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ABSTRACT

The occurrence of postharvest rots is a major issue for the New Zealand avocado industry, and much research is being carried out to find ways to control them. Since the use of many chemical fungicides and insecticides is being prohibited, there is a constant need for alternative, more environmentally friendly, methods to reduce disorders in fruit. One way to decrease the presence of rots in fruit is to maintain good orchard hygiene prior to harvest. There are also a number of ways to control rots, and their postharvest development. In recent years more attention has been turned towards heat treatments and their potential to reduce the development of rots. The aim of this project was to see whether the incidence of postharvest rots in avocados could be decreased by a hot water drench (HWD) of the fruit after harvest.

In September 2002, a project to investigate the efficiency of HWD started in New Zealand. Avocados were drenched in four different water temperatures (44°C, 47°C, 50°C and 53°C) and for different durations (varying between 10s and 80s, depending on temperature), and examined for both external and internal damage after fruit had been stored for 4 weeks.

HWD was associated with a range of damage symptoms in avocado fruit. The main form of external damage at higher temperatures and times was heat damage (browning or blackening) of the skin. The internal quality of avocado fruit also decreased with increasing HWD duration and temperature in experiment 1. This was due to increased incidence and severity of body rots and stem end rots (SERs) compared to control fruit. In experiment 2 we found that by treating avocados at high temperatures for short durations the incidence and severity of postharvest rots could be reduced. Treatments found to minimize body rots were 47°C for 50s and 50°C for 10s. The optimum HWD temperatures for minimum body rot severity were similar to those for minimum damage by SER in both experiments.

Our results show that HWD treatments at high temperatures for short durations may prove useful as a future postharvest control of rots either alone or in combination with other control measures.

SAMMANFATTNING
Förekomsten av röta i avokado efter skörd är ett stort problem för avokadoindustrin i Nya Zeeland, och mycket forskning pågår för att komma till rätta med problemet. Då många kemiska bekämpningsmedel har blivit förbjudna finns ett behov av att finna nya effektiva och miljövänliga sätt att minska förekomsten av vanliga problem och sjukdomar i frukt såsom avokado. Ett sätt att minska förekomsten av röta är att idka god hygien i avokadoodlingarna före skörd. Det finns också många sätt att kontrollera röta och dess utveckling efter skörd. Under senare år har mycket uppmärksamhet ägnats åt värmebehandlingar och deras potential att kunna minska förekomsten av röta. Syftet med det här projektet var att se om förekomsten av röta i avokado efter skörd kunde minskas genom en varmvattensbehandling av frukten efter skörden.

I september 2002 startade ett projekt på Nya Zeeland där effektiviteten av olika varmvattenbehandlingar undersöktes. Avokados behandlades i fyra olika vattentemperaturer (44^{o}C, 47^{o}C, 50^{o}C och 53^{o}C) och i fyra olika tidsintervall (mellan 10s och 80s, beroende på temperaturen), och därefter undersöktes avokadons yttre och inre kvalitet efter att de lagrats i fyra veckor.

Våra varmvattensbehandlingar gav upphov till ett flertal skadesymptom. Den främst förekommande yttre skadan var att avokadons skal blev brunsvart. Den inre kvaliteten minskade i samband med högre temperatur och längre tidsintervall i experiment 1. Det berodde på ökad förekomst, samt grad av, röta både i fruktköttet och i fruktskaftsänden, i jämförelse med kontrollfrukterna. I experiment 2 fann vi att genom att behandla avokado med vatten av hög temperatur i korta tidsintervall så kunde både förekomsten samt graden av röta minskas. De värmebehandlingar som minimerade rötan i avokadons fruktkött var 47^{o}C i 50s och 50^{o}C i 10s. De mest optimala varmvattensbehandlingarna för att minska graden av röta i fruktköttet var nästan samma som de som resulterade i minst skada av röta i fruktskaftsänden i båda experimenten.

Våra resultat visar att behandlingar vid höga temperaturer under ett kort tidsintervall kan vara användbara som en framtida kontroll av röta i avokados efter skörd.

INTRODUCTION

The Avocado

The avocado (*Persea americana* Mill.) is a subtropical fruit that originates from Mexico and Guatemala in Central America (SIU, 1997). Botanically it is described as a berry with a thick, fleshy mesocarp surrounding a single large seed. Its skin, also known as periderm tissue, ranges in colour from green to purple/black, and some cultivars “colour up” and become darker towards the end of the picking season (Anonymous, 1997). The fruit have a shape similar to a pear, and the skin can be smooth or warty. Fruit can range in weight from 50 grams to about 1 kilogram. The avocado is an unusual fruit and differs from most other fruits in that it possesses high oil and protein content. Moreover it is the only fruit known to contain significant amounts of all these nutrient elements; sugars, proteins, lipids, vitamins, minerals, salts and water (Bioplus, 2002). Based on their origin, there are three ecological races of avocados: Mexican, Guatemalan, and West Indian (Smith et al., 1992; Whiley & Schaffer, 1994). The avocado cultivar ’Hass’, which is the key cultivar of trade worldwide, belongs to the Guatemalan race, which is generally the latest maturing of the three races. Avocados are usually consumed ripe, when the flesh is soft and buttery.

The Avocado Season

In New Zealand the season for harvesting avocados run from about August to April. The most prominent avocado cultivar available in New Zealand supermarkets is ‘Hass’, and the export market is almost solely based on this cultivar (AGM, 2001). Other varieties, such as ‘Fuerte’ have lost favour due to inconsistent bearing, and an inability to withstand diverse environmental conditions (Smith et al., 1992; Whiley & Schaffer, 1994). In New Zealand avocados are harvested based on commercial maturity, which is defined by Lee et al. (1983) as “the developmental stage where harvested fruit will undergo normal ripening and provide good eating quality”. In New Zealand ‘Hass’ avocados are not harvested until a commercial maturity of at least 24% dry matter is reached (AGM, 2001). Commercial maturity, measured as dry matter content (%, dry matter is measured by taking a known weight of avocado flesh tissue, and drying it to a point where no further weight loss occurs), correlates well with oil content (Lee et al., 1983), and has been chosen over other maturity indices such as growth measurements for its ease and reliability (Lee & Young, 1983). Lee et al. (1983) showed that the minimum acceptable level of oil was dependent not only on cultivar, but also on the growing location. An increase in dry matter content was attributed to an increase in the oil content since the non-oil dry matter content remained fairly constant throughout development (Lee et al., 1983).

Harvest

Before New Zealand avocados are harvested they must reach the maturity standard (24% dry matter) set by the Avocado Industry Council. How fast they ripen after harvest primarily depends on handling after picking. When harvesting it is important to only pick fruit of a similar size. This will make sorting easier, and simplify grading for export. Smaller fruit can be left on the tree till the next round of picking. Three or four is the average number of pickings in a season by New Zealand growers. The most important things to consider during harvest are minimizing weight loss, skin damage and bruising, as well as removing field heat. In order to reduce the risk of infections and rots harvesting should not be carried out during wet conditions, as this makes it easier for pathogens to enter the fruit through any damage on the fruit surface (AGM, 2001).

According to the current harvesting standard in New Zealand fruit are clipped from the tree using secateurs. The fruit stalk is clipped off < 5 mm from the fruit surface. Snap-picking, a method in which the fruit is “snapped” off the tree, leaving the fruit stalk attached to the tree, is not accepted in New Zealand since it may result in a higher occurrence of stem end rots. However, researchers in California, USA, has shown that this is not the case in dry conditions, and are encouraging their growers to snap-pick their fruit since it results in considerable labour savings (Hofshi, 2002). Much of the crop in Australia is harvested by snap-picking (P. Hofman, pers. comm.).

For small trees picking can be done from the ground, but with larger trees hydraladders (cherry pickers) are needed. In order to reach into the canopy the use of long arm pruners or picking poles might be required. To minimize damage to the skin, pickers should wear cotton gloves and the fruit should be handled gently (AGM, 2001).

The importance of maintaining good hygiene while harvesting cannot be stressed enough. Fungal spores may build up on secateurs, and they should therefore be sterilised during breaks and over night, in order to minimize the potential for fruit to be infected by fungus that will lead to postharvest rots (AGM, 2001).

Physiology

Maturity

Avocados can be held on the tree for many months after they are physiologically mature (i.e., will ripen normally when removed from the tree), because they will not ripen until they are harvested. Ripening of avocados occurs postharvest, and transforms the previously inedible plant organ into an edible fruit. Ripening represents the completion of development and the beginning of senescence, and is thought to be stimulated by water loss after harvest (Adato & Gazit, 1974).

Ethylene (C_2H_4) is a naturally occurring gaseous plant hormone that induces the ripening of fruit (Stryer, 1995). For ethylene to have an effect on fruit ripening, it needs to bind to receptors within the plant cell. This induces ripening, but can be prevented by the use of ethylene receptor-blockers such as 1-MCP (1-methylcyclopropene), also known as SmartFresh™.

Avocados are climacteric fruit, and as ripening occurs, this coincides with a rise in respiratory activity, with higher temperatures increasing the climacteric maximum (Eaks, 1978). Ethylene can be applied to hasten uniform ripening and softening (Gazit & Blumenfeld, 1970; Wills et al., 1989). Gazit and Blumenfeld (1970) found that ‘Hass’ avocados did not respond to ethylene while still attached to the tree. It was suggested that while on the tree an inhibiting substance prevents the fruits response to ethylene, but once it has been harvested it becomes sensitive to it. Ethylene treatment (preripening, ethylene conditioning, preconditioning, or ethylene ripening) is a common commercial practice in New Zealand, Australia and USA. Research into ethylene treatments has been carried out in New Zealand to refine the treatment conditions so as to maximize quality and achieve uniform ripening (Woolf et al., 1997; White et al., 1998).

Ripening and colour

Once avocados start to ripen, dormant, or quiescent, rots begin to develop. Depending on the temperature, pathogen type and a range of other factors, rots may develop to a big or small size, and at varying rates. The ripening temperature should be set so that the fruit is allowed to soften quicker than the rots grow (AGM, 2001). Ripening 'Hass' avocados at 15^{o}C provides fruit of the best postharvest internal quality, since the development of postharvest disorders and disease is reduced (Hopkirk et al., 1992). However, ripening occurs more slowly at lower temperatures, such as 15^{o}C, and can result in ripe fruit that are still green (Eaks, 1978; Prabha et al., 1980; Hopkirk et al., 1992; AGM, 2001). Ripening at higher temperatures has produced fruit of darker colour (Woolf et al., 1997), but has negative effects on fruit quality with an increase in pathological disorder (Hopkirk et al., 1992). Thus a ripening temperature of 16^{o}C to 18^{o}C is recommended for ripening of New Zealand avocados (AGM, 2001).

Colour is the most obvious change the consumer notices, and in many fruit is often the main criterion used to determine whether the fruit is 'ripe to eat', e.g. bananas. Unripe 'Hass' avocados are usually green in colour due to the presence of chlorophyll. With ripening, chlorophyll decreases slightly, and the purple/black colour found in some varieties correlates with the increase of anthocyanins (Cox et. al., 2004).

The Avocado Market

World Production

In the calendar year of 2001, the world production of avocados was 2.4 million metric tonnes, an increase of less than 1% from the previous year. Mexico was the world's largest producer with a production of 940 000 tonnes, 40% of the world total. The United States (US) was the second largest producer with 164 500 tonnes. The other countries in the top five were Indonesia (130 000 tonnes), Chile (120 000 tonnes) and Peru (89 800 tonnes). The underlying reason for these three countries to make it to the top five in 2001 was decreases in production in Israel, Spain and South Africa (FAS, 2002).

World Trade

Total exports of avocados in 2000 reached 310 671 tonnes, up 13% from 1999. The top exporters in 2000 were Mexico (29%), Chile (18%), South Africa (16%), Israel (14%) and Spain (14%). France led the world in 2000 by importing 105 249 tonnes of avocados, 31.2% of world imports that year. The French market imported most of its fruit from Israel, Spain and South Africa. The US imported 78 533 tonnes, the second largest amount in 2000 (FAS, 2002).

New Zealand Production

The New Zealand avocado industry is a rapidly growing sector in the horticultural industry. The main growing regions are the Bay of Plenty, the Mid North, the Far North, and Auckland, Gisborne and Opotiki regions. The Western Bay of Plenty produces more than 70% of the national crop (AIC, 2001). For the 2001/2002 season, the number of growers registered for export exceeded 700, and the total number of growers was estimated to be more than 1000. Mature orchard areas of registered export growers are estimated at ca 1600 ha. Yield per hectare average just less than 10 tonnes per mature hectare. The overall production is expected to increase as new plantings come into production and improved orchard management systems are applied. There is more than 1500 ha of young trees, planted over the last five years that are not yet producing commercial yields (AIC, 2001).

New Zealand Trade

The New Zealand avocado industry is export driven (Requejo-Tapia, 1999). During the 2001/2002 season 61% of New Zealand's crop was exported. The export was worth approximately NZ$34 million. The focus of the industry is on exporting avocados of the cultivar 'Hass' (AIC, 2001). The primary export market for avocados has traditionally been Australia, but in the last five years the USA has also become an important export market

(AIC, 2001; Requejo-Tapia, 1999). The market dominance of New Zealand avocados in Australia is predicted to decrease in the near future due to a constant increase in Australian domestic avocado production (Requejo-Tapia, 1999).

New Zealand's export season begins as early as mid August and continues through to late March. When the peak period for export is depends on whether the market is Australia or USA, as their seasons are opposite. Export sales account for approximately 65% of total avocado production. Avocado exports have increased from 671 tonnes in 1989/1990 to approximately 7260 tonnes in the 2001/2002 season. As this increase has occurred, avocados have become a substantial export-earning horticultural crop in New Zealand (AIC, 2001).

Since fruit for export must be of superior quality, the fruit that reaches the local market is of a lower grade. It is mainly the exterior of the fruit that makes it a lower quality fruit, while the interior is equal to that of the exported fruit. Recently a new use for third grade fruit, fruit with severe ridging and sunburn etc., has been developed. New Zealand is one of the first countries in the world to produce a stable, high quality cold-pressed avocado oil as an alternative for the more commonly used olive oil (Olivado, 2002). The removal of third grade fruit for processing into oil also help enhance the quality of fruit offered to the consumer, and grower returns (The Orchardist, 2001).

Postharvest Diseases of Avocados

There are many diseases and disorders that occur in avocados postharvest. They affect the fruits quality in a number of different ways, and to varying degrees. These are a few of the common disorders of avocados and their descriptions (AAM, 2001, Woolf and Lay-Yee, 1997):

Body rots: rots entering through the skin
Stem end rots, SER: rots entering only through the fruit peduncle
Vascular browning, VB: browning of the vascular strands running vertically through the fruit tissue. This disorder is a common symptom of internal chilling injury when fruit have been held in coolstore for long periods and have begun to ripen in storage.
Flesh browning, FB: browning of the fruit tissue not due to disease or vascular browning
Greying: diffuse areas of discoloured flesh, with no well-defined margin
Vascular leaching: browning of the flesh around the vascular bundles that run longitudinally through the fruit
Skin adhesion: a thin layer of flesh (about 1 mm) adheres to the skin when the skin is peeled back
Pinking: pink/purple/crimson discolouration of the flesh
Tissue breakdown, TB: a "slimy" breakdown of flesh directly below the skin
Stringy vascular: thickening of the vascular bundles that run longitudinally through the fruit. When a fruit quarter is broken in half the flesh comes away from some or all of the vascular bundles without the fibres being broken.
Seed cavity browning, SCB: browning of the flesh directly adjacent to the seed, observed when the stone is removed.

The aim of this project was to look at postharvest disorders in avocados, with the focus lying on the occurrence of body rots and stem end rots. Experiments were carried out to see whether the frequency of body rots and stem end rots could be reduced by the means of a postharvest hot water drenching of the fruit.

Body Rots

One of the most important postharvest problem in New Zealand 'Hass' avocados is rots (Everett, 1996). Anthracnose, a term specifically used for disease caused by *Glomerella cingulata*, of which the conidial state is *Colletotrichum gloeosporioides,* is an important disease in avocado-growing countries such as New Zealand, Australia, USA, Israel, India, South Africa and Puerto Rico (Everett, 1996: Snowdon, 1990). Body rots are caused by fungi that enter through the skin (White et al., 1999). Body rots are recognized as discrete areas of discoloured flesh, and they can be firm and symmetrical or soft, more irregular, areas (White et al., 2001). Spores are washed down from dead branches by rain, and the disease is therefore associated with persistent wet conditions in the orchard (Snowdon, 1990). Wounding also enhances the infection. The initial infection can occur at any time during the growing season, and even sound developing fruit can be affected, but body rots usually remains quiescent until ripening commences (Everett, 1996).

The fungus will rarely completely penetrate the skin until ripening has started. This is because there are antifungal chemicals in the skin that prevents the rot from growing any further. However, once ripening starts, these chemicals start to break down, and the rot spreads from the skin into the flesh. Spores produce a germ tube that forms into a hard round protective structure called an appressorium. This appressorium attaches itself to the outside of the skin by producing a form of glue, and then produces a short penetration peg that will penetrate 1-2 mm into the skin of the fruit, and then stop because of the antifungal chemicals in the skin. Since they are not resistant to environmental factors like ultraviolet radiation and bacteria, both the spore and the germ tube will eventually disappear, leaving only the appressorium. This is the latent infection that remains dormant until the time of ripening. After harvest the antifungal chemicals begin to break down in the skin and the avocado flesh as the fruit begins to ripen. Eventually the germ tube of the appressoria will assume growth and penetrate through the skin and into the fruit. The fungal mycelium will then grow between and into the cells of the flesh, causing a brown rot that will taste rancid if eaten (Everett, 1996).

Signs of body rots usually appear as the fruit begin to soften, and patches of brown, sunken, skin can indicate their presence (Fig. 1) (AGM, 2001; White et al., 2001). It can however be difficult to discover the rots in 'Hass' avocados due to their dark colour when ripe (AGM, 2001; White et al., 2001). In severe cases, the rot can produce masses of pink spores on the outside of the fruit that are clearly visible (AGM, 2001).

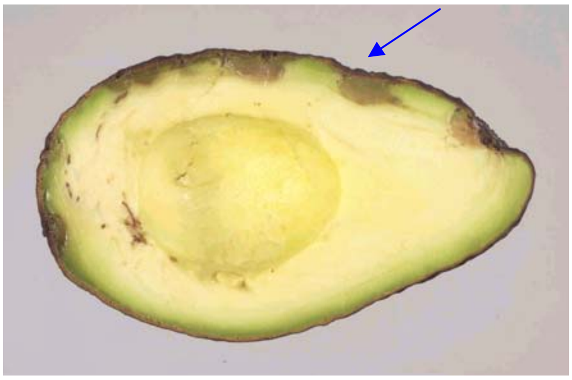

Fig. 1. Body rots in an avocado. As is visible, body rots grow from the skin, into the fruit. One of the body rots also shows how the skin can sink in somewhat (see arrow), thus indicating where a body rot is present. Not only the colour, but also the texture of the fruit change because of the rot.

Body rots are generally soft and a little slimy. They may remain attached to the avocado skin, even when the fruit flesh is peeled off.

Stem End Rots, SER

Stem end rots (SER) can be caused by a number of different fungi that enter through the fruit peduncle (White et al., 1999) or via the picking scar, if the stem has been removed (White et al., 2001). The SER begins at the stem end, and spreads rapidly throughout the fruit. SER discolours the flesh and is usually softer than surrounding flesh (White et al., 2001). The spores grow down through the vascular bundles (Fig. 2.), and from there into the flesh of the fruit. There is no need for an appressorium for these spores to gain entry to the fruit since no skin is encountered upon entry through the vascular bundles (AGM, 2001). The stem end rot fungi inhabit dead branches and bark of avocado trees, and their spores are distributed by rain. The rot begins as a small ring of firm brown tissue, and the decay eventually spreads throughout the fruit (Snowdon, 1990). The most prominent fungi causing it in New Zealand are *Botryosphaeria dothidea*, *Botryosphaeria parva*, *Colletotrichum gloeosporioides*, *Colletotrichum acutatum* and *Phomopsis spp.* (Everett, 1996).

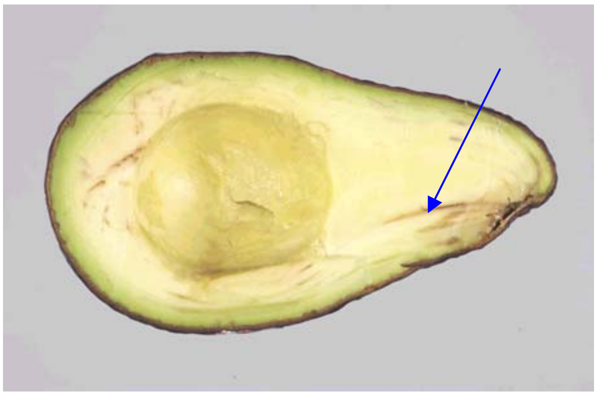

Fig. 2. Stem end rot (SER) starting at the peduncle, and spreading throughout the fruit through the vascular bundles. The dark lines that are visible in the fruit flesh (see arrow) are the vascular bundles that the SER is growing through.

Methods to Control Rots

Preharvest

Good orchard management with regular clearing of debris such as leaf litter and old decaying branches will reduce infection. Another way of reducing rots is by applying orchard fungicide sprays from the time of fruit-set up till harvest (Snowdon, 1990). Preharvest sprays with copper have been shown to reduce postharvest diseases, however twelve sprays were needed before a significant reduction in the number of postharvest rots were obtained. Preharvest treatment with Benlate, a fungicide, is also recommended in New Zealand. It has been shown to significantly reduce disease when applied three times as a spray during the season (Everett, 1996).

Postharvest

The occurrence of postharvest rots is a major issue for the New Zealand avocado industry, and measures must be taken to find new alternative, environmentally friendly, ways to control them. The current fungicide treatment employed in New Zealand is a Sportak® dip (prochloraz dip), at a suspension of 5.5 ml/l for 30 seconds to 2 minutes. However, it is not allowed on fruit exported to the USA, Asia and countries in Europe, and hence there is a need to develop alternative treatments (White et al., 1999; Everett, 1996). Experiments have been carried out where alternative control methods have been examined. Among others, the effect of methyl jasmonate (a natural occurring compound), ethanol, phosphorous acid, and different biocontrol agents (BCA) on postharvest rots has been examined. Out of these, a phosphorous acid dip at a concentration of 1600 ppm was the most effective (White et al., 1999).

A future solution to postharvest rot problems in avocados might be found in the use of biological control. By using antagonistic microorganisms the fungi causing the rot could be reduced or eliminated. Attempts have been made overseas to commercialize a BCA by the name of AvoGreen (White et al., 1999).

Heat Treatments

Much research is currently being carried out in the field of heat treatments, both on presently used and new techniques. Researchers are also looking into the responses to high temperature treatments displayed by fruits, vegetables, fungal pathogens and insects. Heat treatments are currently used commercially in several countries, for example as hot water brushing techniques, hot water dips, and hot air treatments. Much of the recent research on the topic has been conducted in Israel (Ferguson et al., 2000).

Research has showed that most plants respond to heat shock by inducing or enhancing synthesis of heat shock proteins (HSP). These are believed to confer tolerance to heat by protecting proteins from irreversible denaturation and breakdown (Ferguson et al., 2000).

An interesting aspect of postharvest heat treatments is the beneficial effect in reducing chilling injury in a range of fruits during subsequent low temperature storage (Ferguson et al., 2000). Data suggest that effective temperatures for heat treatments are all around 38-42^{o}C, regardless of crop or tissue. This temperature range is effective in both reducing chilling injury and inducing tolerance to the higher temperatures needed to kill insects (Ferguson et al., 2000). Heat can have a conditioning effect on fruit, thus making it more capable of "coping" with subsequent higher or lower temperatures. Both hot air and hot water treatments (HWTs) can reduce external skin damage of 'Hass' avocado caused by subsequent heat and/or cold treatments (Hofman et al., 2002).

Postharvest heat treatments can also have a positive effect in reducing the levels of pathogens and disease development. This can occur in a variety of ways, one of which is through the physical effect of heat on the fruit surface. For example, heat treatments can result in a lower frequency of wounds caused by pathogens by decreasing the number of cuticular fractures and wounds. This is believed to be the result of melting of the cuticular waxes by the heat, and thus "healing over" the wounds. These results seem to be enhanced further by additional physical treatments such as hot water brushing (Ferguson et al., 2000).

The main effects of heat on fungal pathogens are on inhibiting the elongation of the germ tube, or on killing the spores, thus reducing inoculum size and subsequent lesion development (Ferguson et al., 2000).

Other research has been more focused on how heat can induce defence mechanisms in fruit. This research has showed that it is likely that there is a multi-layered suite of mechanisms that the fruit has developed against pathogen and insect attacks. However, it seems as though a heat treatment alone is not enough to activate this defence system, but there seems to be a need for an additional physical treatment parallel with heat for the defence mechanisms to become active. For this reason various mechanisms have been developed one of which is hot water brushing (Ferguson et al., 2000).

Hot Water Treatments

Water is a more efficient medium than air for transferring heat, and thus the use of hot water treatments (HWT) could reduce the time required to obtain temperatures lethal to pests and diseases (Woolf et al., 1994). Several different techniques for postharvest treatments using hot water have been developed. Examples of these are hot water brushing, hot water dips, and hot water drenching (HWD). Previous trials with postharvest hot water treatments of avocados have been carried out, and these have showed that treatment with 40 ^{o}C and 41^{o}C for 30 min was the most effective in reducing the incidence of body rots (Hofman et al., 2002). The continuing loss of postharvest chemicals for decay and insect control will increase commercial interest in treatments such as these (Ferguson et al., 2000).

Hot Water Brushing

Hot water brushing (HWB) involves treatment with hot water combined with a physical treatment; brushing. HWB involves the use of several moving brushes that simultaneously rinse and disinfect with pressurized hot water at a set temperature, depending on what crop is being treated. This type of combined method can result in the obstruction of cuticular fractures and microwounds, which in turn leads to reduced levels of pathogens and disease development (Ferguson et al., 2000).

Hot Water Dips

Hot water dipping involves immersing fruit in water baths for a range of durations and temperatures. This is often carried out either as a pre-treatment or subsequent to other types of treatment.

Hot Water Drenching

Hot water drenching is an alternative to hot water dipping, using flowing water instead of still. At the top of the drencher, water from is pumped out into a boxlike compartment with holes evenly spaced in the bottom. As the water pours through the holes in the box it cascades over the avocados underneath. As the water runs off the fruit it returns to the waterbath where it was originally pumped from, and can thus be reheated and pumped back up again. It is important with an even water pressure over the whole upper level, so that all avocados are hit with equal force and equal amounts of water.

MATERIALS AND METHODS

Preliminary experiment

On October 30th, 2002, a preliminary hot water drenching (HWD), experiment was carried out in order to decide what temperatures should be used for the subsequent larger HWD experiments. The treatments used in the preliminary experiment were 45^{o}C for 30s, 45^{o}C for 60s, 50^{o}C for 20s, 50^{o}C for 45s, 55^{o}C for 10s, 55^{o}C for 30s, 60^{o}C for 2s and 60^{o}C for 10s. The external damage (external browning) was rated on a relative scale of 0 to 3 in 0.25 intervals (0 = none, 0.5 = <10%, 1.0 = 10% to 20%, 1.5 = 21% to 50%, 2 = 51% to 75%, 2.5 = 76% to 90%, 3.0 = >90%). The study showed that after a HWD of 50^{o}C 45s, the avocados started to show an average skin damage of as high as 0.6 after three days of assessments of the external damages. A rating of 0.6 is considered the point where the amount of external browning exceeds what consumers can accept.

Experimental Design

Experiment 1

For experiment 1, four different temperatures were selected, and four durations for each temperature (Table 1). The temperatures chosen were 44^{o}C, 47^{o}C, 50^{o}C, and 53^{o}C. The decision to use these temperatures was based on the results from the preliminary study. The reason for keeping the 50^{o}C treatment and adding a 53^{o}C treatment was to see if it was possible to reduce the external damage, and also have a reduced occurrence of rots, by using shorter durations than in the preliminary study at high temperatures.

Each treatment was carried out with three replicates of 15 fruit each. There was also one control treatment and two chemical treatments, each with three replicates. These three replicates each consisted of 16 fruit, except for the Sportak (a fungicide used for rot control on fruit into the Australian market) that had 20 fruit in each replicate. For assessment of external damage 14 fruit were treated at each temperature’s longest duration. In total, external quality was assessed for 10 treatments. The fruit for external assessment only, was not stored. The degree of external damage of all 19 treatments was assessed immediately after removal from cold storage (Appendix B, Fig. 15-19).

This was the chain of events in the two experiments:
HWD→ Drying → Storage → External Damage (experiment 1) → Firmness → Internal damage (rots)

Table 1. Treatments in experiment 1

Treatment	Durations			
Sportak	30s			
Chlorine	80s			
Non-treated				
44 ^{o}C	30s	45s	60s	80s
47 ^{o}C	20s	35s	50s	65s
50 ^{o}C	15s	30s	45s	60s
53 ^{o}C	10s	20s	30s	40s

Experiment 2

Based on the results from experiment 1, the design of experiment 2 was slightly altered. Only three temperatures were used, and three durations for each (Table 2). However, one more control treatment was added: Oxine (a chlorine dioxide compound). The temperatures used in experiment 2 were 44°C, 47°C, and 50°C. Based on the results from experiment 1, the use of water at 53°C was excluded, since it was obvious that both the external and internal quality was reduced by treatments at that temperature.

In total there were 13 treatments in experiment 2, each with 3 replicates, and each replicate consisted of 20 fruit. In order to maximize the correlation between experiment 1 and 2, the Chlorine treatment was for the duration of 80s, which was the longest duration out of all in experiment 1, although the longest duration in experiment 2 was only 60s.

Table 2. Treatments in experiment 2

Treatments	Durations		
Sportak	30 s		
Chlorine	80 s		
Oxine [15 ppm]	30 s		
Non-treated			
44 °C	30 s	45 s	60 s
47 °C	20 s	35 s	50 s
50 °C	10 s	20 s	30 s

Fruit

Experiment 1

'Hass' avocados (*Persea americana* Mill. cv Hass) of export quality were harvested in a commercial orchard in Mangawhai, in the Mid North, in the afternoon of November 5th, 2002. There was the odd shower during harvest, and the temperature was ca. 20°C. The fruit was collected from the orchard the same afternoon, <5 hours after harvest. Fruit of similar size and colour were selected from three picking bins (~700 kg) and placed in 20-count cardboard trays. A total of 51 trays, 1020 fruit, were collected and brought back to the Mt Albert Research Centre (MARC), in Auckland in the evening. Fruit were held in an air-conditioned lab where the temperature was 19°C. Room temperature was measured using a Squirrel Datalogger (model 1250; Grant, Cambridge). Handling, treatment and storage of all fruit was carried out using commercial cardboard trays, fitted with a cardboard pocket pack of size 16. Fruit were kept in the lab over night.

Experiment 2

'Hass' avocados (*Persea americana* Mill. cv 'Hass') of export quality were harvested, in the same commercial orchard as in experiment 1, in Mangawhai, in the Mid North, in the morning of January 7th, 2003. The temperature was 22°C, and it was overcast. The fruit was collected from the orchard in the afternoon, <5 hours after harvest. Fruit of similar size and colour were selected from three picking bins (~700 kg) and placed in 20-count cardboard trays. A total of 41 trays, 780 fruit, were collected and brought back to MARC in Auckland in the evening. Fruit were held in a lab overnight where the temperature was 23°C. Handling, treatment and storage of all fruit was carried out using commercial cardboard trays, fitted with a cardboard pocket pack, plix, of size 20.

Hot Water Drenching, HWD

Hot water drench

Allan Woolf and Richard Jackman at HortResearch in New Zeeland designed the structure used for the hot water drenching (Woolf and Jackman, pers. com.). The framework is made of aluminium, but the sides and top, as well as the "door", is made out of Plexiglas (Fig. 3). At the top of the drencher, water from the 90L waterbath (in which the drencher sits) is pumped out using a Grundfos 245 w pump (Hiflo Pumps, Penrose), through a strainer into a boxlike compartment with holes evenly spaced in the bottom. The holes measured 4mm in diameter and were drilled into the bottom of the reservoir at 15 mm by 15 mm apart. Water depth inside the reservoir was 30 mm. Flow rate through the drencher was 200L/min. As the water pours through the holes in the box it cascades over the avocados underneath, which have been placed there by opening the door and sliding in mesh trays of fruit. As the water runs off the fruit it returns to the waterbath where it was originally pumped from, and can thus be reheated and pumped back up again. There were three 2.1 Kw temperature controllers set to the desired temperature (Fig. 3), and water temperature was monitored inside the reservoir. It is important with an even water pressure over the whole upper level, so that all avocados are hit with equal force and equal amounts of water. The water temperature was monitored throughout the experiment to see how big the temperature difference was between the water in the delivery tray (above the fruit), and the "return" temperature measured in a shallow tray immediately under the fruit. In addition, water temperature near the fruit was monitored by positioning a probe in the water shower, 5 cm above the fruit.

Experiment 1

On the morning of Nov. 6th, 15 avocados were placed in each of 20 wire mesh trays. These are the trays used in the drencher. Chlorine (sodium hypochlorite, or "bleach") at a concentration of 160 ppm was added to the waterbath before replicate one was started. This was carried out in order to inhibit or decrease the build-up of spores in the water throughout the treatments. In order to carry out true replications, the order of temperatures as well as durations in which the drenching was carried out was randomized, so that the same treatment would, for example, not be the last one in each replicate (Appendix, Table 3). This was also done to ensure that there would not be a greater concentration of, for example, spores in the last treatment of each replicate. After the avocados had been treated, they stayed in the mesh trays, but were moved into a neighbouring room where they were surrounded by fans to help them dry quicker. When fruit was dry it was placed in trays, with 16-count plix, and then labelled. After the whole experiment had been carried out, all the fruit (except the ten trays that were not to be stored, but checked for external damage) were placed in a cool store with an air temperature of 5.5^{o}C. This included the controls, and fruit were stored for 4 weeks. A water sample (ca 75ml) was collected at every temperature, before the drenching was started for that temperature for measurement of FAC (freely available chlorine; Appendix A, Fig. 5). The water was changed and the waterbath was rinsed between each replicate. A new water sample for each temperature was taken in each replicate, in order to investigate whether the concentration of chlorine changed throughout each replicate.

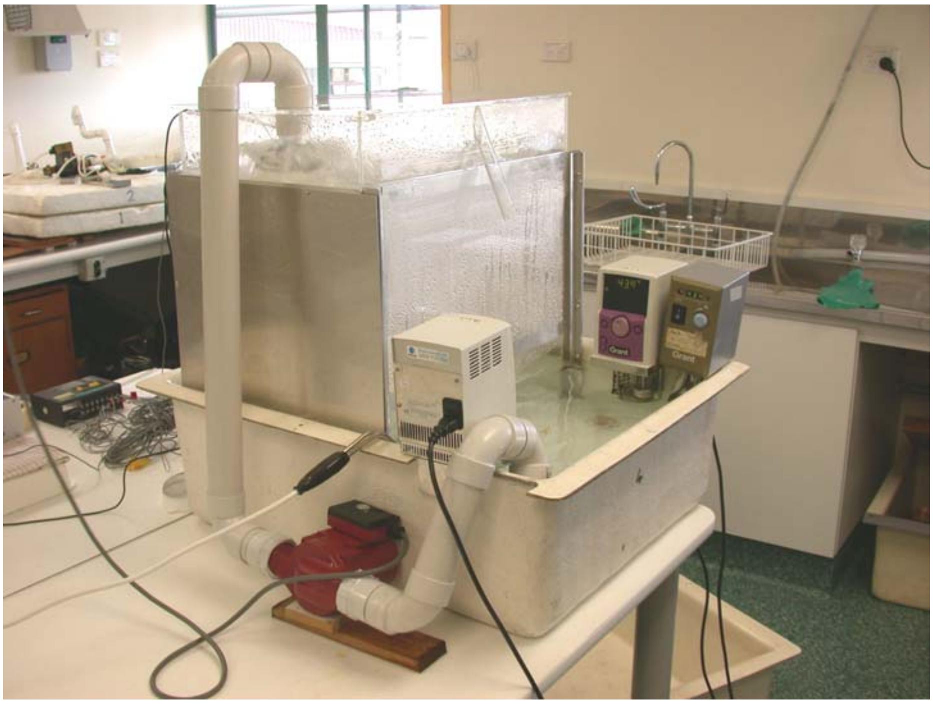

Fig. 3. The hot water drencher placed in the waterbath, with three heaters and the pump.

Experiment 2

The waterbath was filled with ca 115 l of water, on the morning of January 8th. A temperature controller set for 44°C was placed in it. Twenty avocados were placed in each of 20 mesh trays. Chlorine at a concentration of 160 ppm was added to the waterbath before replicate one was started. As in experiment 1, the order of temperatures as well as durations in which the drenching was carried out was randomized, in order to get true replicates (Appendix, Table 4). After the avocados had been treated, they stayed in the mesh trays, but were moved into a neighbouring room where they were surrounded by fans to help them dry quicker. When the fruit was dry it was placed in trays, with 20-count plix, and then labelled. After the whole experiment had been carried out, all the fruit were placed in a coolstore with an air temperature of 5.5°C, along with the non hot water drenched controls, for 4 weeks.

Controls

Experiment 1

The Sportak treatment was carried out on the evening of Nov. 5th, and stayed in open trays over night. The following day, in the morning of Nov. 6th, they were packed into boxes and labelled. There were three replicates in the Sportak treatment, each consisting of 20 fruit.

When all the three replicates of the HWD had been carried out, the waterbath was filled again, but this time with cold water. Chlorine to the same concentration (160 ppm) was added and the three replicates with Chlorine added to the water (each tray consisting of 16 fruit) were treated for 80 s each (the longest treatment in the whole experiment).

The control consisted of 3 trays (consisting of 16 fruit each) of non-treated fruit.

Experiment 2

For the second run of the experiment a control and the same two chemical treatments were used as in experiment 1, with the addition of Oxine. It was added as a third chemical treatment as requested by the grower that supplied the fruit for the experiments. Oxine is a chlorine-dioxide based sanitizer that may reduce rots. Citric acid was used as the activating ingredient for Oxine. It was mixed with Oxine at a ratio of 1:10. The windows were opened, and ventilation turned on to make sure the room was adequately ventilated when the citric acid was poured into the Oxine. In order for the citric crystals to dissolve completely, the solution was left for 5 minutes before it was poured into water. This resulted in a solution that contained 15 ppm of available chlorine dioxide.

Water Samples

A water sample was collected at every temperature, before the drenching was started for that temperature (Appendix A, Table 3). The water was changed and the waterbath rinsed between each replicate. For each temperature a new water sample was taken in each replicate.

Storage

After the whole experiment had been carried out, all the fruit (except the ten trays that were not to be stored, but checked for external damage) were placed in a cool store with an air temperature of 5.5°C. This included the control and the chemically treated fruit. They were stored for 4 weeks.

External Assessments of non-coolstored fruit

The reason for assessing external damage on non-coolstored fruit was that the development of damage in the fruit that is being stored may not be apparent when it is removed from storage. This is because external damages may not show up until the fruit ripens (naturally gains a dark purple/black colour), and this damage is not visible, due to the colouring of the fruit (Woolf and Lay-Yee, 1997).

External assessments were carried out on ten trays (consisting of 14 fruit each) of fruit. The fruit was treated for the three longest durations of each temperature, except for at 44°C where they were only treated for the longest duration, 80 seconds.

The external damage, visible as browning/blackening of the skin, was rated on a relative scale of 0 to 3 in 0.25 intervals (0 = none, 0.5 = <10%, 1.0 = 10% to 20%, 1.5 = 21% to 50%, 2 = 51% to 75%, 2.5 = 76% to 90%, 3.0 = >90%). A rating of more than 0.5 is considered unacceptable from a commercial perspective.

Firmness

In order to see whether there were any ripening differences between the fruit, their firmness was measured using an Anderson digital Firmometer on the fourth day after they had been removed from storage. The firmness of a total of four randomly chosen fruit per tray was measured.

Before internal assessments can be carried out, it is important for the fruit to be ripe. Generally, it is only when the fruit start to ripen that rots start to develop (as described previously; section Body Rots p. 10). It is also important that all fruit are assessed at the same stage of ripeness, since avocados must soften before they are eaten (unlike apples for example). If fruit are assessed at one point in time (as is often carried out for other fruit such as apple or kiwifruit) treatments which delay ripening will give the appearance of reducing rots, which may not be the case. This makes it necessary to carry out assessments daily over the time fruit are ripening. There are two ways one can determine whether an avocado is ripe or not, by gentle hand squeezing of the fruit or by using an instrument of some kind, for example a digital Firmometer. Hand squeezing is the method used by consumers when purchasing avocados, but it is a somewhat subjective method. Using this method, fruit ripeness is determined by holding the fruit in the palm of the hand, and gently squeezing it with the whole hand. Depending on how much “give” there is in the fruit, its stage of ripeness can be determined according to a scale of 1 to 7 (please see Appendix A p. 36). It is very important that care is taken when performing the hand squeezing since excessive squeezing will lead to bruising of the fruit. By using the digital Firmometer one can get a strictly objective measurement of ripeness, and it can also be used to “calibrate” ones hand assessments. The digital Firmometer measures the whole fruit’s resistance to compression when a force is applied through a 17mm diameter button over a 10 s period. Force is applied by using a 200g or 300g weight, depending on how soft the fruit is. The displacement of the button (mm) is multiplied by 10 to give the Firmometer value (Fv). The Fv increases as the fruit softens, from 0 to a maximum of approximately 109. A fruit is considered ripe to eat at the Fv 80 if the 200g weight is used, or a Fv of 100 if the 300g weight is used. The force from the Firmometer will bruise the fruit, and it is important to mark the point where the fruit was measured (using a whiteout marker pen), and to disregard any damage at that point when assessing the fruit’s internal quality (AAM, 2001).

Internal Assessments

Once the external assessments had been carried out and the fruit was ripe, internal fruit quality was assessed as described in White et. al. (2001). The fruit was cut into quarters and examined for these key disorders: body rots, stem end rots (SER), vascular leaching, vascular browning (VB), greying, pinking, flesh browning (FB), seed cavity browning (SCB), stringy vascular and skin adhesion. Apart from pinking and stringy vascular that are only rated on whether they are present or not, the disorders are rated on a scale from 0 to 3, with 0.5 intervals. A severity of more than 2 for any disorder (except FB which could have been caused when handling the fruit) makes the fruit unsound, i.e. unacceptable.

Data analysis and presentation

The incidence of internal disorders was calculated as a percentage of the total number of fruit in order to make the results easier to analyze. The percentage of fruit with a rating of >0 gave the incidence, and fruit with a rating >1.5 gave the percentage of unacceptable fruit, i.e. unsound fruit. Data is presented in graphical form with error bars representing the standard error of the mean (SEM) (initially, the incidence of internal disorders was calculated for each replicate, and the mean and SEM were derived from those results).

RESULTS

Experiment 1

External damage

Non-coolstored fruit

External assessments were carried out on ten fruit trays (consisting of 14 fruit each). The fruit was treated for the three longest durations for each treatment temperature, except for at 44^{o}C where only the longest duration (80s) was examined. In total, external quality was assessed for 10 treatments. The fruit for external assessment was not stored.

Our results show that all treatments but 53^{o}C for 30s and 53^{o}C for 40s had an acceptable average amount of external damage (i.e. $\leq$0.5). However, the two treatments mentioned had external damage of an average of 0.85 and 1.5, respectively. The treatments with the least externally damaged fruit was 47^{o}C for 30s (average rating of 0.1) and 47^{o}C for 50s (average rating of 0.15).

Coolstored fruit

Immediately after cold storage, external damage associated with heat treatment was evident as skin browning/blackening that became more distinct as the fruit ripened. Figure 4 clearly shows the difference between damaged and undamaged skin. In this case the fruit has most likely been touching the fruit beside it during the hot water drenching, hence the green parts of the skin were not touched by the hot water.

Fig. 4. External damage of the skin caused by hot water drenching. Green skin was most likely not touched by the water, and was therefore not damaged.

Appendix B illustrates the effect of HWD treatment on external damage after cold storage. It was clear that external damage (i.e. skin browning) increased with the temperature. The skin damage first became apparent as patchy darker spots, predominantly around the stem end of the fruit. These initially became visible in the fruit treated at 47^{o}C for 35s, and then became even more apparent in the fruit treated at 47^{o}C for 50 and 65s. Avocados treated at 50^{o}C for 60s, as well as fruit treated for the three longest durations at 53^{o}C; 20s, 30s and 40s, all showed near complete skin blackening. The results of the external damage of the coolstored fruit corresponded well with those of the non-coolstored fruit, however, the coolstored fruit was not analyzed individually, but was judged by over all appearance.

Internal fruit quality

The two treatments 47°C for 35s and 50°C for 15s both resulted in the highest number of sound fruit (96%; Fig. 5). The treatment that resulted in the lowest number of sound fruit (worst overall fruit quality) was 50°C for 60s, which also showed the highest incidence of SER (62%; Fig. 8). The lowest incidence of SER was found in the Sportak control (8%; Fig. 8). The lowest incidence of body rots was found in fruit treated at 47°C for 20s (13%; Fig. 6), and the highest incidence was found in fruit treated at 53°C for 20s, where 78% of the fruit was affected.

The results in Fig. 5 clearly indicate that an increase of both temperature and duration independently of each other significantly reduces the number of sound fruit in each treatment.

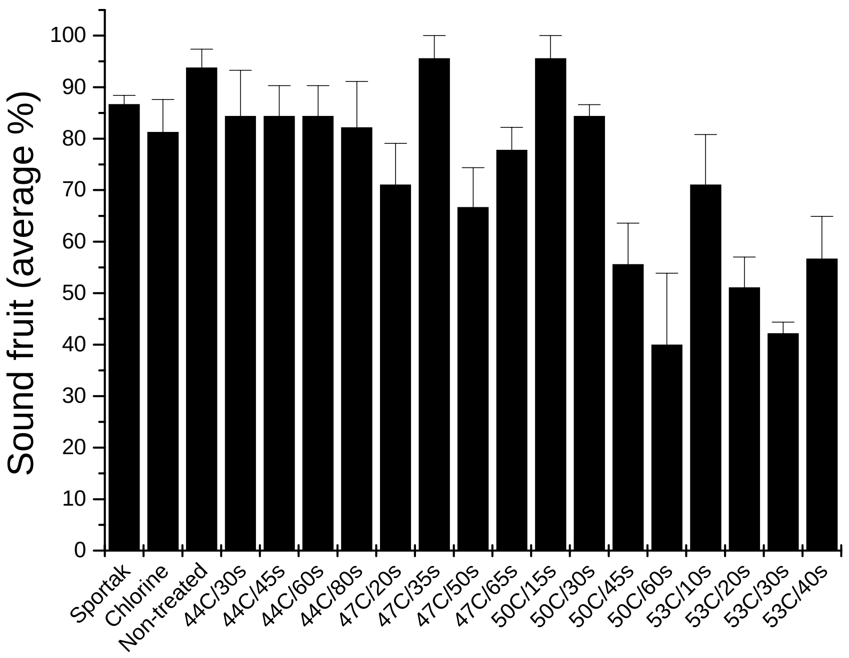

Fig. 5. Percentage of fruit regarded as sound in each treatment. A fruit was regarded as sound if it had no disorder at a severity of 2 or higher (disorders were rated at a scale from 0 to 3).

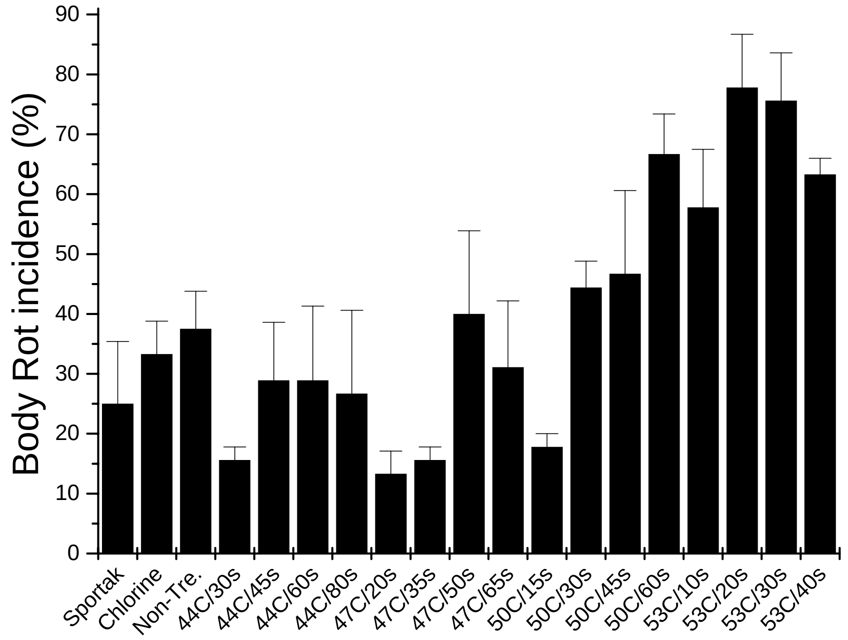

Fig. 6. Incidence of body rots in the different controls and treatments.

The highest severity of body rots were found in fruit treated at 53°C for 30s (Fig. 7), which also had a low percentage of sound fruit (Fig. 5). The least severe body rots were found in fruit treated at 47°C for 20s, and these fruit also had a low occurrence of SER (Fig. 8).

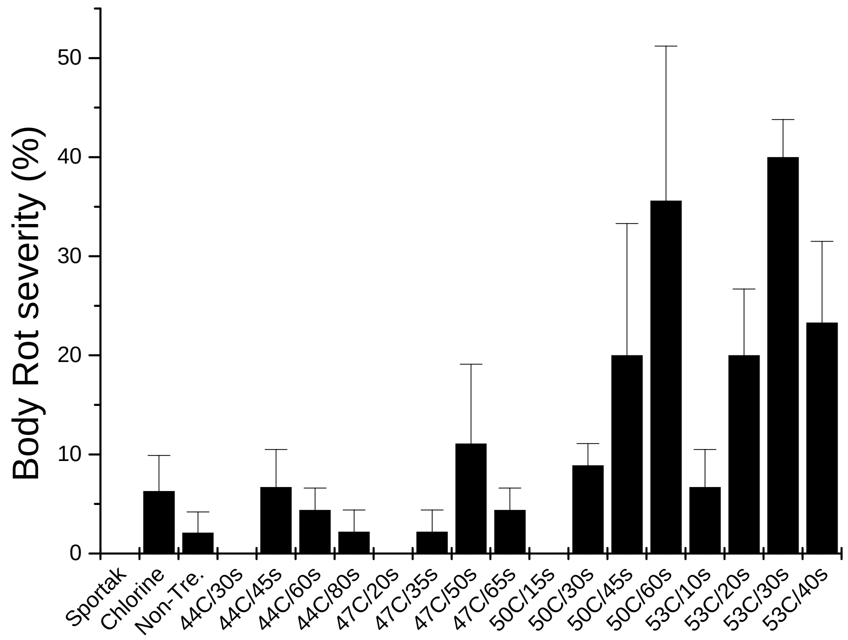

Fig. 7. Severity of the body rots in the different controls and treatments.

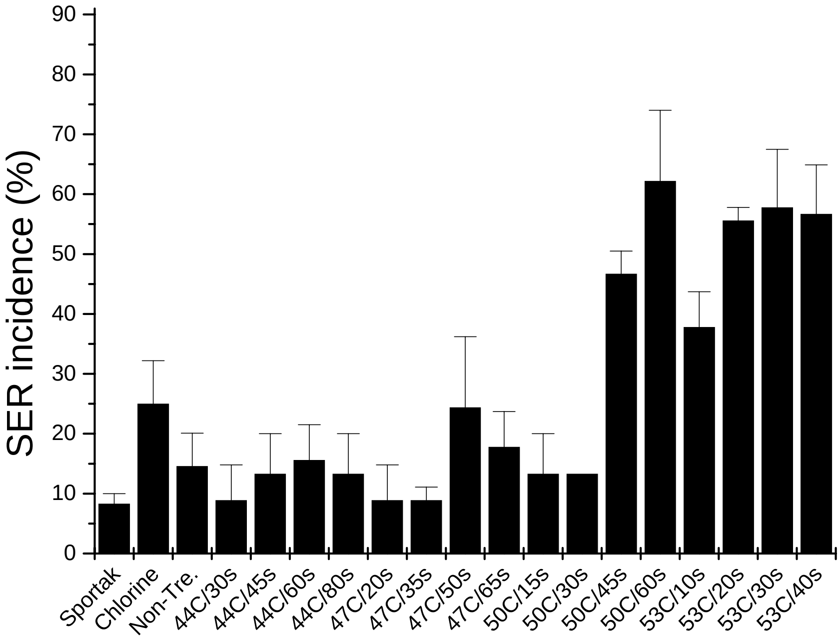

Fig. 8. Incidence of stem end rots (SER) in the different controls and treatments.

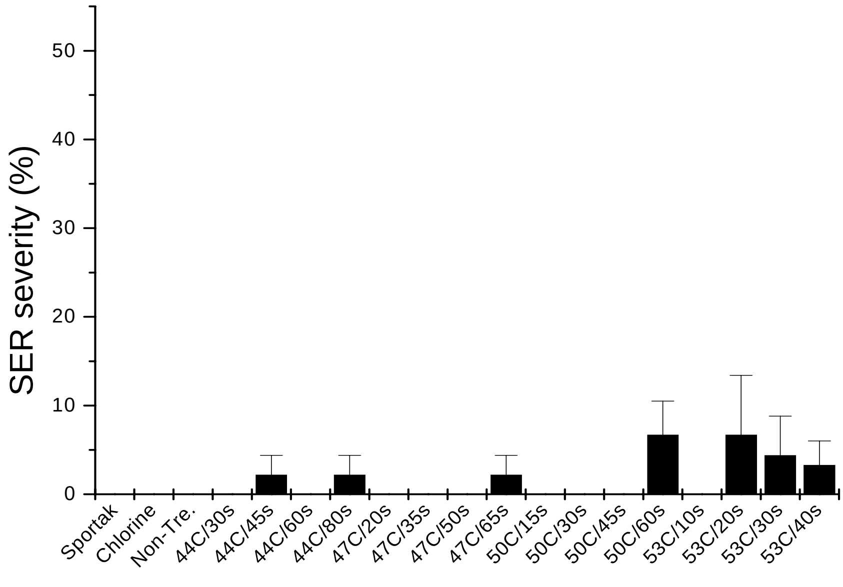

Fig. 9. Severity of stem end rots (SER) in the different controls and treatments.

The current New Zealand standard fungicide treatment for export to Australia (but not the USA) is Sportak (a. i. Prochloraz). Sportak dips resulted in the lowest number of fruit with SER (Fig. 8). Only 8% of fruit treated with Sportak had SER, and of low severity (Fig. 9). However, the treatments 47°C for 20s and 47°C for 35s showed nearly as low incidence of SER, and of equally low severity as the Sportak treated fruit.

Vascular browning (VB) was most prominent in fruit treated at 53°C for 30s. The severity of the VB was however significantly worse in fruit treated at 50°C for 60s (Appendix C, Fig. 20 and 21). The average Firmometer value (Fv) for all the treatments in experiment 1 was 67. Fruit treated at 47°C for 50s had the highest Fv, 74 (Appendix C, Fig. 22).

Experiment 2

Internal fruit quality

In experiment 2, the treatment that resulted in the highest proportion of sound fruit (98%) was 50°C for 10s (Fig. 10). The treatment that gave the highest number of unsound fruit was the Sportak (Fig. 10) that only had 70% sound fruit. The lowest incidence of body rots was found in fruit treated at 47°C for 50s (38%) (Fig. 11), and the highest incidence was found in fruit treated with Oxine, where 71% of the fruit was affected. Fruit treated at 47°C for 50s also showed the lowest incidence of SER with only 22% of the fruit affected (Fig. 13).

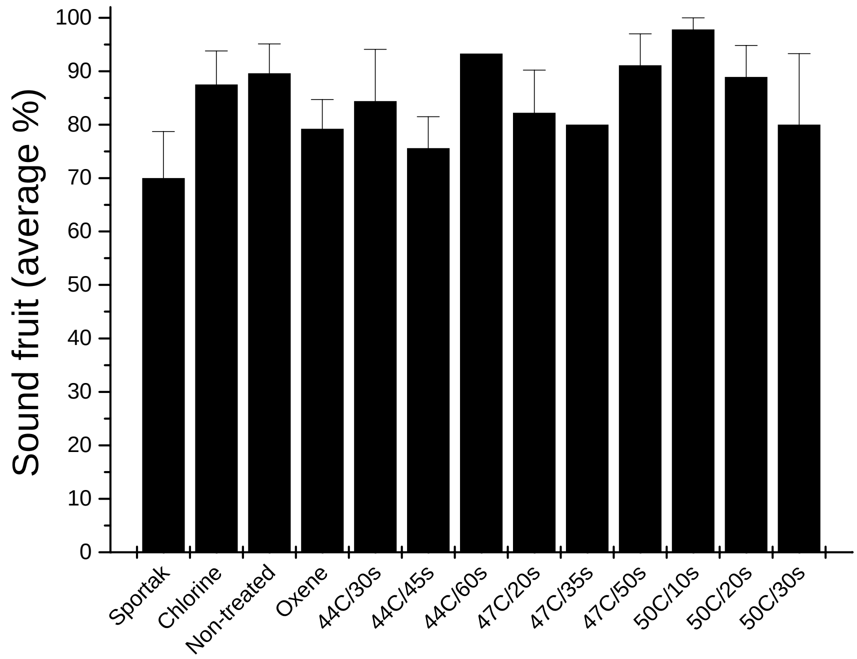

Fig. 10. Percentage of fruit regarded as sound in each treatment.

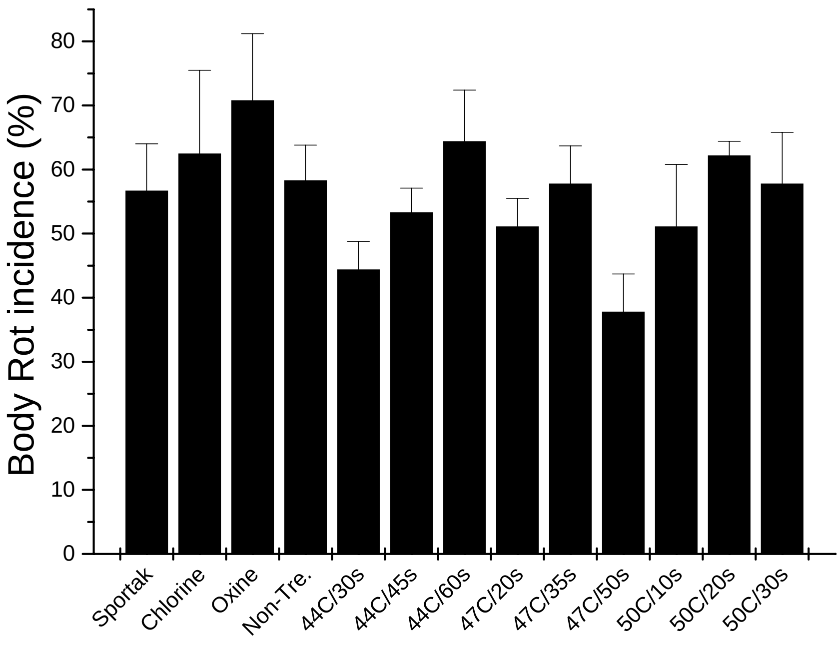

Fig. 11. Incidence of body rots in the different controls and treatments.

Fruit treated with Sportak were not significantly different in terms of incidence of body rots to the non-treated fruit, but both the Oxine and Chlorine treated fruit showed lower body rot severity in comparison to the control and the fruit treated with Sportak (Fig. 12). The most severe cases of body rots were found in fruit treated with Sportak (Fig. 12), which, as mentioned earlier, also had the lowest percentage of sound fruit (Fig. 10). The least severe body rots were found in fruit treated at 50^{o}C for 10s (Fig. 12).

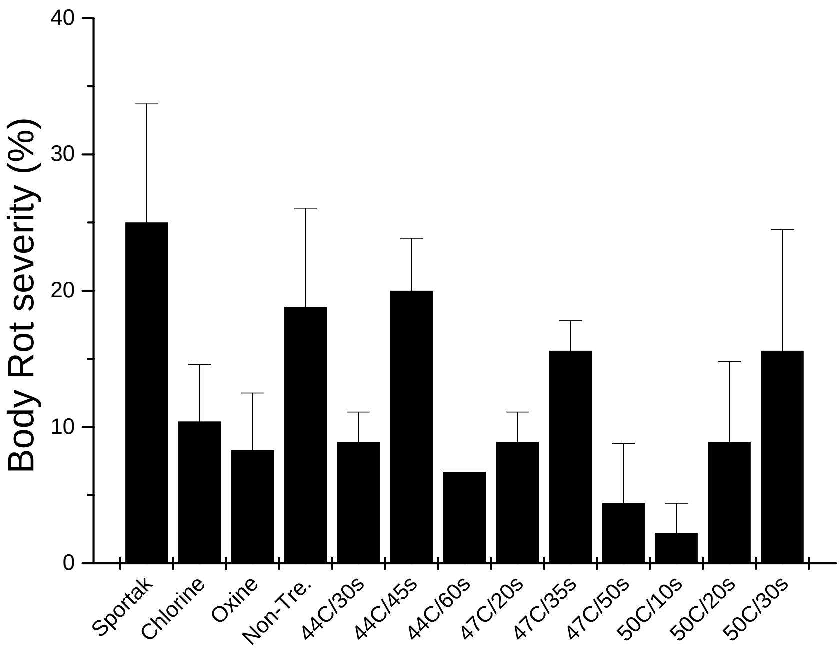

Fig. 12. Severity of the body rots in the different controls and treatments.

The two treatments that resulted in the highest number of fruit with SER were 44°C for 30s and 47°C for 20s, both with 47% of the fruit affected (Fig. 13). The lowest incidence of SER was found in fruit treated at 47°C for 50s with 22% of the fruit affected.

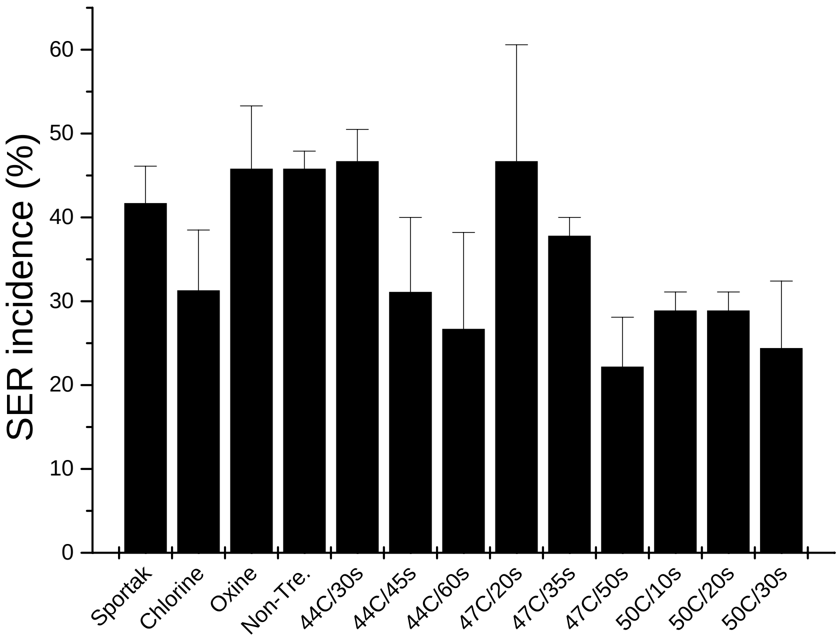

Fig. 13. Incidence of stem end rots (SER) in the different controls and treatments.

The most severe cases of SER were found in fruit treated at 47°C for 20s (Fig. 14), and these fruit also had the highest incidence of SER (Fig. 13). These results are however contradictory to the results of experiment 1, where fruit treated at 47°C for 20s had both the lowest incidence and severity of not only SER, but also body rots (Fig. 6, 7, 8 and 9).

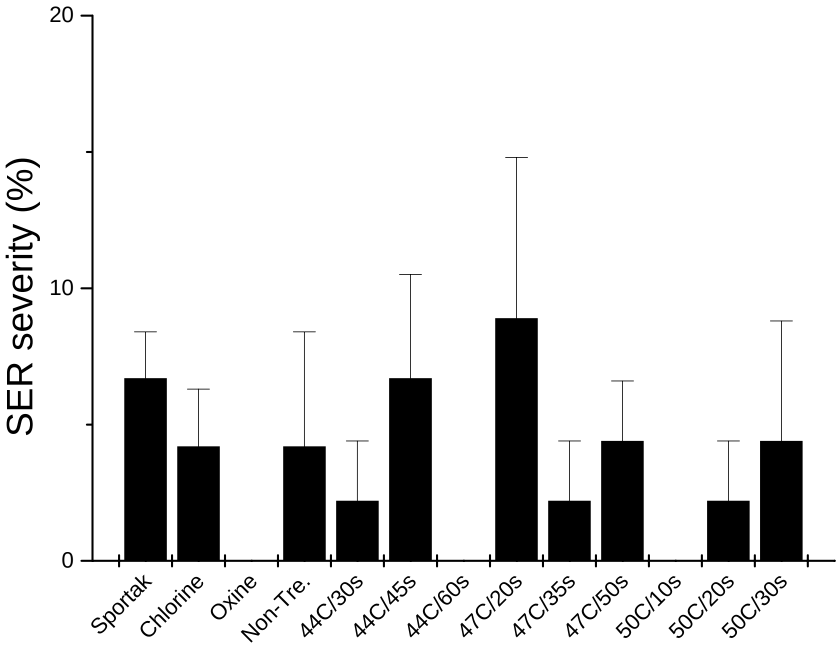

Fig. 14. Severity of stem end rots (SER) in the different controls and treatments.

Vascular browning (VB) was most prominent in fruit treated with Sportak, and the severity of the VB was significantly worse in this treatment than any other (Appendix C, Fig. 23 and 24). The average Firmometer value (Fv) for all the treatments in experiment 2 was 61. Fruit treated at 50^{o}C for 20s had the highest Fv, 67 (Appendix C, Fig. 25).

DISCUSSION

The aim of this experiment was to define a hot water drenching (HWD) treatment that would decrease the incidence of postharvest rots in avocados without affecting neither the external nor the internal quality of the fruit.

Disease incidence appears to be one of the main factors limiting the postharvest quality of New Zealand avocados (Woolf et al., 1994). More than 50% of non-treated control fruit (in experiment 2) had body rots of varying severities. This reflects the high levels of postharvest rots that develop in New Zealand avocados (Woolf and Lay-Yee, 1997).

HWD was associated with a range of damage symptoms in avocado fruit. The main form of external damage was browning or blackening of the skin (Appendix B, Fig. 15-19). This skin damage is similar to the natural ripening colour of 'Hass' avocados, but is not acceptable to consumers since they assume that the dark colour indicate ripeness, although in this instance the fruit might still be hard (i.e. unripe). It has been proposed that hot water treatments may cause damage to different cell membranes, and chloroplast membranes in particular. This would be one way of explaining the discolouration of the avocado surface, as suggested by Woolf et al. (1994).

The fact that the treatments that resulted in more skin damage generally had higher disease severity suggest that it is likely that HWD treatments at temperatures that did not result in much skin damage reduced rots through reduced skin damage, and improved ability to retard disease development.

The internal quality of avocado fruit decreased with increasing HWD duration and temperature in experiment 1. This was due to increased incidence and severity of body rots and stem end rots (SER) compared to control fruit. These internal damage symptoms were also observed in the chemically treated fruit, but to a much lesser frequency and severity. One possible reason for the increase of disease incidence in treatments >50^{o}C could be that the damaged skin tissue allows decay organisms to invade. This could thus also be the explanation for the reduced proportion of sound fruit in HWD treatments at high temperatures in experiment 1.

In experiment 2 it was found that by treating avocados at high temperatures for short durations, the incidence and severity of postharvest rots could be reduced (Fig. 11-14). Treatments found to minimize body rots were 47^{o}C for 50s and 50^{o}C for 10s. The optimum HWD temperatures for minimum body rot severity were similar to those for minimum damage by SER in both experiments.

In experiment 1 the treatments that resulted in the highest number of sound fruit were 47^{o}C for 35s and 50^{o}C for 15s, with as many as 96% of the fruit rated as sound. In experiment 2 the slightly altered treatment 50^{o}C for 10s resulted in the highest average of sound fruit, with 98% of the fruit sound. These results suggest that HWD at 50^{o}C for a short duration could be effective in order to increase the number of sound fruit.

The incidence of SER in fruit treated at 50^{o}C for 10 s increased from 13% in experiment 1 to 29% in experiment 2. The same was true for body rots. The incidence of body rots increased with 33% between the two experiments, from 18% in experiment 1 to 51% in experiment 2. Although the incidence of both body rots and SER increased between the treatments 50^{o}C for 15s and 50^{o}C for 10s, the severity of both disorders remained very low in both experiments.

This high incidence (but very low severity) of rots suggests that the fruit ripened before the rots were of unacceptable levels (Everett and Korsten, 1996).

Differences in results between the two experiments could reflect differences in fruit susceptibility between the two times of harvest. The fruit used in experiment 2 was harvested two months later than the fruit in experiment 1, but the fruit came from the same orchard in both experiments.

The standard industry application of Sportak resulted in a slight reduction in the incidence and severity of body rots, but also resulted in an increase of vascular browning compared to non-treated control fruit to such a degree that the non-treated control fruit actually had a higher average of sound fruit in both experiments. It is known that a delay in application of Sportak lessens its efficacy (White et al., 1999), and it might have been the time elapsed between harvest and the application of Sportak that gave this result.

The results from the two experiments were also contradicting for the Sportak treatment. The results from experiment 1 suggest that treating fruit with Sportak decreases the occurrence of SER, and results in a high average of sound fruit. However, in experiment 2 the Sportak treatment showed a relatively high incidence of SER, and also had the lowest average of sound fruit. One can assume that the different harvesting times between experiment 1 and 2 had some impact on the effectiveness of Sportak, as the fruit harvested later were more mature and had a higher dry matter (DM).

Sportak appeared to increase the severity of both body rots and SER in experiment 2. That application of Sportak could increase the incidence and severity of rots was also found by Everett and Korsten (1996). Perhaps it is possible that the chemicals provide nutrients that encourage growth of fungi.

The contradicting results of the two experiments in regards to the Sportak treatments suggest that further studies should be carried out in regards to the efficiency of the fungicide, since a Sportak-dip is currently the standard postharvest fungicide treatment in New Zealand for Australian-bound exports.

A high temperature treatment for a long duration greatly increased not only the incidence, but also the severity of body rots, as indicated in Fig. 6 and 7. However, by treating fruit at 47^{o}C for 20s both incidence and severity of body rots were reduced, suggesting that treatment at an intermediate temperature for an intermediate duration may prove useful as a method to reduce the occurrence of body rots.

This indicates that this treatment could possibly substitute the Sportak treatment, especially for fruit for the American market where Sportak treated fruit is not allowed.

The two treatments that resulted in the highest number of fruit with SER were 44^{o}C for 30s and 47^{o}C for 20s, both with 47% of the fruit affected (Fig. 13). The lowest incidence of SER was found in fruit treated at 47^{o}C for 50s with 22% of the fruit affected. As the graph in Fig. 13 clearly displayed, these results indicate that a higher temperature treatment reduced the incidence of SER in fruit.

The results suggest that postharvest hot water drenching of avocados at temperatures 47-50^{o}C for variable durations can be a successful way of decreasing the occurrence of postharvest rots, without also ending up with a high average of unacceptable fruit. Overall, the best treatments observed in this project were 47^{o}C for 50s and 50^{o}C for 10s. However, further research is required to improve the fruit quality at temperatures and durations that are also effective as disinfestation treatments.

Future work should identify at what temperature and at what duration the best internal as well as external avocado quality is achieved. It would also be of value to find out whether the time of harvest and fruit source (i.e. orchard) has any effect on the success of different HWD treatments.

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APPENDIX A

The "give" or deformation of the fruit is rated using the following scale:

0 = Hard, no "give" in the fruit
1 = Rubbery, slight "give" in the fruit
2 = Sprung, can feel the flesh deform by 2-3 m ("break") under extreme thumb force, very rubbery
3 = Softening, can feel 2-3 mm deformation with moderate thumb pressure
4 = Near-ripe, 2-3 mm deformation achieved with slight thumb pressure, whole fruit deforms with extreme hand pressure
5 = Ripe or eating soft, whole fruit deforms with moderate hand pressure
6 = Over ripe, whole fruit deforms with slight hand pressure
7 = Very over ripe, flesh feels almost liquid

Source: AvoCare Assessment Manual, 2001, The Horticulture and Food Research Institute of New Zealand Ltd.

Table 3. Start times for the randomized order of treatments in experiment 1

	Temperature					H_20 samples
Replicate	Durations	30s	45s	60s	80s	
1	44°C	09:40	09:45	09:42	09:47	09:30
	Durations	20s	35s	50s	65s	
1	47°	10:42	10:39	10:41	10:37	10:35
	Durations	15s	30s	45s	60s	
1	50°C	10:00	10:06	10:04	10:08	10:05
	Durations	10s	20s	30s	40s	
1	53°C	11:03	11:01	10:57	11:04	10:55
Replicate	Durations	30s	45s	60s	80s	
2	44°C	14:14	14:16	14:10	14:06	14:06
	Durations	20s	35s	50s	65s	
2	47°	13:44	13:39	13:43	13:45	13:40
	Durations	15s	30s	45s	60s	
2	50°C	12:31	12:30	12:33	12:35	12:37
	Durations	10s	20s	30s	40s	
2	53°C	12:51	12:49	12:45	12:52	12:45
Replicate	Durations	30s	45s	60s	80s	
3	44°C	15:44	15:47	15:51	15:49	15:43
	Durations	20s	35s	50s	65s	
3	47°	15:15	15:11	15:17	15:13	15:08
	Durations	15s	30s	45s	60s	
3	50°C	16:49	16:48	16:50	16:45	16:45
	Durations	10s	20s	30s	40s	
3	53°C	16:18	16:20	16:21	16:15	16:13

Table 4. Start times for the randomized order of treatments in experiment 2

	Temperature			
Replicate	Durations	30s	45s	60s
1	44^{o}C	14:10	14:08	14:05
	Durations	20s	35s	50s
1	47^o	14:32	14:28	14:26
	Durations	10s	20s	30s
1	50^{o}C	14:50	14:47	14:42
Replicate	Durations	30s	45s	60s
2	44^{o}C	16:39	16:35	16:41
	Durations	20s	35s	50s
2	47^o	16:07	16:02	16:14
	Durations	10s	20s	30s
2	50^{o}C	17:05	17:00	17:07
Replicate	Durations	30s	45s	60s
3	44^{o}C	19:38	19:36	19:34
	Durations	20s	35s	50s
3	47^o	19:47	19:45	19:44
	Durations	10s	20s	30s
3	50^{o}C	18:03	18:08	18:11

Table 5. Available chlorine titrations of water samples.

Sample		µl thiosulphate used in titration N/10	N/20	N/20	% Available chlorine	**Chlorine (ppm)**
Control Chlorine	Time sampled	213	410	411	0.0146	**146**
44/R1	09.30	245	473		0.0168	**168**
44/R2	14.06	225	440		0.0156	**156**
44/R3	15.43	242	473		0.0168	**168**
47/R1	10.35	230	449		0.0159	**159**
47/R2	13.40	215	421		0.0149	**149**
47/R3	15.08	252	491		0.0174	**174**
50/R1	10.05		462	459	0.0163	**163**
50/R2	12.37		484	482	0.0171	**171**
50/R3	16.45		450	445	0.0159	**159**
53/R1	10.55		428	427	0.0152	**152**
53/R2	12.45		465	465	0.0165	**165**
53/R3	16.13		472	472	0.0167	**167**

APPENDIX B

External damage: The following photos show the degree of external damage for each of the treatments in Experiment 1. The photos were taken immediately after the fruit was removed from the cold storage. The external damage is evident as skin browning/blackening.

Fig. 15. These images show the extent of the external damage for the non-treated control and the two chemical treatments.

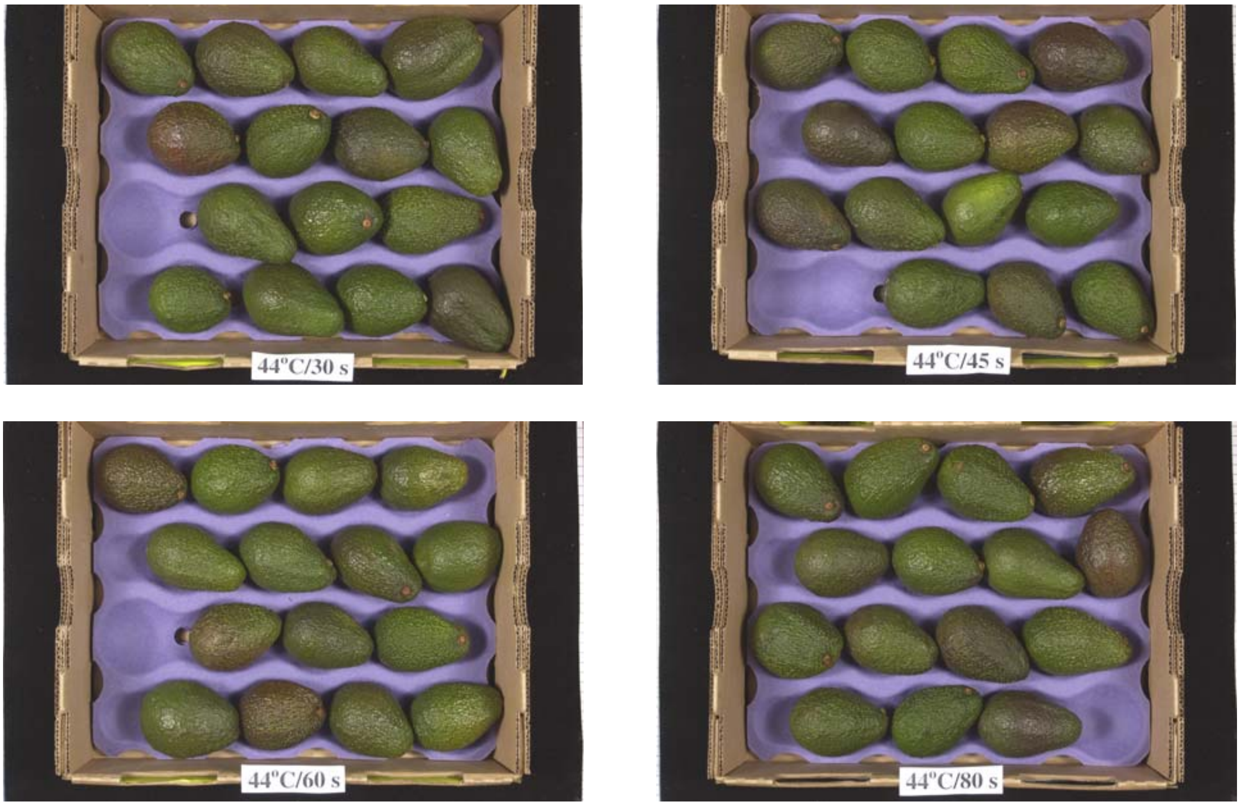

Fig. 16. These images show the extent of the external damage for the four treatments at 44°C.

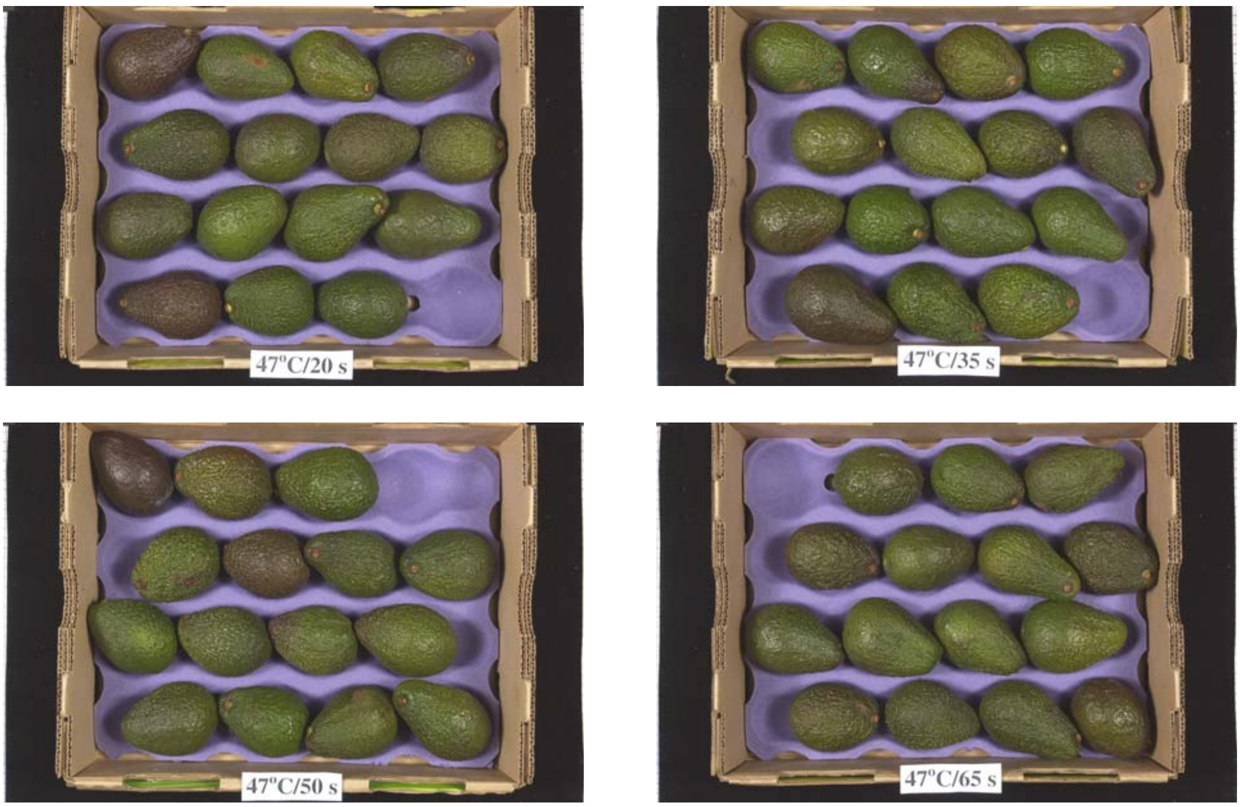

Fig. 17. These images show the extent of the external damage for the four treatments at 47°C.

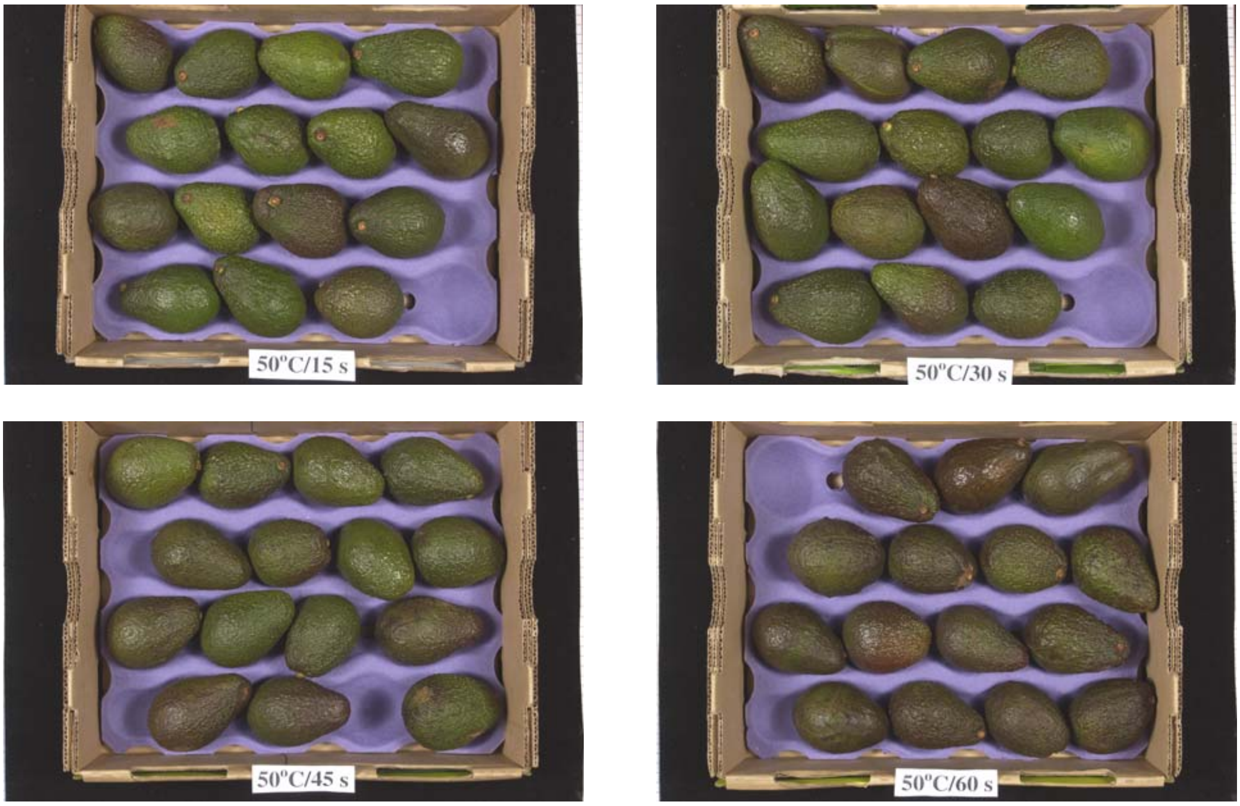

Fig. 18. These images show the extent of the external damage for the four treatments at 50°C.

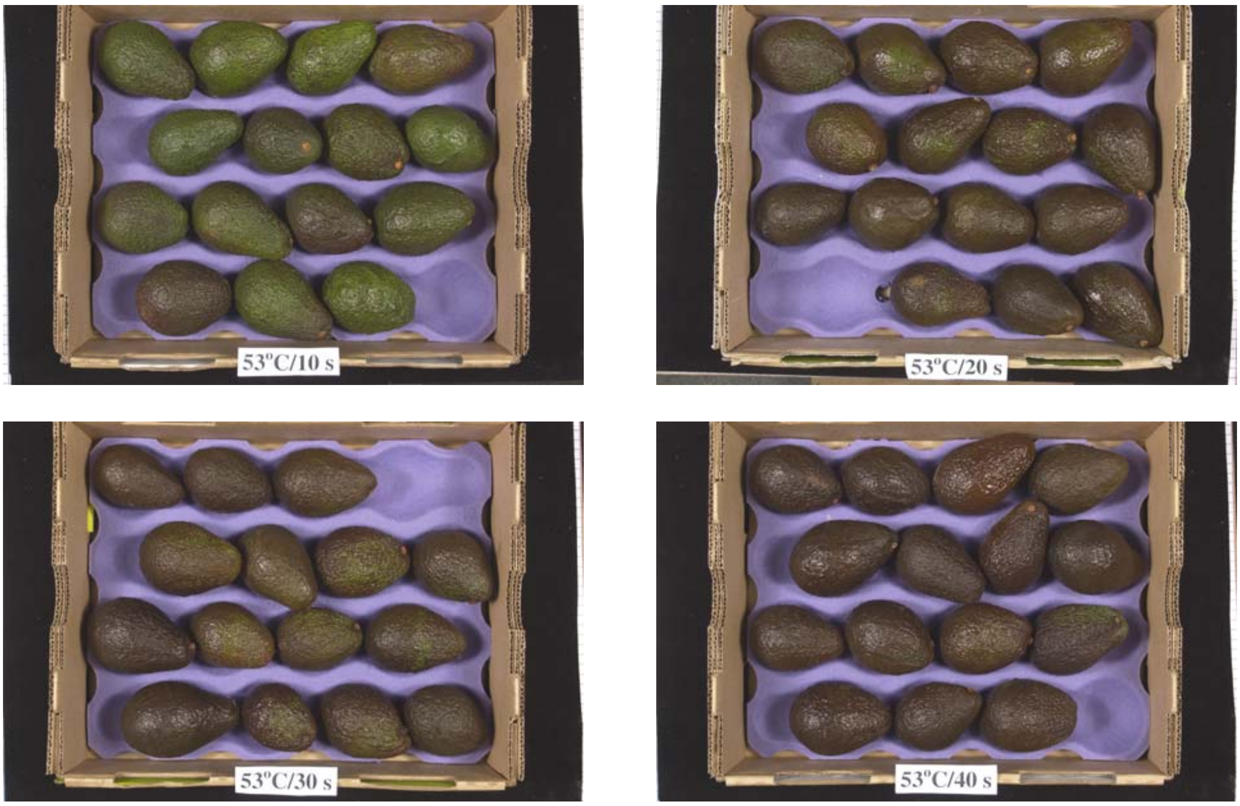

Fig. 19. These images show the extent of the external damage for the four treatments at 53°C.

APPENDIX C

Graphs of the results from experiment 1:

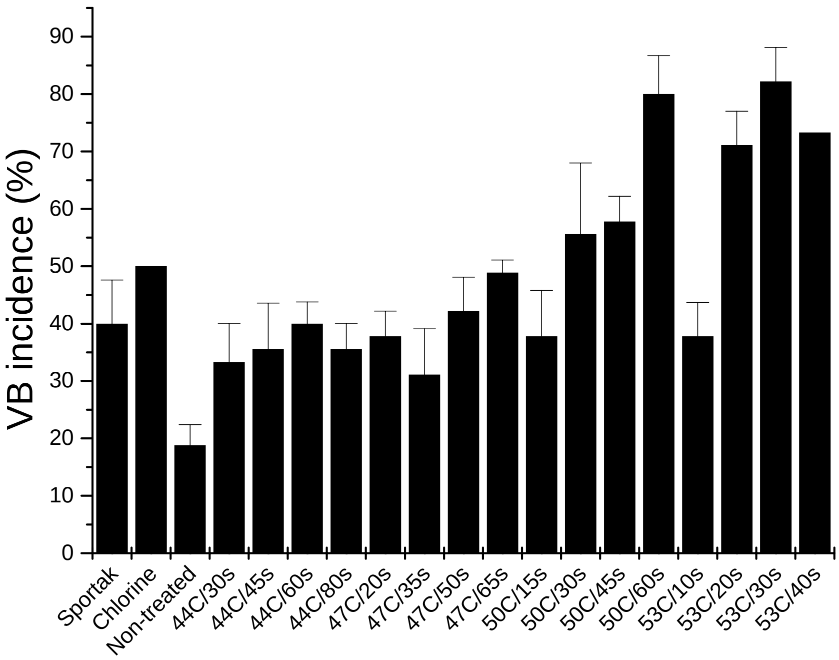

Fig. 20. The incidence of vascular browning (VB) in the different controls and treatments.

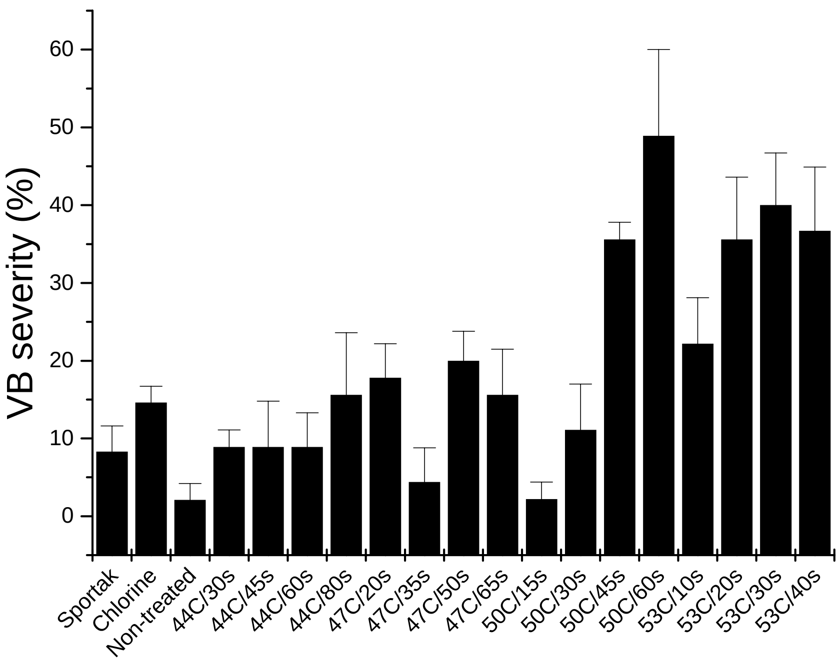

Fig. 21. The severity of vascular browning (VB) in the different controls and treatments.

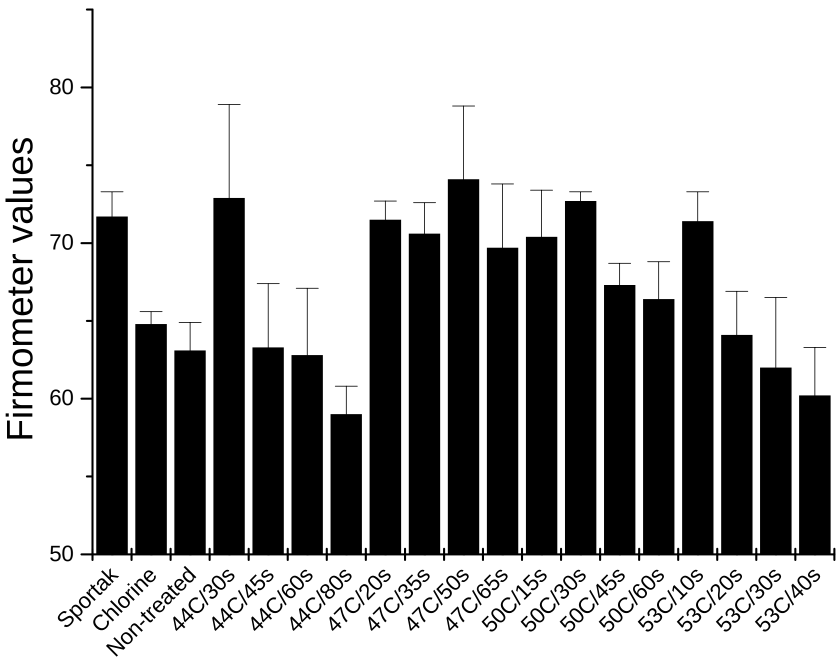

Fig. 22. This graph shows the average Firmometer value of four randomly picked fruit in each treatment.

Graphs of results in experiment 2:

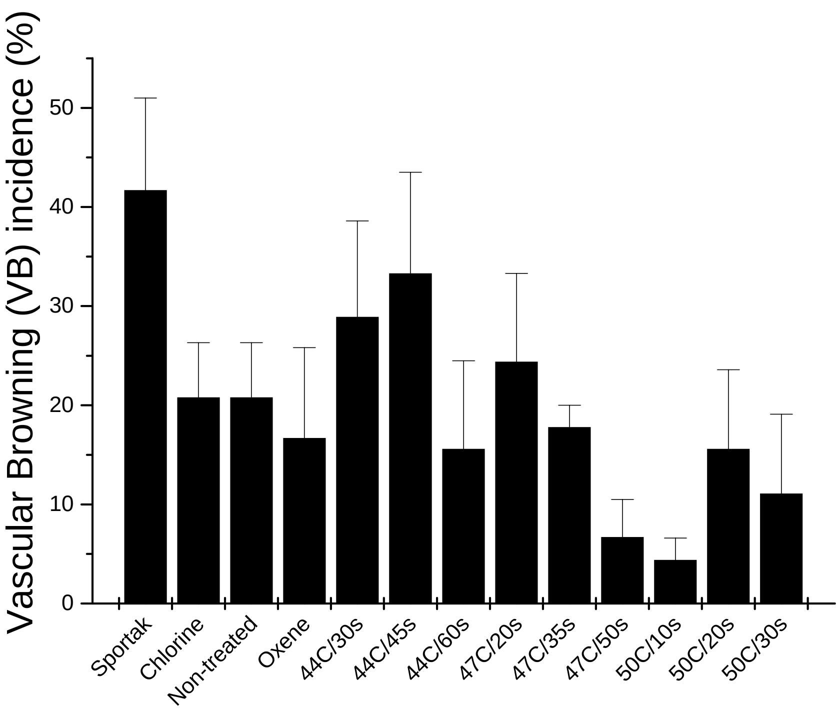

Fig. 23. The incidence of vascular browning (VB) in the different controls and treatments.

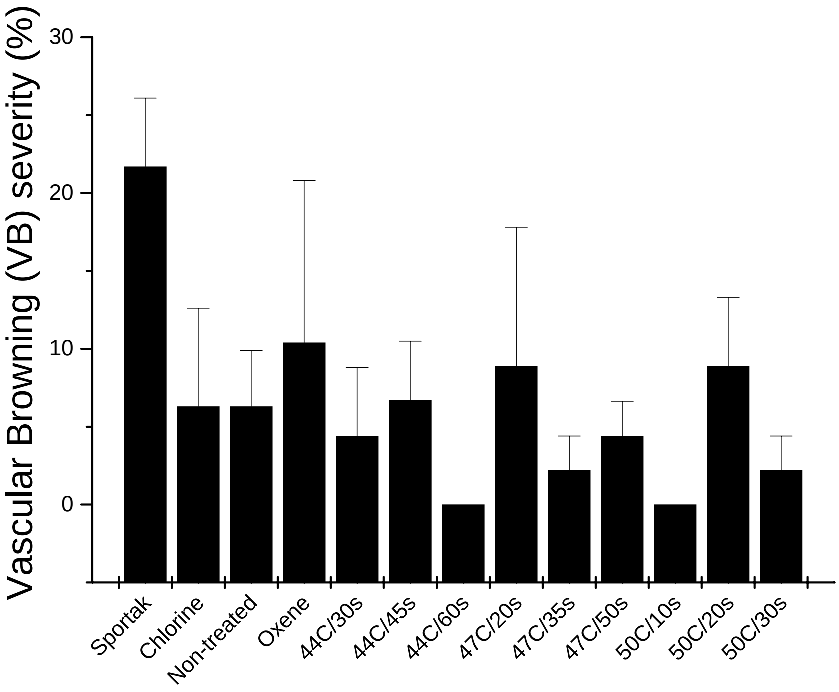

Fig. 24. The severity of vascular browning (VB) in the different controls and treatments.

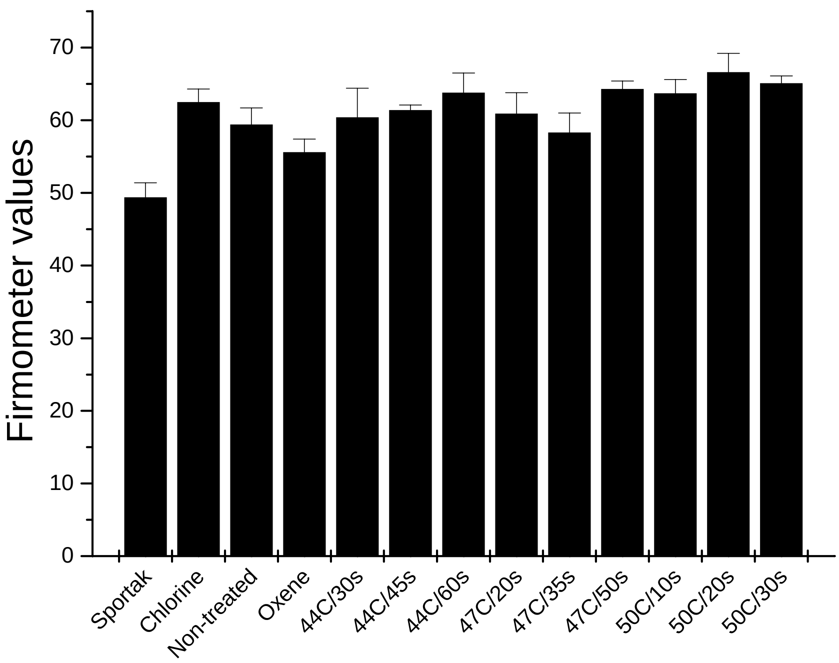

Fig. 25. This graph shows the average Firmometer value of four randomly picked fruit in each treatment.