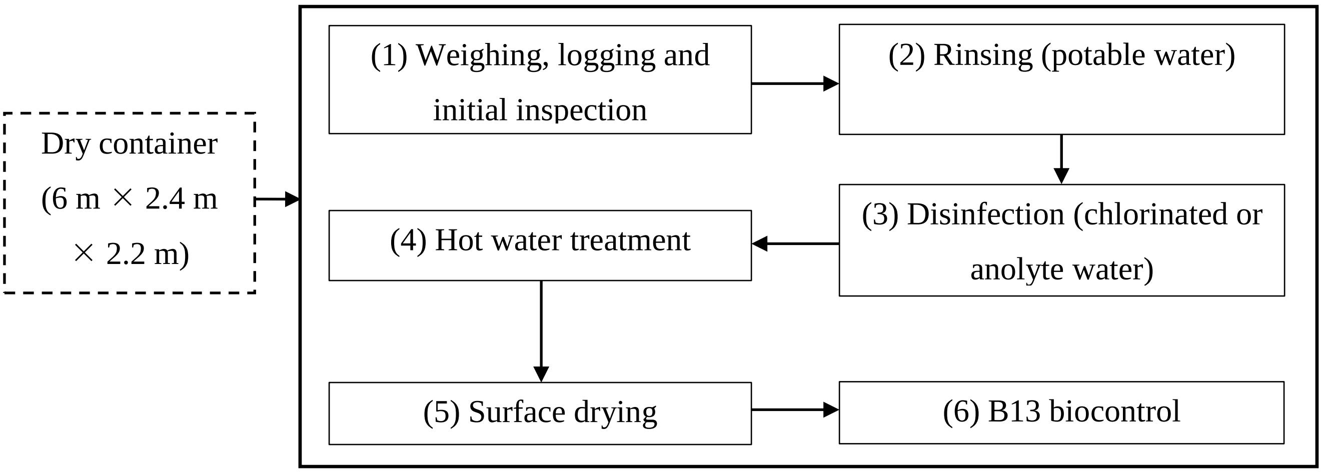


Figure 8.1 The concept of the integrated pre-packaging treatment unit

1. Weighing, logging and initial inspection zone (Module 1): The fruit weight harvested by each picker will be logged at this zone. This ensures that pickers are paid according to the mass (kg) of fruit harvested. Trained personnel will inspect the harvested fruit and remove fruit that do not meet the initial criteria (incorrect colour, damaged fruit or any other irregularities). Training of personnel is not included within the scope of this study. Undesirable material, such as twigs and stones, will also be removed at this stage.
2. Rinsing zone (Module 2): the fruit will be washed with potable water at ambient temperature (approximately 25°C) using spray nozzles to remove dirt/soil and to cool the fruit by removing the field heat, spraying for approximately 10 seconds at a delivery pressure of 200 kPa (Grierson and Smith, 1986; Petracek *et al.*, 1998; Ladaniya, 2008). The water will be stored in a tank and delivered to the nozzles via a pump.
3. Surface disinfection zone (Module 3): disinfection is required to kill any existing coliforms on the surface of the fruit. Two alternatives will be considered:
    - 3.a. Chlorination: food grade calcium hypochlorite ($Ca(OCl)_2$) or sodium hypochlorite (NaOCl) will be used. Chlorine levels should be maintained at 100 ppm at a pH between 7.0-7.2 (Laing, 2014c). Exposure time will be for 30 seconds. The chlorine treatment will be applied with the aid of nozzles. The chlorine water will be stored in a tank and conveyed to the nozzles via a pump.
    - 3.b. Anolyte water: alternatively, depending on the outcome of the preliminary experiment, electrochemically dissociated anolyte water may be used. Anolyte water will be supplied by *Radical Waters* (Pty) Ltd. A concentration of 100%, at a pH of 6.0-7.5, ORP > 750 mV and an exposure time of 30 seconds will be applied with the aid of nozzles (Lesar, 2002; Louw, 2014). The anolyte water will be stored in a tank and conveyed to the nozzles via a pump.
4. Hot water zone (Module 4): the fruit will then be treated with hot water (53°C for 20 seconds) using spray nozzles.
5. Surface drying zone (Module 5): the fruit must then be dried, to allow for the biocontrol agent to effectively adhere to the fruit surface (≈ 95% moisture removal). A drying time of 10 seconds with an air velocity of 2 $m.s^{-1}$, at a temperature of 25°C, will be used (Fito *et al.*, 2004).
6. Biocontrol zone (Module 6): a yeast isolate, B13 (*Candida fermentati*) has been selected as the biocontrol agent as it has rendered positive results when applied to citrus fruit in South Africa (Abraham *et al.*, 2010). The biocontrol agent will be applied using nozzles or a dip treatment.

A dry container (6 m × 2.4 m × 2.2 m) will be used to house the unit responsible for the in-field treatment of kumquat fruit, therefore the size of the unit will also be governed by the dry container dimensions. Each module will be designed, constructed and tested individually before being combined and tested as a unit. The necessary design components for modules 1-6 are as follows:

1. scale and an automatic logging system that will be able to identify and record the weight of fruit harvested by each picker,
2. perforated nylon conveyor belt or modular conveyor belt to transfer fruit between treatments,
3. motor/s to control the speed of the conveyor at each treatment,
4. nozzles to rinse, disinfect, apply hot water, and biocontrol,
5. water tank to store clean rinsing water,
6. tank to store chlorine or anolyte water,
7. tank to store heated water,
8. filtration systems to ensure all debris and foreign material are removed from the water,
9. fan or blower for surface drying of the fruit,
10. heat pump coupled with an immersion heater to provide heated water,
11. pump/s to pump water through the nozzles,
12. generator to provide the energy source (preferably a commercially available diesel generator), and
13. a dry container (6 m × 2.4 m × 2.2 m) to house all the treatment equipment.

The unique characteristic of this integrated unit is that it is being designed to be mobile and to be transported into the orchards in-field for operation immediately after the fruit is harvested. A dry container (6 m × 2.4 m × 2.2 m) will be used to house the unit for protection against the natural elements. The efficiency of the unit will be determined by: (1) the effect of the pre-packaging treatments on the fruit quality; (2) the energy and water use and (3) the cost benefit.

8.2.3 Experimental design and sampling procedure

The study is divided into two factorial experiments. A preliminary experiment will be conducted on a laboratory trial basis, incorporating chlorine water and anolyte water as the disinfectant treatments, hot water as the curative treatment and B13 yeast isolate as the preventative treatment. This experiment will aid in determining the suitability of either chlorine water or anolyte water to be used as the disinfectant treatment of the unit. The postharvest quality changes of the kumquat fruit will be evaluated upon which the unit design will be based. The fruit will be subjected to 12 treatments, which are: (1) chlorine water; (2) anolyte water; (3) hot water; (4) biocontrol; (5) combined chlorine and hot water; (6) combined chlorine and biocontrol; (7) combined chlorine, hot water and biocontrol; (8) combined anolyte and hot water; (9) combined anolyte and biocontrol; (10) combined anolyte, hot water and biocontrol; (11) hot water and biocontrol and (12) a control. After application of the treatments, the samples will be stored for a period of 28 days under ambient conditions. Three HOBO® data loggers will be used to measure the ambient conditions (temperature and relative humidity).

Samples will be tested at the following time intervals during storage:

1. T_0 - 0 day,
2. T_1 - 7 days after treatment,
3. T_2 - 14 days after treatment,
4. T_3 - 21 days after treatment, and
5. T_4 - 28 days after treatment.

The experimental design selected is a Randomised Complete Block Design (RCBD) as it accounts for any variations in the samples (Compton, 1994). Three replications will be performed for each treatment and a total of six fruit will be used per replication. Of the six fruit, three will be inoculated with *Penicillium digitatum* (green mould) and three will be inoculated with *Penicillium italicum* (blue mould) prior to application of the treatments. The inoculation will assist in evaluating the efficacy of the treatments in controlling the microbial growth. The green and blue moulds will first be harvested from the surface of infected fruit and plated in potato dextrose agar. The plates will then be incubated at 28°C for a period of 5 to 7 days, depending on the rate of sporulation. Conidia suspension concentrations will then be adjusted using a Neubauer hemocytometer before inoculating individual fruit. The experimental design is presented in Table 8.1.

Table 8.1 Experimental design for the preliminary experiment

No.	**Treatments (12)**	**Replications (3)**	**Sample Interval (5)**					**Number of fruit Tested per Sampling Interval (6)**
1	Chlorine water (A)	3	T_0	T_1	T_2	T_3	T_4	6
2	Anolyte water (B)	3	T_0	T_1	T_2	T_3	T_4	6
3	Hot water (C)	3	T_0	T_1	T_2	T_3	T_4	6
4	Biocontrol (D)	3	T_0	T_1	T_2	T_3	T_4	6
5	AC	3	T_0	T_1	T_2	T_3	T_4	6
6	AD	3	T_0	T_1	T_2	T_3	T_4	6
7	ACD	3	T_0	T_1	T_2	T_3	T_4	6
8	BC	3	T_0	T_1	T_2	T_3	T_4	6
9	BD	3	T_0	T_1	T_2	T_3	T_4	6
10	BCD	3	T_0	T_1	T_2	T_3	T_4	6
11	CD	3	T_0	T_1	T_2	T_3	T_4	6
12	Control	3	T_0	T_1	T_2	T_3	T_4	6

The actual number of fruit required for the preliminary experiment, according to equation 8.1, is 1080. However, to accommodate for any losses as a result of fruit that may be discarded due to damage, irregular shape or colour, a total of 1100 fruit will be obtained from the orchard.

$$\begin{aligned}\text{Fruit number} &= \text{Treatments} \times \text{replications} \times \text{sampling interval} \times \text{fruit per interval} \qquad (8.1)\\ &= 12 \times 3 \times 5 \times 6\\ &= 1080\end{aligned}$$

The main experiment will follow the same procedure as the preliminary experiment. However, this experiment will be conducted using the designed and constructed integrated pre-packaging treatment unit. The treatments include: (1) chlorine or anolyte water; (2) hot water; (3) biocontrol; (4) combined chlorine or anolyte water and hot water; (5) combined chlorine or anolyte water and biocontrol; (6) combined hot water and biocontrol; (7) combined treatments chlorine or anolyte water, hot water and biocontrol; (8) testing of the entire unit (Modules 1-6), and (9) control. Weighing, logging, initial inspection, rinsing, and drying are not considered for their individual effect on the fruit quality. The experimental design is presented in Table 8.2.

Table 8.2 Experimental design for the main experiment

No.	**Treatments (9)**	**Replications (3)**	**Sample Interval (5)**					**Number of fruit Tested per Sampling Interval (6)**
1	Chlorine or anolyte water (A)	3	T_0	T_1	T_2	T_3	T_4	6
2	Hot water (B)	3	T_0	T_1	T_2	T_3	T_4	6
3	Biocontrol (C)	3	T_0	T_1	T_2	T_3	T_4	6
4	AB	3	T_0	T_1	T_2	T_3	T_4	6
5	AC	3	T_0	T_1	T_2	T_3	T_4	6
6	BC	3	T_0	T_1	T_2	T_3	T_4	6
7	ABC	3	T_0	T_1	T_2	T_3	T_4	6
8	Running the entire unit (Modules 1-6)	3	T_0	T_1	T_2	T_3	T_4	6
9	Control	3	T_0	T_1	T_2	T_3	T_4	6

The actual number of fruit required for the main experiment, according to equation 8.2, is 810. However, to accommodate for any losses as a result of fruit that may be discarded due to damage, irregular shape or colour, a total of 850 fruit will be obtained from the orchard.

$$\begin{aligned}\text{Fruit number} &= \text{Treatments} \times \text{replications} \times \text{sampling interval} \times \text{fruit per interval} \qquad (8.2)\\ &= 9 \times 3 \times 5 \times 6\\ &= 810\end{aligned}$$

Construction of the prototype will be done at Ukulinga Research Station in Pietermaritzburg, South Africa (29°40′11″S, 30°24′50″E). Locally sourced low cost parts will be used. Each zone will be constructed individually and tested before being merged into a single unit.

8.2.4 Data collection

The evaluation of the physical, chemical fruit and microbiological quality parameters will be conducted in the Food Science and Agricultural Engineering Laboratory at UKZN. The *Penicillium digitatum* and *Penicillium italicum* fungi will be grown in the Plant Pathology laboratory at UKZN. The laboratories are well equipped with the necessary resources and equipment to conduct the experiments and sampling procedures. The physical, chemical, and microbiological quality parameters to be evaluated during sampling are presented in Table 8.3. On day 0 untreated fruit will each be sampled for their physical, chemical and microbiological quality prior to application of the treatments and immediately after the treatments (before storage). Thereafter, during storage on days 7, 14, 21 and 28 three fruit inoculated with *Penicillium digitatum* and three fruit inoculate with *Penicillium italicum* from each treatment replicate will be sampled. The methods that will be used to determine the kumquat quality are referenced in Table 8.3.

Table 8.3 Quality parameters to be evaluated

Quality Parameters		**Equipment/ Consumable/ Chemicals**	**Available/To Purchase**	**Estimated Cost**	**Unit**	**Reference**
Physical	Peel colour	Konica Minolta CR-400 colorimeter	Available	-	-	Choi *et al.*, 2002; Li *et al.*, 2008
	Firmness (Puncture)	Instron Universal Testing Machine	Available	-	-	Churchill *et al.*, 1980; Valero *et al.*, 1998
		Probe for puncture (1.5 mm)	Available	-	-	
	Weight loss	Mettler PJ 300 scale	Available	-	-	Singh and Reddy, 2006; Hong *et al.*, 2007
	Peel moisture content	Oven	Available	-	-	Singh and Reddy, 2006
		Mettler PJ 300 scale	Available	-	-	
		Aluminium foil	To purchase	R 60.00	20	
		Mini plastic bags	To purchase	R 11.90	100	
Chemical	Total soluble solids	Refractometer	Available	-	-	Hong *et al.*, 2007
		Ethanol (99.99%)	To purchase	R 250.00	2.5 *l*	
	Total titratable acid	Phenolphthalein indicator	To purchase	R 95.00	500 ml	Porat *et al.*, 2000
		0.1 N Sodium Hydroxide	To purchase	R 110.00	1 *l*	
		Industrial paper towel	To purchase	R 191.92	1 roll	
		Titration apparatus	Available	-	-	
	Maturity index	-	-	-	-	Olmo *et al.*, 2000
Microbiological	Blue mould and green mould (decay incidence)	Autoclave	Available	-	-	Droby *et al.*, 1998, Smilanick *et al.*,1999; Abraham *et al.*, 2010; Basdew, 2014
		Plastic petri dishes	Available	-	-	
		Potato dextrose agar	Available	-	-	
		Automatic pipette	Available	-	-	
		Infected fruit	Available	-	-	
				R 718.82		

The actual efficiency of the unit can be determined by the overall input efficiency (OIE), overall equipment efficiency (OEE) and the total equipment efficiency (TEE) as indicated by equations 8.3, 8.4 and 8.5 (Sheu, 2006). The SuperPro Designer® software by Intelligen Inc.

will be used to simulate the desired unit processes/operations and perform material and energy balances.

$$\text{TEE} = \text{OIE} \times \text{OEE} \tag{8.3}$$

$$\text{OIE} = f\,(\text{labour, raw materials, consumables, utilities, acquisition cost}) \tag{8.4}$$

$$\text{OEE} = f\,(\text{performance efficiency, quality efficiency, availability}) \tag{8.5}$$

An economic cost-benefit analysis will be conducted to evaluate the actual cost required to produce the equipment (labour, materials, utilities) compared to the average cost incurred by farmers under the current method of processing after harvest (packhouse conditions). The ‘with-and-without project’ approach will be used, as explained by Marshall and Brennan (2001) and Campbell and Brown (2003). In addition the SuperPro Designer® software by Intelligen Inc. is able to also perform economic evaluations and costing.

8.2.5 Statistical data analysis

The statistical analysis was performed by the GenStat software, 14th Edition. The differences between treatments were determined by an analysis of variance (ANOVA) and the means were separated using the Duncan’s Multiple Range Test, with a significance level of 0.05 (Duncan, 1955; Droby *et al*., 1998; Irshad *et al*., 2012; Workneh *et al*., 2011b).

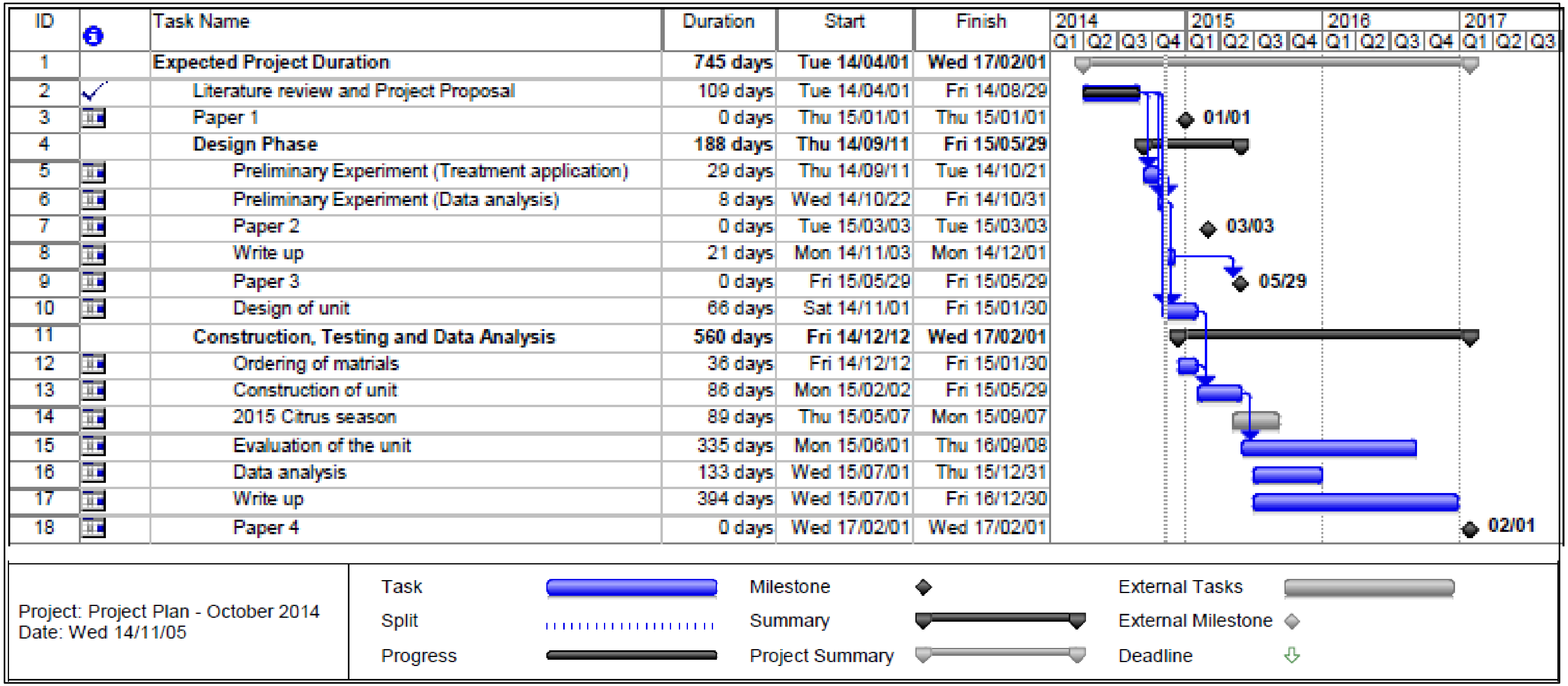
8.3 Innovation and Potential Outcomes

This project is primarily aimed at alleviating the challenge posed by the *Penicillium* moulds on kumquat fruit by implementing integrated pre-packaging treatments. This project focuses on small-scale citrus farmers, specifically kumquat farmers, to gain access to a wider export market. A mobile unit will aid in reducing the investment of small-scale farmers in large packhouses. The unit will be designed to be mobile and transported to orchards to commence the postharvest treatments immediately once the fruit is harvested. An understanding of the effect of the postharvest treatments of kumquat fruit immediately after harvest will also support the maintenance of fruit quality from the point of harvest till the final market destination has been reached. This will lead to improving local postharvest handling and marketing systems.

8.4 Project Plan

This project is composed of a design phase and construction and evaluation phase as indicated in the proposed project plan presented in Figure 8.2.

Figure 8.2 Proposed project plan



ID	ℹ	Task Name	Duration	Start	Finish
1		**Expected Project Duration**	**745 days**	**Tue 14/04/01**	**Wed 17/02/01**
2	✓	Literature review and Project Proposal	109 days	Tue 14/04/01	Fri 14/08/29
3	▦	Paper 1	0 days	Thu 15/01/01	Thu 15/01/01
4		**Design Phase**	**188 days**	**Thu 14/09/11**	**Fri 15/05/29**
5	▦	Preliminary Experiment (Treatment application)	29 days	Thu 14/09/11	Tue 14/10/21
6	▦	Preliminary Experiment (Data analysis)	8 days	Wed 14/10/22	Fri 14/10/31
7	▦	Paper 2	0 days	Tue 15/03/03	Tue 15/03/03
8	▦	Write up	21 days	Mon 14/11/03	Mon 14/12/01
9	▦	Paper 3	0 days	Fri 15/05/29	Fri 15/05/29
10	▦	Design of unit	66 days	Sat 14/11/01	Fri 15/01/30
11		**Construction, Testing and Data Analysis**	**560 days**	**Fri 14/12/12**	**Wed 17/02/01**
12	▦	Ordering of matrials	36 days	Fri 14/12/12	Fri 15/01/30
13	▦	Construction of unit	86 days	Mon 15/02/02	Fri 15/05/29
14	▦	2015 Citrus season	89 days	Thu 15/05/07	Mon 15/09/07
15	▦	Evaluation of the unit	335 days	Mon 15/06/01	Thu 16/09/08
16	▦	Data analysis	133 days	Wed 15/07/01	Thu 15/12/31
17	▦	Write up	394 days	Wed 15/07/01	Fri 16/12/30
18	▦	Paper 4	0 days	Wed 17/02/01	Wed 17/02/01

Project: Project Plan - October 2014
Date: Wed 14/11/05

Task
Split
Progress
Milestone ◆
Summary
Project Summary
External Tasks
External Milestone ◇
Deadline ⇩

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10. APPENDIX

Table 10.1 Summary of diseases and physiological disorders of citrus fruit

Disease Classification	Citrus Cultivar	Disease/ Physiological Disorder	Symptoms	Additional Information	Prevention/ Remedy/ Control	Reference
Pre-harvest						
Bacterial disease	All citrus cultivars but may differ in the degree of susceptibility	Asiatic citrus canker caused by *Xanthomonas axonopodis* pv.*citri* (Xac A)	Raised lesion appearing on leaves, corky/ scab-like lesions on the fruit, premature fruit drop and poor fruit quality	Affects citrus trees. Areas that are susceptible experience high rainfall and humidity	Plants own defense mechanism, cultural practices, such as wind breaks, copper sprays	Stall (1988); Khalaf *et al*. (2007)
Fungal Disease in Nursery and Orchards (affecting the fruit)	All citrus, mainly affecting orange, mandarin, lemon, and grapefruit	Black spot caused by *Guignardia citricarpa* (Kiely)	Premature fruit abscission. The four catagories of symptoms are (1) hard spot, (2) freckle spot, (3) virulent or spreading, and (4) false melanose or speckled blotch	Symptoms may appear during late stages fruit development or after harvest. Symptoms vary among cultivars	Removal of infected trees and fruit from orchards, copper fungicides, spore trapping, fruit maintained at below 20°C after harvest	Kotze (1988); Korf *et al*. (2001); Bonants *et al*. (2003); Yonowa *et al*. (2013)
Postharvest						
Postharvest fungal disease	All citrus	Blue mould caused by *Penicillium italicum* Wehmer	Diseased tissue appears to be soft, watery and discoloured. Formation of a white powdery growth forms on lesions and develops into a mass of blue spores	Healthy fruit can be infected due to the movement of spores	Application of synthetic fungicides, hot water treatment, sodium carbonate, and sodium bicarbonate	Brown and Eckert (1988a); Palou *et al.* (2002); Venditti *et al.* (2005)
Postharvest fungal disease	All citrus	Green mould caused by *Penicillium digitatum*	The initial symptoms are similar to that of blue mould. The fruit becomes enveloped in a	Wounding during harvesting and postharvest handling initiates the action of this pathogen. Healthy fruit can	Application of synthetic fungicides, hot water treatment, sodium carbonate, and sodium	Brown and Eckert (1988b); Smilanick *et al*. (1997); Smilanick *et al*. (1999); Pavoncello

Disease Classification	Citrus Cultivar	Disease/ Physiological Disorder	Symptoms	Additional Information	Prevention/ Remedy/ Control	Reference
		(Pers.:Fr.) Sacc.	mass of olive green spores	be infected due to the movement of spores	bicarbonate	*et al*. (2001); Palou *et al*. (2002); Venditti *et al*., 2005, Youssef *et al*. (2014)
Postharvest fungal disease	All citrus, particularly	*Geotrichum candidum*	Light to dark yellow water-soaked, raised lesions. White or cream mycelium may appear	Sour rot is stimulated by the presence of green mould	Preventing fruit contact with the soil during harvest. Delayed harvesting till later in the day. Minimizing fruit storage temperatures	Merciera and Smilanick, 2005; Smilanick *et al*., 2005; Ladaniya, 2008; Talibi *et al*., 2012
Postharvest fungal disease	All citrus	Stem-end rot caused by *Diplodia natalensis* P. Evans	The fungus starts at the stem and penetrates the rind and core. Decay is uneven and resembles finger-like projections of brown tissue. Mycelium form at the advanced stage of infection	Citrus that have been degreened using ethylene (5-10µl.l^{-1}) are particularly susceptible. Temperatures in excess of 21°C promote fungal growth	The use of fungicides before and after degreening. Immediate cooling after packing	Brown (1986); Brown and Eckert (1988c); Brown and Lee (1993); Zhang and Swingle (2005)
Rind disorders	All cultivars, but mainly grapefruit, lemons and lime	Rind disorder caused by chilling injury	Browning of the flavedo, albedo and dark, sunken tissue	Chilling injury is as a result of exposing the fruit to too low temperatures before and/or after harvest	Heat treatments, intermittent warming, temperature conditioning, application of a wax, modified atmosphere packaging	Wardowski (1988a); Porat *et al*. (2004); Sapitnitskaya *et al*. (2006)
Stem-end rind breakdown	All cultivars but mainly in oranges	Rind disorder caused by aging.	Darkening and collapsing of the rind around the stem-end	Can result from an imbalance in potassium and nitrogen. Stem-end breakdown is associated with moisture loss and occurs mainly in thin-skinned small fruit. Symptoms usually occur two to seven days after packing	Maintaining high humidity environments, harvested fruit should be protected against heat and water loss, which can be achieved by use of a wax	Grierson (1986); Wardowski (1988b); Ritenour *et al*. (2004)

Table 10.2 The effects of different heat treatments applied to citrus fruit

Type of Treatment	**Exposure Time**	**Exposure Temperature**	**Fruit**	**Effect**	**Reference**
Thermal curing	3 days	36°C	Eureka lemons	Prevention of *Penicillium* decay for > 2 months at 17°C	Kim *et al*. (1991)
				Production of scoparone	
Hot air	3 hours	48°C	Marsh grapefruit	Maintained fruit market quality	McGuire and Reeder (1992)
	2 hours	49°C			
Hot Water	-	53°C	Kumquat	Improved fruit appearance, reduced weight loss and rot development	Schirra *et al*. (1995)
Hot water	120 seconds or 30 seconds	53°C or 56°C	Kumquat	Reduction in blue and green mould	Ben-Yehoshua *et al*. (2000)
Hot water (dipping)	120 seconds	52°C	Oroblanco	Reduced fruit softening and button abscission.	Rodov *et al*. (2000)
				Inhibited yellow colour formation in combination with individual polyethylene packaging	
Hot drench brushing	10 seconds	60°C	Oroblanco	Reduced fruit softening and button abscission.	Rodov *et al*. (2000)
				Delayed colour change	
Hot water (dipping)	120 seconds	53°C	Kumquat	Reduced decay	Rodov *et al*. (2000)
				Reduced weight loss	
Hot water (rinsing)	20 seconds	62°C	Star Ruby Grapefruit	Reduced chilling injury by 85% after 8 weeks	Sapitnitskaya *et al*. (2006)
Hot water dipping	120 seconds	50°C	Kumquat	Maintained 'fresh' appearance, reduced decay, reduced weight loss, maintained quality traits	Schirra *et al*. (2011)
Hot air	30 hours	37°C	Kumquat	Loss of exterior gloss, excessive weight loss, diminished fruit quality	Schirra *et al*. (2011)
Hot water dipping	20 seconds	56°C	Tarocco oranges	Reduced weight loss, inhibition of green mould spore germination, maintained internal and external quality traits	Strano *et al*. (2014)
Hot water dipping	180 seconds	52°C	Tarocco oranges	Increased levels of alcohols, esters and aliphatic aldehydes	Strano *et al*. (2014)

‘-’, Information not provided in the research source.

Table 10.3 The effects of different surface coatings applied to citrus fruit

Description of Coating	Fruit	Effect	Reference
Beeswax emulsion and TAL Pro-long	Pineapple orange	Improved fresh orange juice volatiles and flavour	Nisperos-Carriedo *et al.* (1990)
Patented edible composite coating	Mature oranges	Improved volatiles and flavour	Nisperos-Carriedo *et al.* (1991)
Citral (120 second dipping time)	Mature light green lemons	Significantly reduced decay	Ben-Yehoshua *et al.* (1992)
		Fruit dipped in 1% citral resulted in phytotoxic damage	
Low molecular weight chitosan (0.1% and 0.2%)	Murcott tangor	Improved firmness, TTA, TSS, ascorbic acid, reduced water loss	Chien *et al.* (2007)
		Reduced postharvest decay (blue and green mould)	
Chitosan and $CaCl_2$ complex	Kumquats	Delay in ripening and senescence	Li *et al.* (2008)
Imazalil (3000 $mg.l^{-1}$) supplemented polyethylene wax	Navel oranges	Shiny fruit but resulted in off-flavours, compared to uncoated fruit	Njombolwana *et al.* (2013)
		Higher weight loss and less firm fruit, compared to carnauba wax supplemented with imazalil	
Carboxymethyl cellulose (1.5% w/v)	Rishon and Michal mandarins	Improved firmness, reduced weight loss and a glossy exterior	Arnon *et al.* (2014)

Table 10.4 The effects of different UV irradiation intensities on citrus fruit

UV Irradiation Intensity	Fruit	Effect	Reference
5.0 $kJ.m^{-2}$	Lemon	Increased production of scoparone	Ben-Yehoshua *et al.* (1992)
		Reduced green mould	
1.5 $kJ.m^{-2}$	Kumquat	Increased production of scoparone	Rodov *et al.* (1992)
		Reduced green mould	
2.2 $kJ.m^{-2}$	Marsh grapefruit	Reduced the incidence of green mould to 14%	Stevens *et al.* (1996)
1.3 $kJ.m^{-2}$	Dancy tangerines	10-fold reduction in the onset of green mould	
3.2 $kJ.m^{-2}$	Mature grapefruit	Reduced decay from 72% to 16 %	Lers *et al.* (1998)
3.0 $kJ.m^{-2}$	Washington Navel orange	Significant decay reduction in late harvested fruit	D’hallewin *et al.* (1999)
	Biondo Comune orange	Significant decay reduction in late harvested fruit	
0.5 $kJ.m^{-2}$ of UV-C	Star Ruby Grapefruit	Reduced decay caused by green mould to 2-3%	D’hallewin *et al.* (2000)
>0.5 $kJ.m^{-2}$ of UV-C		Higher doses resulted in tissue necrosis and peel browning	
		Fruit harvested earlier (less mature) exhibited more severe damage	
7.28 and 15.66 $kJ.m^{-2}$ of UV-C	Valencia oranges	Did not effectively control citrus black spot. However, the appearance of quiescent black spot lesions were reduced	Canale *et al.* (2011)

Table 10.5 The effects of different hypochlorite concentrations applied to citrus fruit

* Hypochlorite Concentration	Exposure Time	Fruit	Effect	Reference
200-250 ppm and pH 6.0-7.5 (10% strength sodium hypochorite)	120 seconds	Kumquat	Reduced decay	Hall (1986)
150 $mg.l^{-1}$ active chlorine, pH 8	60 seconds	Lemons	Hypochlorite treatment alone resulted in higher decay rates	Stange and Eckert (1994)
100 $\mu g.ml^{-1}$ free chlorine	120 seconds	Satsuma mandarin	Significant reduction in decay. Positive influence on the b* component colour	Sen *et al*. (2007)
1000 ppm	120 seconds	Nagpur mandarins	Reduced decay for 30 days at ambient conditions	Ladaniya (2008)

*Assume 1 ppm = 1 $mg.l^{-1}$ (Chiou *et al*., 1977).

Table 10.6 The effects of sodium carbonate and bicarbonate treatments in citrus fruit

Description of SC or SB Solution	Exposure Time	Solution Temperature	Fruit	Effect	Reference
4% or 6% SC	120 seconds	40.6°C or 43.3°C	Oranges	Significant reduction in green mould	Smilanick *et al*. (1997)
3% SC	60 seconds	56°C or 61°C	Navel oranges	Rind injury	Smilanick *et al*. (1999)
3% SC	150 seconds	50°C	Clementine mandarins	Significant reduction in blue and green mould, no visible injury to the fruit	Palou *et al*. (2002)
2% or 3% SB	60 or 150 seconds	Room temperature (20±1°C)		Reduced incidence of blue and green mould by 40-60%	
2% SB	-	-	Grapefruit	Reduced decay as a result of green mould by 61%	Porat *et al*. (2002)
5% SC	-	-	Fairchild mandarin	Resulted in accumulation of scoparone, associated with a reduction in decay	Venditti *et al*. (2005)
			Biondo comune oranges	Green mould decay reduced by 97.2% and blue mould decay reduced by 93.9%	

'-' Information not provided in the research article.
SB, sodium bicarbonate; SC, sodium carbonate.

Table 10.7 The effects of different postharvest biocontrol agents used on citrus fruit

Type of Biocontrol Agent	Fruit	Effect	Reference
Candida famata isolated from fig leaves	Orange	95-100% reduction in infected fruit in terms of green mould	Arras (1996)
		Promoted the production of scoparone	
Candida oleophila isolated from tomato fruit surface	Grapefruit	Production of fungal cell wall degrading enzymes resulting in a reduction in green mould infected fruit	Bar-Shimon *et al*. (2004)
		Reduced infected wounds to 10% in yeast-treated wounds, compared to 100%	
Yeast isolates (B13 and Grape)	Navel oranges and lemons	Prevented the onset of decay as a result of green mould	Abraham *et al*. (2010)
		Suitable as a preventative mode of action rather than curative	
Pichia guilliermondii (Z1)	Valencia-late oranges	Significant reduction in blue mould by at least 85%, independent of temperature or relative humidity	Lahlali *et al*. (2011)
		Well suited as a preventative mode of action	

Table 10.8 The effects of combined pre-packaging treatments applied to citrus fruit

Number	Description of Treatments	Additional Information	Fruit	Effect	Reference
1	Hot water	43 or 46°C for 180 seconds	Valencia oranges	Significant reduction in citrus black spot lesions	Korf *et al*. (2001)
	Chlorine	100 µm.ml^{-1} and 15 µg.ml^{-1}			
	High pressure spray	20-35 kPa			
	Polyethylene wax	-			
2	Biocontrol	*Bacillus* F1	Valencia and Shamouti oranges	Significant reduction in both blue and green mould.	Obagwu and Korsten (2003)
	Hot water	45°C for 120 seconds			
3	Biocontrol	*Bacillus* F1	Valencia and Shamouti oranges	Significant reduction in both blue and green mould.	Obagwu and Korsten (2003)
	SB	1% Solution			
4	Thermal curing	35-36°C for 72 hours	Nagami kumquat	Reduction in fruit decay	Ben-Yehoshua *et al*. (2005)
	UV-C Irradiation	0.5, 1.5, or 3.0 kJ^{-2}			
5	Hot water dipping	52°C for 120 seconds	Washington Navel orange	Reduction in fruit decay	Ben-Yehoshua *et al*. (2005)
	UV-C Irradiation	0.5, 1.5, or 3.0 kJ^{-2}			
6	SB	1% Solution	Eureka lemons	Incidence of green mould reduced to 22%	Smilanick *et al*. (2005)
	Imazalil	10 µg.ml^{-1}			
7	Free chlorine	100 µg.ml^{-1}	Satsuma mandarin	Closing of stomatal cracks by melting epicuticilar wax, reduction in decay caused by blue and green mould, Reduced weight loss	Sen *et al*. (2007)
	Hot water dipping	53°C for 180 seconds			
8	Biocontrol	*Bacillus amyloliquefaciens* HF-01	Wuzishatangju mandarin	Firmer fruit, high ascobic acid, reduced levels of TSS, weight loss and decay	Hong *et al*. (2014)
	Hot water	45°C for 120 seconds			
	SB	1% or 2% Solution			

'-' Information not provided in the research article.

SB, sodium bicarbonate; UV-C, ultra-violet C.

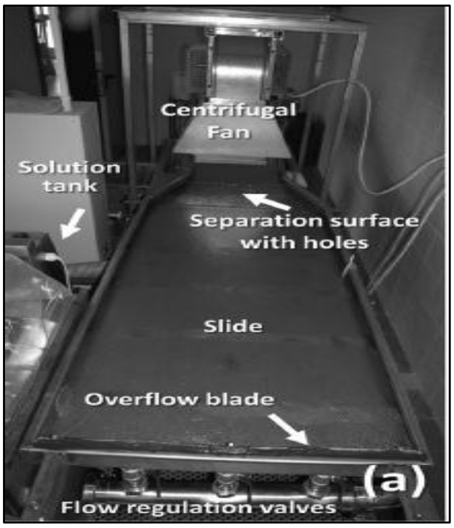

Figure 10.1 Application mechanism of imazalil fungicide (Altieri *et al*., 2013)

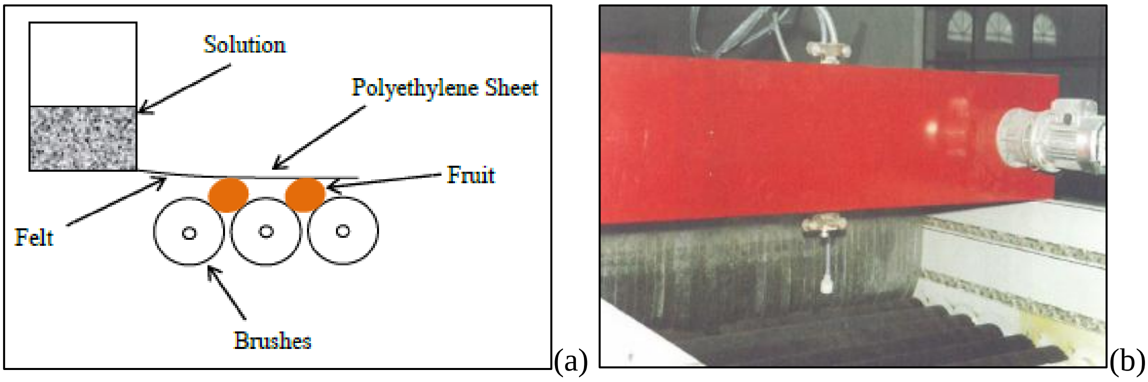

Figure 10.2 Wax applicators with (a) felt sheet (after Kitinoja and Kader, 1994) and (b) wax applicator with nozzle (Ladaniya, 2008)

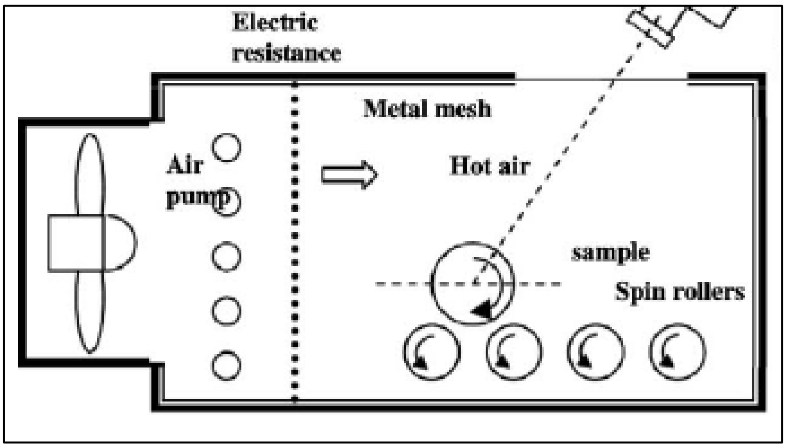

Figure 10.3 Experimental drying equipment (Fito *et al*., 2004)

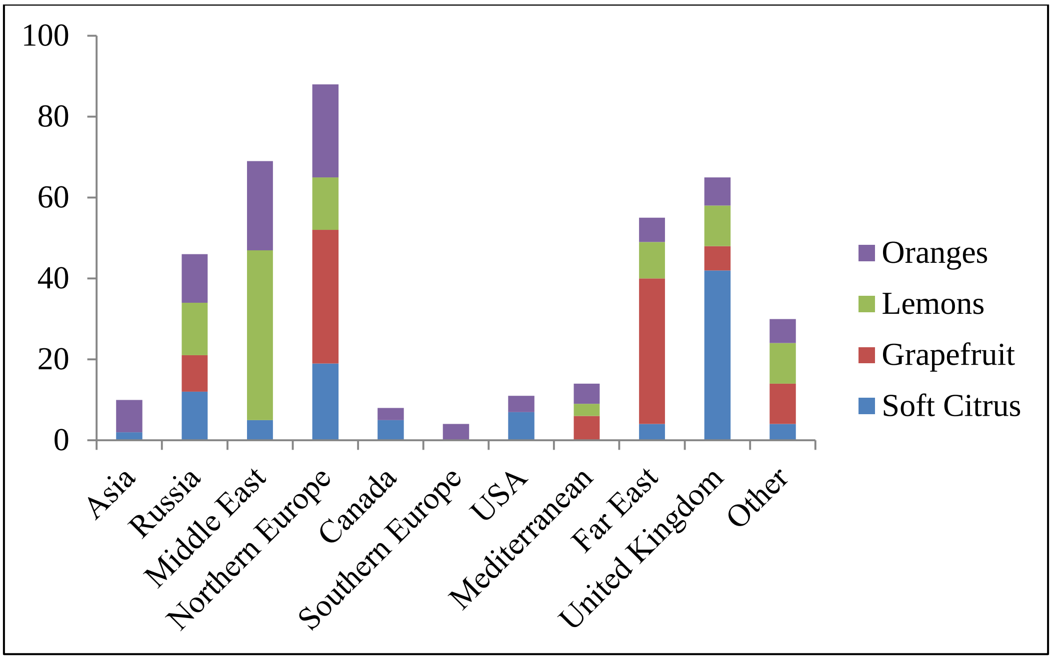

Figure 10.4 Distribution of exported oranges, lemons, grapefruit and soft citrus form South Africa in 2012 (after Citrus Growers' Association, 2013)