Greenhouse Production of Watermelon (*Citrullus lanatus*)

by

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree

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ABSTRACT

Various researchers have determined that salinity causes several kinds of damage to plants such as germination inhibition, metabolic disturbances, yield reduction and quality losses. However, the severity of salt damage has been found to be dependent on the cultivar, level of salinity, period of exposure to salinity, and the growth stage of the plant. An understanding of the severity of salinity and its potential negative impacts on crops is essential to optimise production. Knowledge of seed vigour, expressed as germination percentage and germination rate at the optimum temperature for germination, would provide growers with valuable information to measure and compare the viability of seed lots.

A study was done where fresh and aged seeds of two watermelon cultivars were investigated in germination tests under laboratory conditions at four salinity levels and five temperature regimes. The best germination was achieved at 4 mS cm^{-1} for both cultivars, Odem and Paladin. At 8 mS cm^{-1}, the germination percentage for Paladin was 31% better than for Odem. The germination time for aged Odem seeds was significantly delayed at this EC 8 level but ageing of Paladin seeds had no detrimental effect at this EC level. Paladin germinated significantly better than Odem at the relatively low temperature range of 15-20°C, indicating that it is well-adapted for early planting.

A new plant growing system, using vertical training of two shoots was tested in a greenhouse, aiming to optimise the growth regulating capabilities of this crop environment. Traditional watermelons are open-field planted in rows at low densities. Even with this plant spacing, by harvesting time the vines are spread in such a way that the foliage laterally covers the inter-row spacing, making cultivation practices such as spraying, weeding and harvesting difficult and almost impossible. The production of greenhouse crops is advantageous, but involves a number of cultural inputs and techniques for optimum yields. The effects of plant pruning systems and salinity levels on watermelon cultivars (Odem and Paladin) in a low-cost greenhouse were studied using a drain-to-waste fertigation system. Changing the nutrient solution from a low salinity level

(EC 2 mS cm^{-1}) during vegetative growth to EC 4 mS cm^{-1} after pollination, did not reduce fruit mass, but significantly increased the sugar yield of Odem, the icebox-type cultivar. Excessive pruning (less leaves per shoot) was more efficient with low salinity levels than at a high salinity level. Moderate pruning (more leaves per shoot) represented a good system, producing fruits of lesser weight and acceptable quality.

UITTREKSEL

Verskeie navorsers het reeds die skadelike gevolge van brak toestande op ontkieming, plant metabolisme, opbrengs en kwaliteit van gewas plante ondersoek. Die omvang van die skade kan deur kultivars, die konsentrasie soute, die periode van blootstelling asook plante se groeistadium bepaal word. ‘n Goeie begrip van die potensiële skadelikheid van hoë sout konsentrasies op gewasse is nodig om produksie te optimaliseer. Inligting oor die kiemkragtigheid van saad, uitgedruk as die persentasie ontkieming asook die ontkiemingstempo, is vir kwekers nodig ten einde te verseker dat goeie saad gebruik kan word.

‘n Ondersoek is gedoen waar vars asook verouderde saad van twee waatlemoen kultivars onder laboratorium toestande by vier sout peile en vyf temperature ontkiem is. Die beste ontkieming vir beide kultivars, Odem en Paladin, is gevind waar die elektriese geleiding (EC) 4 mS cm^{-1} was. Teen 8 mS cm^{-1} was die persentasie ontkieming vir Paladin 31% beter as vir Odem. Veroudering van Odem saad het ‘n betekenisvol swakker ontkiemingstempo met‘n EC van 8 mS cm^{-1} getoon terwyl verouderde Paladin saad nie by hierdie EC swakker vertoon het nie. Paladin het by die relatief lae temperatuur sone van 15-20°C betekenisvol beter as Odem saad ontkiem wat daarop dui dat dit vir vroeë aanplantings geskik is.

‘n Nuwe produksiestelsel, waar twee lote per plant vertikaal in ‘n V-vorm opgelei is, is in ‘n kweekhuis getoets in ‘n poging om die groeiregulerende potensiaal van so ‘n omgewing te optimaliseer. Waatlemoene word tradisioneel in rye teen ‘n lae plant-digtheid in veldaanplantings verbou. Met so ‘n praktyk ontwikkel daar soveel ranke tussen die rye dat praktyke soos onkruid beheer, plaagbeheer en oes bemoeilik word. Die produksie van gewasse in kweekhuise hou voordele in maar ‘n aantal insette en spesiale tegnieke is nodig vir optimum opbrengs. Die invloed van snoeipraktyke en soutpeile is met twee waatlemoen kultivars (Odem en Paladin) in ‘n lae-koste kweekhuis ondersoek deur ‘n sisteem te gebruik waar voedingsoplossings in vry dreinerende sakke met saagsels gedrup is. Waar die EC van die voedingsoplossing voor vrugset 2 mS cm^{-1} was

en toe vir die periode van vrugontwikkeling tot 4 mS cm^{-1} verhoog is, het geen vrugverkleining by Odem gevolg nie terwyl die suikeropbrengs wel verhoog het. Oormatige verwydering van blare was minder skadelik met 'n lae EC as waar die EC hoog was. 'n Matige snoeiproses met meer blare per loot, het 'n goeie produksie van aanvaarbare vruggrootte en 'n goeie kwaliteit verseker.

CONTENTS

CHAPTER 3: INFLUENCE OF DIFFERENT SALINITY LEVELS AND PRUNING METHODS ON YIELD AND QUALITY OF WATERMELONS (*CITRULLUS LANATUS*) GROWN IN GREENHOUSES

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LITERATURE REVIEW

1. General Introduction

The species in the family *Cucurbitaceae* that have been used as vegetables have enriched and diversified the diets of humankind for many centuries (Wien, 1997). Among the 115 genera belonging to the *Cucurbitaceae* family, four are of great economic importance: *Citrullus*, *Cucumis*, *Cucurbita* and *Lagenaria*. In support of this, Nayar and More (1998) reported that muskmelon, cucumber and watermelon are the most extensively grown crops among the cucurbits. The most cultivated cucurbit in 1996 was watermelon, followed by cucumber, melon, and *Cucurbita* species (Pitrat, Chauvet and Foury, 1999). *Citrullus lanatus* cultivars are among the main vegetables grown in Italy (Pardossi and Tognoni, 1999), Korea (Goh, 1998), Cyprus (Ioannon, Ioannon and Hadjiparaskevas, 2002) and Japan (Sahata and Sugiyama, 2002) under protected cultivation of plastic films. Four countries (China, Turkey, Iran and USA) produce about 50% (29 900 000 ton) of the world production of watermelon (Pitrat *et al.*, 1999).

Watermelons are annual plants, completing their life cycle (seed, seedling, flowering, fruiting and death) in one growing season (Acquaah, 1999). Watermelons are similar in their appearance and requirements for growth to other cucurbits (Lerner and Dana, 2001). The fruits are rich in water and highly appreciated during summer in hot countries. It is also cultivated for its seeds, which are, as most of the seeds of other cucurbits, rich in proteins and lipids (Pitrat *et al.*, 1999). Wild species such as *C. colocynthis* is harvested not only for its seeds, but also for the bitter flesh that has been used as a medicine for a long time (Pitrat *et al.*, 1999; Sarafis, 1999).

Watermelon is of southern African origin (Korkmaz & Dufault, 2002) and has been introduced relatively late in Europe (Pitrat *et al.*, 1999) and the United States in 1929 (Hassell, Dufault & Phillips, 2001). The African origin of watermelon is almost certain because of the diversity of spontaneous forms of *C. lanatus* and the presence of wild related species on this continent (Pitrat *et al.*, 1999), and in particular Namibia (Sarafis, 1999).

The world's challenge in agriculture today is to substantially increase production to meet the demands for rapidly growing populations, especially in developing countries. Despite the evident importance of watermelon species, hardly any research has been done under intensive production systems within the African context, and none in the Southern African region. Bearing this in mind, experimental studies aimed to evaluate salinity effects and cultural practices on watermelon growth and yield under greenhouse production systems have been conducted at Welgevallen Experimental farm of the Stellenbosch University. The second experimental study entailed seed vigour tests, followed by temperature and salinity germination tests under laboratory conditions.

2. Morphology

From a botanical point of view, the *Cucurbitaceae* family can be divided into two sub-families: the *Cucurbitoideae* with one style in the female flower, and the *Zanonioideae* with three free styles. Pitrat *et al.* (1999) denotes that there is no species of *Zanonioideae* of economic importance. Of the four genera mentioned above, seven species are socio-economically important, specifically: watermelon (*Citrullus lanatus*), cucumber (*Cucumis sativus*), muskmelon (*Cucumis melo*), squash (*Cucurbita pepo*), pumpkin (*Cucurbita moschata*), and bottle gourd (*Lagenaria vulgaris*).

Watermelon plants are prostrate, sprawling vines, usually with tendrils (Lerner & Dana, 2001). Each vine bears many large, lobed leaves and the flowers are bright yellow. Two kinds of flowers are found, namely: pistillate (female) and staminate (male). Wild *C. lanatus* plants found in the central Namib Desert have green-fleshed fruit, perceptibly unknown from the domesticated watermelon. According to Sarafis (1999) white, yellow, orange, pink, red, and crimson flesh types are known. The red flesh cultivated watermelon from the north of Namibia has some green zone within the fruit suggesting that the green flesh character can be easily introduced (Sarafis, 1999). In a study with yellow watermelon cultivars, Simon, Morales and Charles

(1994) found that the fruits did not exhibit cracking and were relatively uniform in external appearance. Most yellow cultivars however, had a mealy texture and a light yellow flesh colour. The study identified the need for further improvement in fruit quality, in order for the fruits to exhibit greater uniformity and a deeper, brighter, and more uniform yellow colour.

3. Germination and seedling growth

Watermelon seeds germinate poorly at 16°C (Wien, 1997). Based on the findings of a 1979 MSc thesis by Hassell at Cornell University, Korkmaz & Dufault (2002) reported that low temperatures are known to reduce germination of watermelon. However, washing the seed for 2 hours in water could significantly improve cold temperature germination (Wien, 1997). Hassell *et al.* (2001) showed that the temperatures that maximized germination for all selections evaluated were 29,4°C to 32,2°C for diploids and 29,4°C for triploids. If grown in soil, almost all cucurbits require very warm soil to germinate, at least 12°C (Lerner & Dana, 2001). Wien (1997) reports that growth-inhibiting effects of cold soils on cucumber is overcome by grafting of the plant on cucurbit species less susceptible to low root temperatures. *Curcubita ficifolia* grows actively and takes up water and nutrients at a temperature as low as 12°C.

Of all vegetable plants, cucurbit seedlings such as that of watermelon is among the fastest growing. This is chiefly due to the large seed size, which contain on average about 0,1g of oil as well as 0,6g of protein. Large quantities of these reserves are made available for seedling growth before commencement of photosynthesis in the cotyledons and true leaves. Secondly, the large initial seedling size provides plants with early light interception and assimilation, reaching a transplanting size in a short period of 2-3 weeks, compared to 6-8 weeks in peppers and tomatoes (Wien, 1997). Cucurbits should be transplanted when plants have developed two adult or true leaves (Lerner & Dana, 2001).

4. Flowering

According to Wien (1997), watermelon has a monoecious flowering habit of male and female flowers on the same plant. The ratio of male to female flowers and the potential to bear female flowers in the lowest node varies from one cultivar to the other. Most commonly, female flowers of monoecious plants increase with time. Wien (1997) reported that cool conditions favours female flower production in cucumber, and induce male flowering in squash.

In other cucurbits, ethylene stimulates female flower development. Ethephon applied to cucumber eliminate male flowers on lower nodes and increases female flowers. However, watermelons are sensitive to ethephon, since a low level of this chemical, at 30 μl per litre, retards female flower formation, but has little effect on male flowers. Exposure to an ethylene action inhibitor (aminoethoxyvinylglycine) results in detrainment of female flowers with little reduction of male flowers. These out of the ordinary responses to hormones in the sex expression context, needs to be clarified (Wien, 1997). Time of flowering and the duration of an individual flower opening, is primarily determined by temperature. A watermelon plant will open its flowers at a temperature of about 15°C, and its duration is generally for the entire daylight period (Wien, 1997).

5. Pollination

Watermelons are dependent on insects for pollination due to their separate male and female flowers (Wien, 1997). However, plants can be pollinated manually (Watanabe, Nahano & Okano, 2001a). The physiology of the plant may influence its attractiveness to pollinating insects. Absence of nectar and/or pollen may lead to sporadic visits by domestic bees, hence lead to poor pollination, and ultimately poor fruit set and low yields (Wien, 1997). Insecticides should be used in late afternoon or early evening to avoid injury to pollinating bees (Lerner & Dana, 2001). Generally, for successful pollination male and female flowers must be open on the same day.

When pollen from the same plant or another plant of the same species is deposited on the stigmatic surface, pollen germination follows in less than 30 minutes under normal conditions (Wien 1997). In studies carried out in Japan, pollen grain with diameters of 52 μ resulted in pollen tube growth of 6 and 2,5 mm h^{-1} at 30 and 43 °C respectively. Calculations show that the tubes would reach the nearest ovules in 3 hours. The pollen tube growth rates are higher for larger ovary and final fruit sizes, and may be related to the size of pollen grains. In another experiment, pollination time did not influence fruit weight, the number or type of empty seeds or the percentage of fruit with brown empty seeds (Watanabe, Nahano, Okano, Sigiyama, & Morishita, 2002). It was concluded that the age of the male flower has no effect on the formation of empty seeds. The conducting tissues joining the style and ovary are chiefly responsible for carrying pollen tubes to the ovary. However, when pollen tubes reach the ovary, they will also travel in cavities between fruit lobes. Pollen distribution on the stigma does affect seed location, and ultimately fruit shape (Wien, 1997).

Currently seedless watermelons are produced by using a new technique of soft-irradiated pollen (Watanabe *et al.*, 2002). Staminate flowers are subjected to soft-x-ray irradiation of 800Gy (Sahata & Sugiyama, 2002), and their pollen is then used to produce pseudogamous, seedless, diploid fruit (Sugiyama & Morishita, 2002). This new method has many advantages: (a) ordinary diploid cultivars can be used; (b) ordinary cultivation practices are sufficient for production; and (c) fruit quality is maintained in the seedless fruit. Techniques by which inactivated pollen can be mass-produced are now under study.

6. Fruit set and parthenocarpy

There are two distinct fruit set cycles in watermelons. According to Nayar and More (1998), fruit set is poorer in the rainy season than in summer under USA conditions. Parthenocarpy is fruit set and fruit growth without fertilizing of the ovules. Parthenocarpic fruit set has been induced by application of chemical auxins to the flower. Fruit set, brought about by many of the synthetic growth regulators, increases the endogenous auxin content of the developing ovary. The production of seedless fruits in watermelon does not occur without special measures, since naturally occurring parthenocarpy has not been found in this species (Wien, 1997). Fruit set without seed set can be brought about by pollinating a self-sterile triploid watermelon with a diploid pollen parent (Wien, 1997). The lack of performance of commercial seedless watermelon is due to various factors, namely; (a) the abnormal thick seed coat impedes germination and makes the use of transplants advisable; (b) yields are decreased by at least 25% since diploids are inter planted to be used as pollinators; and (c) consumers are unenthusiastic to accept the small white empty seed coats found in these parthenocarpic fruits.

7. Fruit growth

Cell division and cell enlargement activities constitute ovary growth before anthesis. Cell enlargement occurs purely after anthesis in outer layers of the fruit. At maturity, cells are largest in the innermost layers of the fruit, and may be loosely arranged or even torn apart. Wien (1997) determined that cell enlargement of the innermost tissues continued until the cells had attained an amazing 350000-fold increase from their size at the end of the cell division stage.

Cucurbit fruit growth rate can be affected by influences from the rest of the plant, and by environmental aspects. In greenhouse cucumber, single fruited plants had maximum fruit growth rates that were three times higher than five-fruited plants. High temperatures increased fruit growth rates of single-fruited plants, but the five-fruited plants had maximum fruit growth rates at 25^{o}C. Fruit growth rates were also enhanced at higher irradiation levels due to increases in assimilate supplies. There is a need to study fruit growth under uniform environmental conditions, and with plants of similar fruit load (Wien, 1997).

The carbohydrate translocated to fruit during development is rafinose polysaccharide stachyose, which is transformed into sucrose and hexose sugars once it reaches the fruit peduncle. The changes in carbohydrate content of watermelon and *Cucurbita* fruits have not been intensively investigated (Wien, 1997). However, during fruit development, watermelon is reported to show an earlier increase in reducing sugar than in sucrose. As a result the fruit has about 10% total sugars at maturity, of which 35% is sucrose. The sucrose fraction increases to roughly 65%, if the fruit is permitted to over-mature on the vine or stored at room temperature. Total sugars and soluble solids increase in the fruit until maturity. Little is known about the enzyme systems responsible for these changes in the fruit (Wien, 1997).

8. Factors affecting productivity

Total harvestable yield can be affected by factors that influence overall plant productivity and those that determine the partitioning of assimilates to reproductive tissue (Wien, 1997). Watanabe *et al.* (2001a) found that vertically trained plants produced smaller fruit than horizontally grown plants. The former had a planting density three times greater (due to upward shoots) than the flat grown watermelons. However, the middle and lower leaves received less solar radiation than the horizontal plants. Therefore, the photosynthetic rate appeared high at upper leaves on the vertically trained plants, but was constantly high with variations at different positions in the horizontal watermelons. High temperatures during fruit development stimulate the formation of brown empty seeds that lower fruit quality (Watanabe *et al.*, 2002). Only a few available studies describe the effect of low temperatures on watermelon growth and yield (Korkmaz & Dufault, 2002).

Productivity also involves issues of timing and concentration of harvests. Fruit quality is an important criterion in the production of muskmelon, watermelon and winter squash. Production systems must provide conditions that allow fruit to develop an acceptable sweetness, taste and size (Wien, 1997). Yellow-fleshed watermelons have received only minor market interest in the past, partially due to the lack of cultivars with high quality fruit as well as consumer resistance to the yellow colour. Many cultivars have had problems with cracking or hollow-heart, mealy textures, or a lack in uniform fruit shape (Simon *et al.*, 1993). In an experiment with salinity treatments, watermelon fruit size decreased using EC's of 1.2, 5.0 and 8.0 dSm^{-1} respectively (Watanabe, Sakamoto & Okano, 2001b). The authors concluded that salinity (EC 8 dSm^{-1}) suppressed fruit enlargement, decreased fruit weight by half, and reduced the photosynthetic rate. At high substrate salinity, growth depression may also originate from inhibited nutrient uptake, transport and utilization in the plants (Marschner, 1995).

9. Grafting

In soil culture, grafting avoids soil-borne diseases (Watanabe *et al.*, 2001b) and improves fruit quality, depending on the rootstock used. In Japan watermelon is usually grafted to *cucurbitaceous* rootstock, e.g. squash, to increase resistance to soil borne diseases and to promote growth at low temperatures (Yamasaki & Sugiyama, 2002). When squash is used as rootstock, the quality of the fruit is often poorer than that of the bottle gourd or the non-grafted scions because the poor flesh texture is attributed to the vigorous root activity of squash roots. Yamasaki and Sugiyama (2002) found that fruit growth was slightly inhibited by grafting.

The following is a summary of problems found with grafting of watermelons (Watanabe *et al.*, 2001b; Yamasaki & Sugiyama, 2002): (a) The process of grafting and after-care is burdensome; (b) the grafted plant's fruits have larger hollow flesh cavities than the non-grafted ones; (c) there are no specific differences between fruits from grafted and non-grafted plants regarding sugar content, hardiness and flesh texture; (d) fruit from grafted plants usually have more empty seeds than fruit from non-grafted plants; (e) the percentage of normal fruits is generally more than three times higher in the non-grafted plant (74% vs. <20%); (f) the rinds of the fruits from grafted plants are thicker than those from the non-grafted ones; (g) soil disinfections or fumigation is tedious and costly; and (h) root diseases and nematodes are common problems in soil culture.

10. Yield and fruit quality

A 'marketable' class of watermelon is based on (a) minimum levels of soluble solids, (b) fruit size, and (c) external appearance characteristics (form, colour, etc.). Watermelon fruit size has been classified by Lerner and Dana (2001) as large (9-13 kg), medium (4.5-6.8 kg), or small (<2.3 kg). Watermelons should have a sugar content of 10% or greater to be considered acceptable (Wien, 1997). Korkmaz and Dufault (2002) noted minimum marketable weight in their study as 5 kg, in line with the USDA Standards. In this regard, watermelons that were malformed or weighed <5 kg were classified as cull. Poor fruit quality was ascribed to poor pollination and fruit setting, excessive vegetative growth, fruit abortion, early fruit drop, and production of deformed fruits, with internal cracks or cavities and white-yellow fibrous material in the edible part (Ioannou *et al.*, 2002). Vertically trained watermelons produced lighter fruits due to shading caused by less light at the middle and lower leaf levels (Watanabe *et al.*, 2001b).

Watermelons are ready when tendrils die and parts of the fruit in direct contact with the soil changes colour from green to creamy white (spot coloration) and the sugar content of the fruit reaches its highest concentration (Acquaah, 1999). Lerner and Dana (2001) outlined the use of a combination of the following four indicators to determine when watermelons are ripe: (a) The light green, curly tendrils on the stem near the point of attachment turn brown and dry. On some varieties this may happen 5-10 days before the fruit is fully ripe. (b) The surface colour of the fruit changes its slick appearance and turns dull. (c) The skin becomes rough and you can penetrate it with your thumbnail. (d) The cultivars that are predominantly dark green will turn a buttery yellow on the ground side. Lighter melons will also turn yellow, but not as deep as darker melons. Local farmers in Southern Africa are keen to check watermelon ripeness by 'knocking' on the fruit, therefore deciding on picking time depending on the sound response of the 'forefinger knock'. Watermelons are harvested manually and require an experienced labour force to determine the correct stage of maturity. If picked unripe, the melons will never reach peak sweetness levels because the sugar content does not increase after harvest.

11. Physiological disorders and diseases

Watermelon fruit are affected by a number of pre-harvest disorders that may limit their marketability and thereby restrict economic returns to growers. Watermelon pathogenic diseases include bacterial rind necrosis (*Erwina* spp.), bacterial fruit blotch (*Acidovorax avenae* subsp. *citrulli*), anthracnose (*Colletotrichum orbiculare*), gummy stem blight/black rot (D*idymella bryoniae*), and phytophthora fruit rot (*Phytophthora capsici*). Rindworm damage is one of the vector mediated disorders on watermelons.

Hollow heart is marked by the separation of the flesh that divides into distinctive segments, thus leaving hallow areas at harvest maturity (Wien, 1997). The disorder is reported to occur in every production area (Maynard and Hopkins, 1999), but the frequency and severity vary considerably among areas and seasons. The disorder occurs more frequently in crown-set (7^{th} and 8^{th} node) fruit than in lateral-set (20^{th} node) fruit (Maynard & Hopkins, 1999). Similarly, Wien (1997) reported that hollow heart is mostly found in the first formed fruit on the plant, as a result of excess nitrogen fertilization and delayed harvests. In contrast, speculations that need confirmation are the water and fertilizer management, as well as temperature and pollination (Maynard and Hopkins, 1999).

Hollow heart is common under conditions of rapid fruit growth, in terms of rapid fruit-rind expansion relative to the interior parts of the fruit. According to Maynard and Hopkins (1999) there are no estimates of economic impact of hollow heart although it is certain to be significant. Hollow heart can be avoided by (a) selection of less susceptible cultivars, (b) cultural practices that control fruit growth rate and final fruit size e.g. ample plant populations, moderate N levels, and timely harvests.

Bottleneck is characterised by constricted growth at the stem end of the fruit. It is attributed to inadequate pollination either because of low bee populations or moreover poor conditions for bee activity, such as cold, wet, or windy conditions (Maynard & Hopkins, 1999). Sunburn is a result of a combination of high temperature and high light intensity in cucumber and pepper fruits. However, the exact cause of the disorder has not been determined for the watermelon fruit (Maynard & Hopkins, 1999). A study on empty seeds by Watanabe *et al.* (2002) suggested that formation of empty seeds was influenced by the cropping season, and that low temperatures promoted the formation of white empty seeds, whereas high temperatures encouraged the formation of brown empty seeds during the fruit development period.

12. Soil-less culture

In the past, the approach to soil fertility problems in crop production emphasized the importance of changing the soil to fit the plant (Marschner, 1995). Watermelons require a long growing season. In response to this, growers should choose early cultivars and use transplants (Lerner & Dana, 2001). Watanabe *et al.* (2001b) evaluated watermelons in different soilless culture systems and found the wet-sheet culture system as the best compared to rockwool culture, aerated deep-flow technique, and deep-flow without aeration. In all the systems tested, the main shoot and one lateral shoot per plant were allowed to grow and were trained vertically. Other lateral shoots were removed, and plants were pollinated manually allowing one fruit to set around the 20th node on the main shoot. The main and lateral shoots were pinched at the 30th and 20th nodes respectively. Marschner (1995) described three major constraints for plant growth on saline substrates namely (1) water deficit arising from the low water potential of the rooting medium, (2) ion toxicity associated with the excessive uptake mainly of Cl^- and Na^+, and (3) nutrient imbalance by depression in uptake and/or shoot transport and impaired internal distribution of mineral nutrients, and calcium in particular.

13. Conclusion

Various authors have mentioned the need for more watermelon research internationally. Wien (1997) ascribed the lack of research on watermelon, squash and pumpkin to their sprawling plant habits making them difficult study material in greenhouses, growth chambers, as well as in field trials. Nevertheless, for the Southern African region, and Namibia in particular, no research on plasticulture of watermelon has been done. Farmers are looking for a range of production methods that expresses diverse characteristics, which will fit into different niches of the farmers' livelihood strategies. In this view some basic aspects need to be investigated whereas some adaptive research, using results from other *Cucurbitaceae* species or different environments, needs to be done.

Understanding the limits of productivity within our environment, both in terms of yields and fruit quality factors such as sweetness, is one of the aspects that need attention. The relationship between salinity and fruit size as affected by cultural conditions has not been sufficiently investigated. There is a need for research in this field in order to determine the effects of mild salinity conditions on the yield and quality of watermelons. About 25% of the world's area of cultivatable soils has acute chemical problems (Marschner, 1995). Cultivation practices for intensive soil-less plant production that are economically wise for farming communities from elsewhere, such as those in Japan and some European countries, should be investigated for their adaptability to local conditions.

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Chapter 2

WATERMELON SEED GERMINATION AND VIGOUR AS AFFECTED BY DIFFERENT SALINITY LEVELS AND TEMPERATURE REGIMES

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Abstract

The aim of this study was to investigate the viability and vigour of seeds of watermelon cultivars Odem and Paladin, under different temperatures and NaCl salinity solutions. Treatments comprised of two cultivars, substrate moistened with 0, 4, 8 and 12 mS cm^{-1} NaCl solutions, five temperature ranges (10-15, 15-20, 20-25, 25-30 and 30-35°C) and two seed pre-treatments. Seeds were subjected to an accelerated ageing test to establish seed vigour and compared to non-aged seeds. Germination tests were conducted on a thermogradient plate under laboratory conditions. Good germination (>80%) was found with Odem at the 30-35°C temperature regime while Paladin germinated well between 15-35°C. Germination of both cultivars was inhibited at 12 mS cm^{-1} even at optimum temperatures, indicating that a critical maximum salinity level was reached. Non-aged seeds had significantly higher germination vigour than seeds subjected to accelerated ageing. Paladin germinated significantly better than Odem at 8 mS cm^{-1}. Paladin seems to be well-adapted to germinate under varying seedbed temperatures and at a relatively high salinity level.

Key words: germination, salinity, temperature, viability, vigour, watermelon

1. Introduction

In arid environments with an unpredictable climate, plant species should be adapted to germinate in conditions that give the best chance for seed emergence and plant establishment. The salinity of soil and irrigation water is a continuing threat to economic crop production in arid and semi-arid environments (Ghoulam & Fares, 2001), where salinity threatens to become, or already is, a problem (Sivritepe, Sivritepe & Eris, 2003). Salinity of the seedbed also affects germination (Souza & Cardoso, 2000; Sivritepe *et al.*, 2003), which is a crucial stage in the life of many plants, and salt tolerance during this phase is critical for the establishment of plants (Ghoulam & Fares, 2001). For several halophytic and glycophytic species, germination is inhibited by salinity (Ghoulam & Fares, 2001), either by creating an osmotic potential that prevents water uptake or by toxic effects of sodium and chloride ions on the germinating seed (Katembe, Ungar & Mitchell, 1998; Souza & Cardoso, 2000; Ghoulam & Fares, 2001; Soltani, Galeshi, Zeinali & Latifi, 2002).

Germination is a process dependent on a multiple of variables, including the integrity of the seed and its physiological state (Neto, Custodio & Takaki, 2001). Temperature is one of the most critical factors for germination of most seeds listed in the International Seed Testing Association (ISTA) rules (Basra, 1995). Various researchers have reported on several environmental factors, which are simultaneously affecting germination, but temperature is often regarded as the most important factor in determining the timing of germination (Hassel, Dufault & Phillips, 2001). Several studies carried out in different temperature regimes have shown a thermal dependence of seed germination on environment, and established temperature limits for optimum germination (Souza & Cardoso, 2000). A series of degenerative events taking place at seed physiological maturity reduces the survival capacity of seeds and leads to a loss of vigour and germination (Neto *et al.*, 2001).

Standardized methods have been developed by which reliable germination tests can be carried out in the laboratory at any time of the year (FAO, 1961). An accelerated ageing test was initially developed to estimate seed longevity in commercial storage, thus predicting the life span of different species, e.g. watermelon, cotton, beans, cabbage, sunflower, corn and sorghum (ISTA, 1999). Subsequently, it was evaluated as an indicator of seed vigour and has successfully been related to field emergence and stand establishment. The principle of the ageing test is to expose seed samples for a defined period of time to an unfavourable environment of high temperature and high seed moisture content (Kruse, 1999). Temperature has a profound influence on the development and ripening of seeds which may ultimately be reflected in seed viability (Basra, 1995). After the ageing period, high vigour seeds are expected to maintain a high germination potential, whereas low vigour seeds are expected to loose germination potential (Kruse, 1999). It is well known that seed quality losses are increased by high humidity and temperature during storage.

One of the greatest hazards in agriculture is sowing seed with no capacity to produce an abundant crop of the required cultivars (ISTA, 1999). Seeds are very important in agriculture, as they serve both as the basic propagule and the harvested product of a crop (Bryant, 1985). Watermelons are annuals propagated from seed, and so the producer needs seed with a good germinability. High quality seed is the basis for higher agricultural productivity that embraces all the physical, biological, pathological and genetic attributes, which contribute to the final yield of a crop (Basra, 1995). It is therefore relevant to consider how many seeds in a given batch will germinate and how long they will take to germinate under field conditions (Bryant, 1985). Watermelon cultivars Odem and Paladin have not been tested under local conditions. In this experiment, we studied some ecophysiological aspects of watermelon seed germination, such as the influence of temperature and salinity, as well as seed vigour under laboratory conditions at Welgevallen, an experimental farm of Stellenbosch University.

2. Material and methods

Temperature and salinity effects on germination were investigated using seeds of two watermelon cultivars (Odem and Paladin) that had been subjected to accelerated ageing (aa) or not. In the aa treatment seeds were placed on wire mesh screens and exposed to humid conditions at 45°C for 144 hours (ISTA, 1999). Twenty seeds were arranged in four quarters of a glass petri dish. Five seeds served as an experimental unit, placed on two layers of filter paper (Schleicher and Schuell, No. 595, Dassel, Germany) moistened with 10ml of NaCl solution and sealed with parafilm. In each petri dish there were five aa treated and 5 non treated seeds of each cultivar. Twenty petri dishes were placed on an aluminium thermogradient plate, arranged in five groups of four petri dishes each per temperature range (10-15; 15-20; 20-25; 25-30; 30-35 °C) as illustrated in Figure 1.

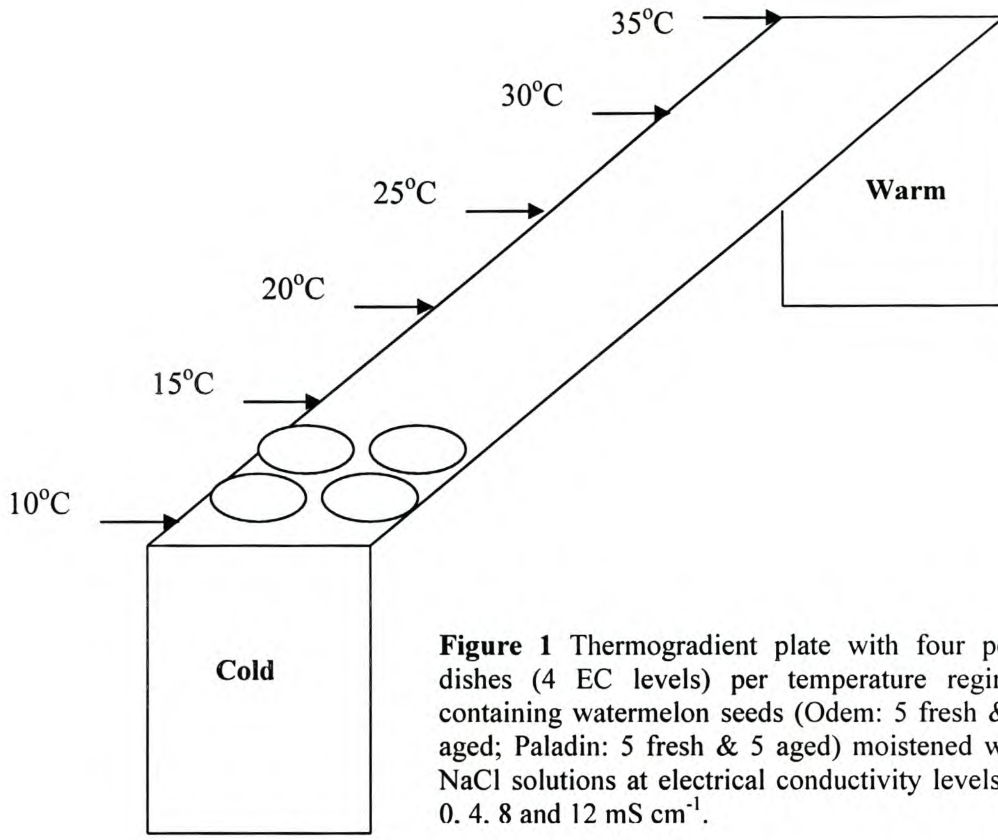

Figure 1 Thermogradient plate with four petri dishes (4 EC levels) per temperature regime, containing watermelon seeds (Odem: 5 fresh & 5 aged; Paladin: 5 fresh & 5 aged) moistened with NaCl solutions at electrical conductivity levels of 0. 4. 8 and 12 mS cm^{-1}.

Four EC treatments (NaCl solutions at 0, 4, 8 and 12 mS cm^{-1}) were applied to the four petri dishes per temperature range and these dishes were rotated (clockwise) within each range every 12 hours. The thermogradient plate's one end was placed in a warm-water bath set at 55°C to provide heat; while a refrigerated bath (Techne RB-5) at 0°C was in contact with the other end of the thermogradient plate. This experiment (2x2x4x5) was conducted under light conditions and repeated twice. The temperature of the thermogradient plate was recorded and controlled every 12 hours at various positions as indicated in Figure 1. Room temperatures were also monitored.

Radicle protrusion (1 mm) was used as germination criterion, and seeds were counted and removed every 12 hours over a period as described by ISTA (1999), from which maximum germination was determined. For each treatment the mean germination time (MGT) was calculated using the equation: $MGT = \sum Dn / \sum n$, where n is the number of seeds germinating on D-day, and D is the number of days counted from the beginning of the test (Ellis & Roberts, 1981).

Data in the experiment were logit transformed and ANOVA was performed for all response variables, using SAS Institute (1999). Statistical significance was assessed at $p<0.05$ (See Appendix). Student's t-Least Significant Difference was calculated to compare treatment means.

3. Results

Germination: Germination was affected by a significant ($P=0.014$) interaction between cultivar and temperature (Figure 2), cultivar and salinity ($P = 0.0087$; Figure 3) as well as by a significant ($P= <0.0001$) ageing, temperature and salinity interaction (Figure 4).

It can be seen in Figure 2 that the percentage germination for Odem increased from 60 to 83%with temperatures increasing from 10 to 35 ^{o}C, while it varied from 78% to 90% for Peladin with temperatures between 15 ^{o}C and 35 ^{o}C. Interestingly, the highest germination percentage for Paladin was at 15-20^{o}C, while no germination was recorded at the lower temperature regime (10-15^{o}C), where 60% of Odem seeds did germinate.

Both cultivars failed to germinate at 12 mS cm^{-1} (Figure 3). The highest percentage germination for Odem and Paladin was 87% and 93% respectively at 4 mS cm^{-1}. At 8 mS cm^{-1} Paladin germinated 31% better than Odem, although this difference was not statistically significant. Apart from aged seeds in distilled water (EC 0), none of the other treatment combinations showed signs of germination at 10–15^{o}C (Figure 4). Our results showed consistent good germination with non-aged (normal) seeds in 4 mS cm^{-1} solutions at temperatures higher than 20^{o}C.

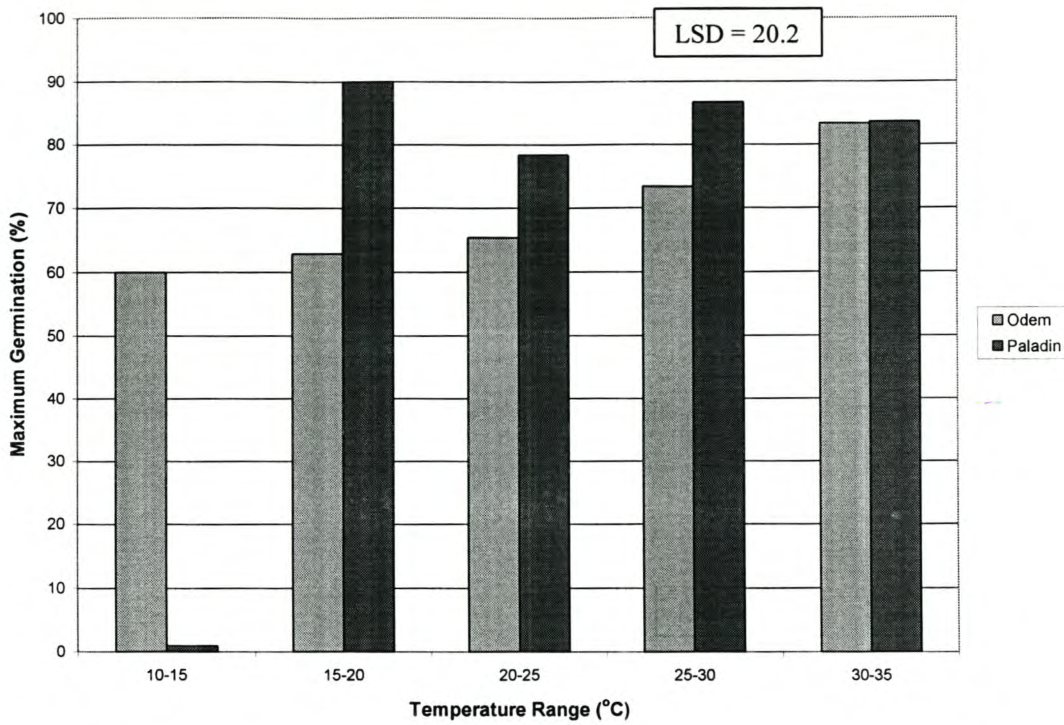

Figure 2 Maximum germination percentages of Odem and Paladin watermelon seeds at different temperature ranges.

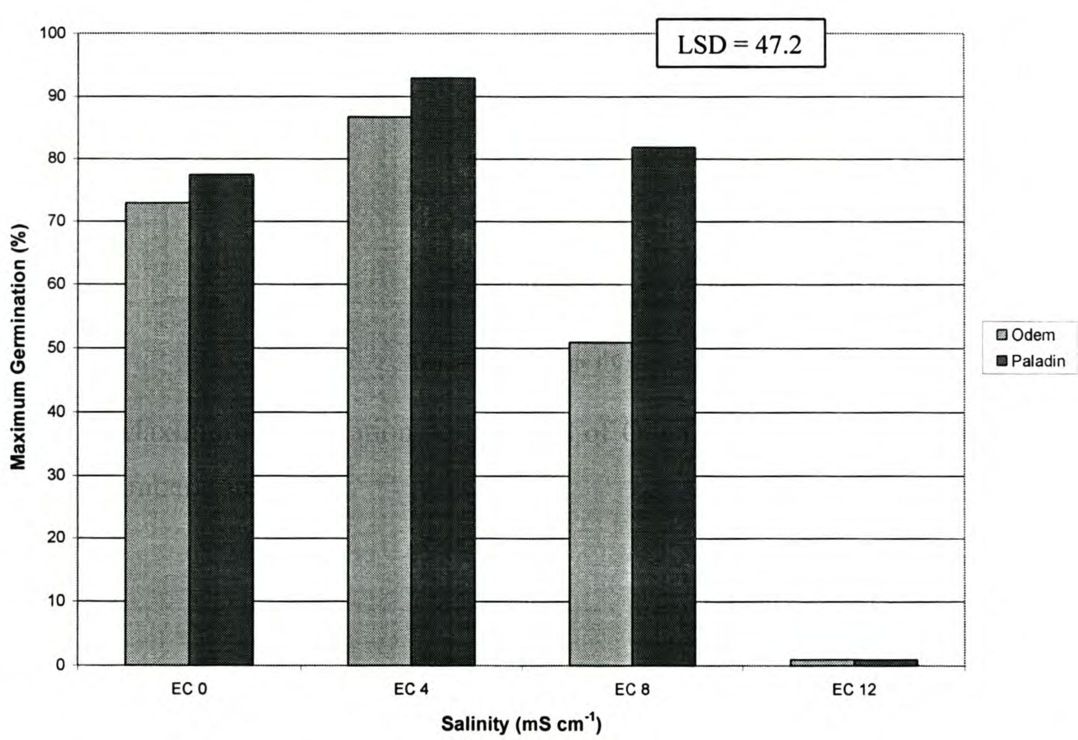

Figure 3 Maximum germination percentages of Odem and Paladin watermelon seeds at different salinity levels

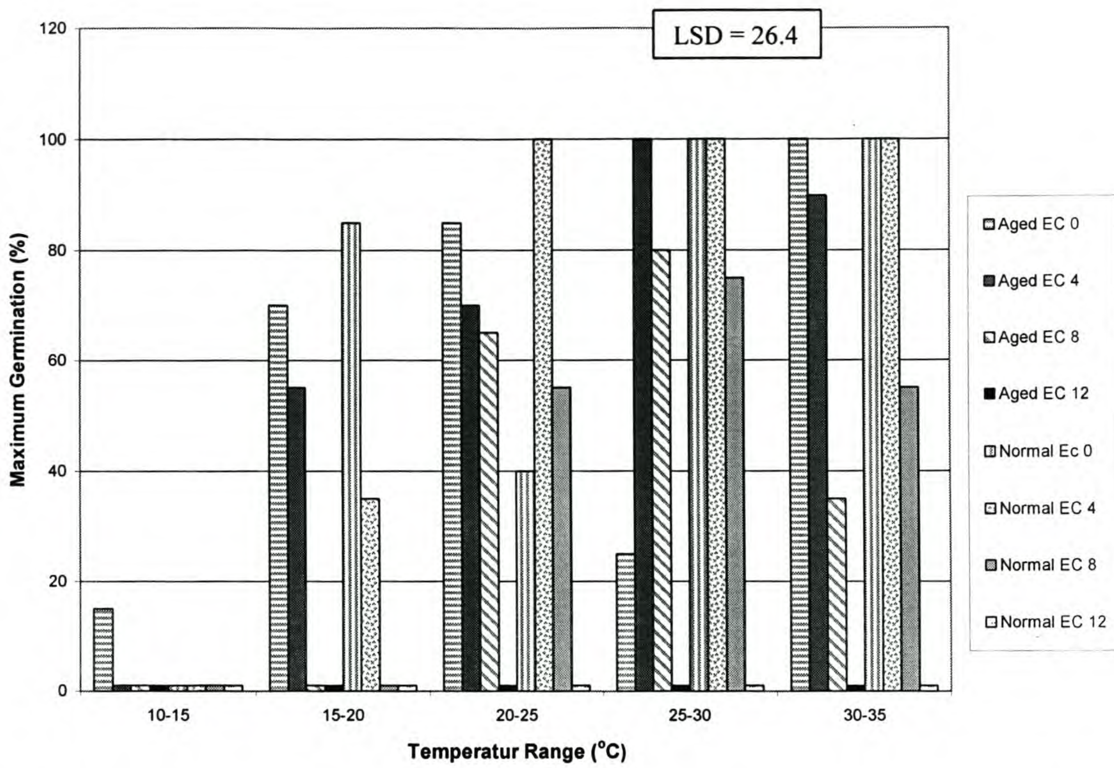

Figure 4 Temperature, salinity and ageing affecting the germination of watermelon seeds

Mean germination time (MGT): The mean germination time was affected by a significant ($P= 0.0071$) interaction between cultivar, salinity and ageing (Figure 5) and an interaction ($P= 0.0089$) between ageing, temperature and salinity (Figure 6).

The interaction, illustrated in Figure 5 clearly shows that at EC levels of 4 mS cm^{-1} and lower, both cultivars reacted in the same negative manner on seed ageing, both with longer mean germination times. However, at an EC of 8 mS cm^{-1}, ageing of Paladin seed had no negative effect compared to a significant longer MGT with aged Odem seeds.

A significant aspect of the interaction between pre-treatment, temperature and salinity is the accumulative detrimental effects of low temperatures, seed ageing and high salinity levels (Figure 6). No germination occurred below 20°C at salinity levels of 8 mS cm^{-1} and higher (Figure 4) and seed ageing caused a significant longer MGT at 20-25°C. This negetive effect disappeared at the higher temperatures (Figure 6).

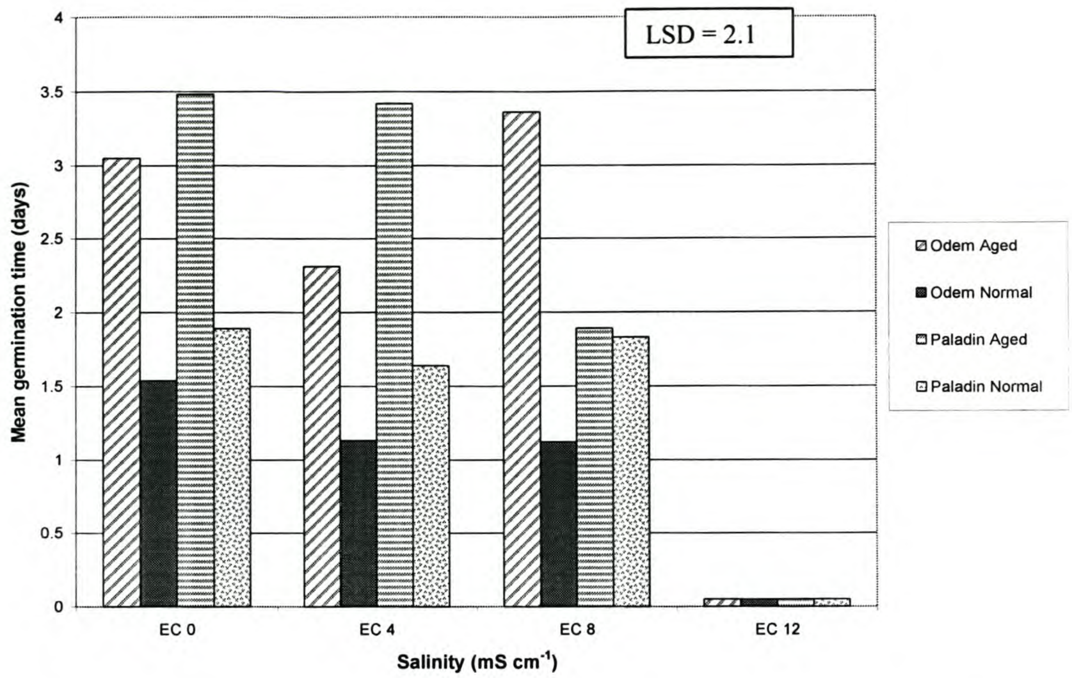

Figure 5 The effects of salinity on the MGT of aged and non-aged Odem and Paladin watermelon seeds.

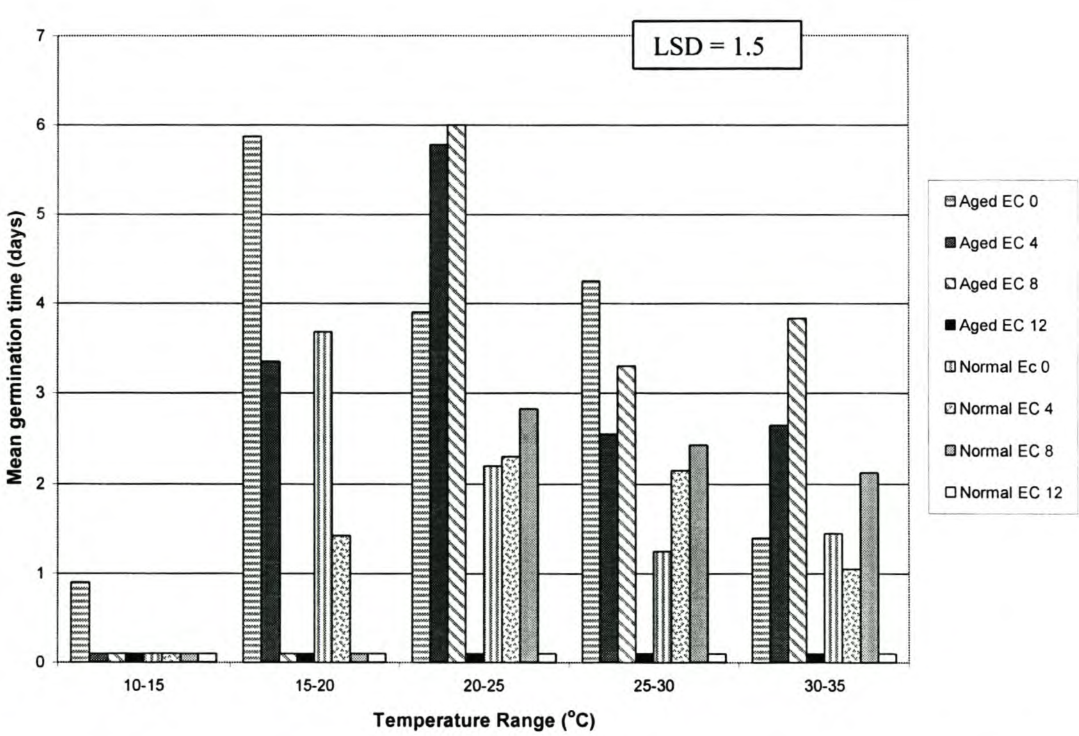

Figure 6 Mean germination time of aged and non-aged watermelon seeds under different temperature regimes and salinity levels.

4. Discussion

Since seed germination is a critical stage in a plant's life cycle (Huang, Zhang, Zheng & Gutterman, 2003), growers try to optimise conditions during germination to establish a crop. It is known that high vigour seeds offer faster germination than low vigour seeds and by planting at the right stage, optimum temperatures should prevail to ensure maximum germination percentages. The germination needs of the two tested watermelon cultivars is important to producers, but of equal value is information relating to the vigour of a given seed lot (Hassell *et al*., 2001). Apart from temperature, it is known that salinity can also affect germination. However, the interaction between different contributing factors is often ignored. The important interactions found in this study showed that single factors should not be evaluated in isolation.

The germination percentage differed between the two tested cultivars, depending on temperature (Figure 2) and salinity (Figure 3). It is well known that watermelons should only be planted in soil with temperatures higher than 15°C, as was stated by Hassell *et al.* (2001). Using a minimum viability of 80% germination as norm, this guideline seems to be correct (Figure 2). However, growers who need early cultivars should keep the fact that 60% of Odem seeds germinated at 10-15°C in mind. On the other hand, Paladin germinated significantly better than Odem in the relatively cool zone of 15-20°C.

Both cultivars failed to germinate at 12 mS cm^{-1} (Figure 3). This may be an indication that watermelons are sensitive to saline conditions. Only Paladin germinated better than 80% at an EC of 8 mS cm^{-1}. The fact that the mean germination time did not differ (both <2days) between aged and fresh Paladin seeds at an EC of 8 mS cm^{-1} (Figure 5) may be a further indication that this cultivar is better adapted to saline conditions than Odem. Seed vigour is related to the speed of germination (Bryant, 1985). In addition, the chance that seedlings may be attacked by pathogens is limited with a shorter germination time. Salinity is a common problem in the arid areas of southern Africa. The mechanism of cellular adaptation of plants growing in saline environments is the control of ion movement (Ramos, Lopez & Benlloch, 2004), a characteristic that should receive more attention by plant breeders.

The interaction between temperature, salinity and seed ageing (Figure 4), illustrates that 100% germination can be expected in the temperature range of 20 to 35°C, only with the EC of the seed environment at 4 mS cm^{-1}, using fresh seed. The importance of using fresh seed is illustrated due to extremely long germination times needed for aged seed, especially at 20-25°C (Figure 6). The fact that some germination (<20%) of aged seed was found at 10-15°C (Figure 4) and that the mean germination time for this treatment was extremely short (Figure 6) is difficult to explain and does not fit into the general pattern found. It should be kept in mind that only five seeds were used as experimental unit and that one seed represented 20%. It is clear that more research is needed in this field. As was suggested by Hassell *et al* (2001), a thermogradient plate proved to be extremely useful for these types of studies. Using petri dishes, placed on the thermogradient plate in this study, it was possible to illustrate important interactions between cultivar, salinity, temperature, and seed ageing.

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Chapter 3

INFLUENCE OF DIFFERENT SALINITY LEVELS AND PRUNING METHODS ON YIELD AND QUALITY OF WATERMELON (*CITRULLUS LANATUS*) GROWN IN A GREENHOUSE.

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Abstract

Salts exert specific effects on crops which directly influence yield. Pruning and training of plants aim to obtain optimum yield and quality of produce. An experiment to evaluate the effects of different pruning systems and salinity levels on watermelon (*Citrullus lanatus*) yield and quality was done in a plastic tunnel, using a drain-to-waste fertigation system at Welgevallen, an experimental farm of the Stellenbosch University. Two shoots per plant, grown in a soilless potting mix, were trained vertically in a V-shape to produce one fruit each. Leaf numbers per shoot were manipulated to have a high and a low leaf density. Application of a high salinity (EC 4 mS cm^{-1}) nutrient solution significantly reduced fruit and sugar yields of the two cultivars used (Odem and Paladin). Changing the nutrient solution from a low salinity level (EC 2 mS cm^{-1}) during vegetative growth to EC 4 after pollination, did not reduce fruit mass, but significantly increased the sugar yield of Odem, the icebox-type cultivar. Fruit mass was not significantly affected by pruning systems, but mild leaf density per plant and an increased salinity at the fruit development stage increased rind firmness and rind thickness.

Keywords: Fruit quality, pruning, salinity, watermelon, yield

1. Introduction

In many Mediterranean countries where large areas of greenhouses are planted with melon, a lot of research on pruning methods has been carried out (Jani & Hoxha, 2002). During the hot summer months in the Western Cape, field-grown vegetables are well supplied to fresh markets. Only a few tunnel grown vegetables with good yield and quality can compete under these conditions. The demand for various types of watermelon (*Citrullus lanatus*) is on the increase in most parts of the world. In the last decade, there has been a strong tendency in many watermelon markets to shift from large fruits toward mini or icebox fruits (Edelstein & Nerson, 2002). Since the watermelon is an indigenous plant, well adapted to tropical and southern African conditions (Korkmaz & Dufault, 2002), it should be used as a source of income and aid to diversify local production. In Greece, early watermelon is a profitable crop for export provided that weather conditions are favourable in early spring (Passam, Rekoumi & Nikolopoulou, 2002).

According to Nayar and More (1998), muskmelon, cucumber and watermelon are the most extensively grown crops among the cucurbits. Production systems should provide conditions allowing watermelon fruit to develop with an acceptable sweetness, taste and size, characteristic to the cultivar (Wien, 1997). The objective of trellising and pruning of plants is to obtain the largest possible high quality yield in greenhouses. Salinity is an important factor affecting the lifespan of agricultural systems (Marschner, 1995). Using soil-less production systems, salinization of soil due to saline irrigation water may be prevented. In addition, growers should accept the challenge to substantially increase production to meet the demands of rapidly growing populations, especially in developing countries. Under mild climatic conditions, out of season vegetables are cultivated in low cost greenhouses that lack the sophistication found in high technology systems of the Northern European glasshouse industry (Passam *et al.*, 2002).

Despite the evident importance of watermelon species, hardly any research has been done under intensive production systems within the African context, and none in the Southern African region. Overall, published data dealing with the growth and yield response of watermelon to salinity and pruning is limited. There is a need to investigate the reaction of watermelons to moderate salinity conditions and pruning methods, in order to optimize production in areas with saline water sources and limited land for cultivation. On this basis, experimental studies were aimed to evaluate the effects of different salinity levels and pruning methods on watermelon yield and quality under greenhouse conditions in South Africa.

2. Material and Methods

This study was done at the Welgevallen Experimental farm of the Stellenbosch University. Seeds of watermelon cultivars Odem and Paladin, obtained from Mayford Quality Seeds Pretoria, were planted at a depth not exceeding 1 cm. The local Welgevallen potting mix of composted pine bark and vermiculite was used to fill seedling trays. The trays were kept in a dark room for three days to germinate and were then moved to a seedling greenhouse for a three-week transplant establishment. The seedlings were fertigated twice a day with a diluted nutrient solution (0.4 mS cm^{-1}). The seedlings were transplanted into 10 L black polyethylene bags filled with pine shavings as substrate (28 January 2004) and placed in a single-span plastic tunnel with a roof about 2 metres high and the floor lined with white polyethylene plastic. Although the greenhouse had three side ventilation openings and netted vents at both ends above the doors, the greenhouse roof was sprayed with $Ca(OH)_2$ in order to form a layer of lime to limit the greenhouse effect on hot days.

The nutrient solution was automatically applied using a drain-to-waste system set at 7 – 8 cycles a day, depending on weather conditions. The electrical conductivity (EC) of the nutrient solution was maintained at about 2 mS cm^{-1} for the low EC application and at about 4 mS cm^{-1} for the high EC treatment (Table 1). The pH and EC of the nutrient solution was recorded every week both in the water tanks and in the production area by using a portable EC and pH meter. The black irrigation piping within the greenhouse was painted white to avoid absorption of heat, thus cooling the nutrient solution.

Table 1 Macro and micro nutrient sources and levels used for Electric conductivity (EC) levels of 2 and 4 mS cm^{-1}

Nutrient Source	Nutrients added (g/1000L)	
	EC 2	EC 4
KNO_3	55	55
K_2SO4	348	348
KCL	149	149
MAP	115	115
Mn: Manganese sulphate	2.23	2.23
Zn: Zinc sulphate	1.47	1.47
B: Solubor	1.51	1.51
Cu: Copper sulphate	0.20	0.20
Mo: Sodium molibdate	0.13	0.13
NaCl	0	1168
$Ca(NO_3)_2$	800	800
$Mg(NO_3)_2$	448	448
Fe: Libfer (Fe-EDTA)	6.54	6.54

A randomized block design was used with two cultivars, three pruning systems and three salinity combinations factorially (2x3x3) arranged using three replications. Four zigzag rows of 21,6m length with interplant spacing of 0.8m were used in a 6m x 24m plastic tunnel. A single plant was used as an experimental unit. The trellising distance between a lower and upper horizontal training wire was 1.70 m.

One fruit was allowed to develop on the main stem where after it was pinched and two side shoots were allowed to develop. Flowers were pollinated manually by using at least one male flower. Where a pollinated fruit aborted, a second flower was pollinated on the same vine. The main stem was pinched at the 10^{th} to 14^{th} nodes, depending on where the fruit set. The two side shoots were trained vertically in a V-shape on plastic twine. All other shoots were removed on a regular basis. This was done when and as soon as the side shoots were observed, in a manner to prevent large pruning wounds, and to limit competition for assimilates. Three pruning systems were used in this trial:

a) Severe pruning, representing excessive pruning of leaves and vines, allowing only one leaf to grow per node on the vertically trained vines

b) Mild pruning, represented three leaves on each node of the two trained vines

c) Mixed pruning, was such that a mild pruning was maintained on the one vine, and an excessive pruning of leaves was done on the other vine.

Three different salinity treatments were applied:

a) Salinity 2/2 – Plants received a nutrient solution application at 2 mS cm^{-1} before and after the fruit development stage (FDS), which represented a low salinity treatment.

b) Salinity 2/4 – Plants were fertigated with 2 mS cm^{-1} nutrient solution before the FDS, and the application was changed to 4 mS cm^{-1} during the fruit development period (FDP).

c) Salinity 4/4 –Plants within this treatment received a constant 4 mS cm^{-1} nutrient solution throughout the entire trial period.

All above-ground plant parts were harvested, and both fresh and dry (70°C for 72 h) mass of stems, leaves and petioles before and after the fruit bearing nodes were recorded. Fruit mass was recorded at harvest and the fruits were then stored at 25°C for three weeks and mass loss determined. Fruit circumferences were measured using a tape measure and the radius measured while fruits were cut in half. The fruit volume was then calculated using the following formulae, depending on the shape index assigned to each fruit:

Shape index 1 (ellipsoid form) – $V= 4\pi ab^2/3$, where a = 0.5 length and b = 0.5 width;

Shape index 2 (sphere form) – $V = d^3/6$, where d = diameter;

Shape index 3 (cone form) – $V = r^2h\pi/3$, where r = radius and h = length

Using the volume of each fruit class to individual fruits, the density of each fruit was calculated as a function of mass over volume.

Rind firmness was measured using a densimeter (Type No.5) at three different longitudinal positions on the rind. Similarly flesh firmness was measured inside the fruit by cutting the fruit in longitudinal half. The rind thickness was measured using a ruler. At the same positions measured for flesh firmness, the edible part of the tissue was removed and hard-pressed inside a dish and the fruit juice soluble solids content was measured with an Ataco hand refractometer in °Brix. Sugar yield was obtained by the function of TSS and fruit mass. The number and mass of brown and white seeds were recorded. The sum of fruit texture, firmness and sugar yield was divided by the shape index to calculate the fruit quality index. Plants were assigned with a disease index value of 1 – 5, depending on the severity of stem and leaf disease attack. A high value represented a high incidence of disease.

The data from the experiment was subjected to ANOVA (analysis of variance) and regression calculations to determine statistical differences between treatments as by SAS Institute (1999), Shapiro & Wilk (1965) and Snedecor & Cochran (1967). Findings on other cucurbit crops have been used to compare our results due to limited reports on the reaction of watermelons to pruning and salinity.

3. Results

Fruit mass and volume: Though no interaction was found between cultivars and pruning systems ($P<0.05$), the interaction between cultivars and salinity levels on fruit mass was significant ($P<0.05$). Figure 1 shows that the fruit mass of Paladin at EC 2 mS cm^{-1} was significantly higher (5.2 kg) compared to Odem (3.5 kg), whereas changing the nutrient solution to EC 4 mS cm^{-1} (2/4) at the FDS, no significant difference was found between cultivars. Equal fruit volumes were obtained from plants at the low EC nutrient solution (2/2) and where the EC was increased (2/4) during the FDS, but volumes were >50% smaller with 4/4, the high EC treatment (Table 2). There were no fruit mass loss differences during the three weeks storage period (results not shown).

It is further shown in Table 2 that no significant differences were found between means of fruit width and fruit radius for salinity 2/2 and 2/4 treatments. Fruit circumference was much higher at low salinity levels compared to the high salinity treatment and the increased EC level treatment. In all fruit size components, the high salinity treatment (EC 4/4) resulted in significantly lower values than the 2/2 and 2/4 treatments (Table 2). The fruit size components were unaffected by pruning treatments and cultivars. Higher TSS values were found with Odem, the small icebox cultivar (Table 2).

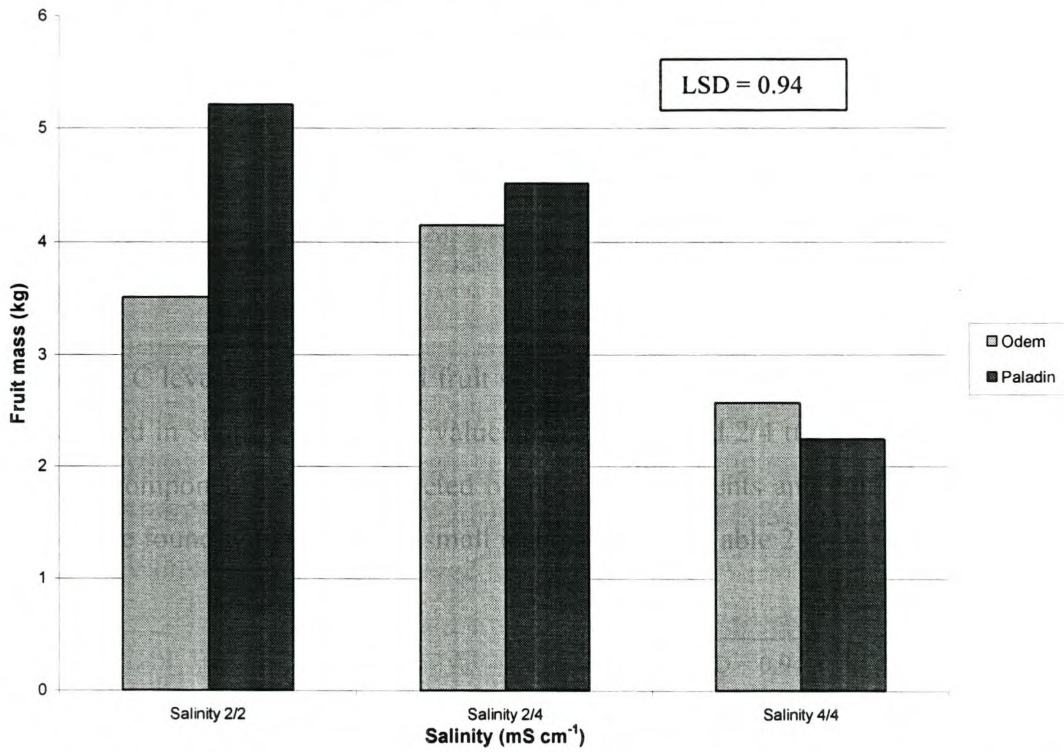

Figure 1 Fruit mass of Odem and Paladin watermelon cultivars affected by salinity treatments.

Table 2 Effects of different cultivars, salinity levels and pruning methods on fruit dimensions (cm) and fruit total soluble solids (TSS) of watermelon

Treatment	Parameters				
	Fruit Circ	Fruit radius	Fruit volume	Fruit width	TSS (^oBrix)
Odem	54.958	8.748	4255.9	17.494	7.397
Paladin	57.530	9.158	3204.6	18.313	6.093
LSD	ns	ns	ns	ns	0.863
Salinity 2/2	60.828	9.683	4546.3	19.362	6.974
Salinity 2/4	59.422	9.458	4514.0	18.916	6.681
Salinity 4/4	48.100	7.657	2067.2	15.312	6.532
LSD	5.785	0.93	1044.7	1.842	ns
Severe pruning	57.706	9.186	3628.4	18.369	6.713
Mild pruning	55.733	8.872	4004.2	17.741	6.553
Mixed pruning	55.444	8.825	3581.7	17.649	6.931
LSD	ns	ns	ns	ns	ns
CV	15.046	15.033	40.877	15.046	22.974

Rind firmness: Significant ($P<0.05$) interactions between cultivars and salinity treatments (Figure 2) and leaf densities and salinity treatments (Figure 3) affected fruit rind firmness. The interaction, as illustrated in Figure 2, showed that Paladin produced stronger rinds than Odem at relatively low EC treatments (2/2 and 2/4), but this was not found at the high EC treatment (4/4) where the rind firmness of Paladin dropped to a level even lower than that found with Odem. In Figure 3, the 2/2 and 2/4 salinity treatments produced higher rind firmness values than the 4/4 treatment, only where severe and mild leaf pruning were applied. With different pruning densities on the two vines per plant, no significant difference was found between the salinity treatments. Rind thickness (Figure 4) was affected in a similar way as rind firmness (Figure 2) by a salinity x cultivar interaction. Rind thickness (Figure 5) was affected in a similar way as rind firmness (Figure 3) by a salinity x pruning interaction.

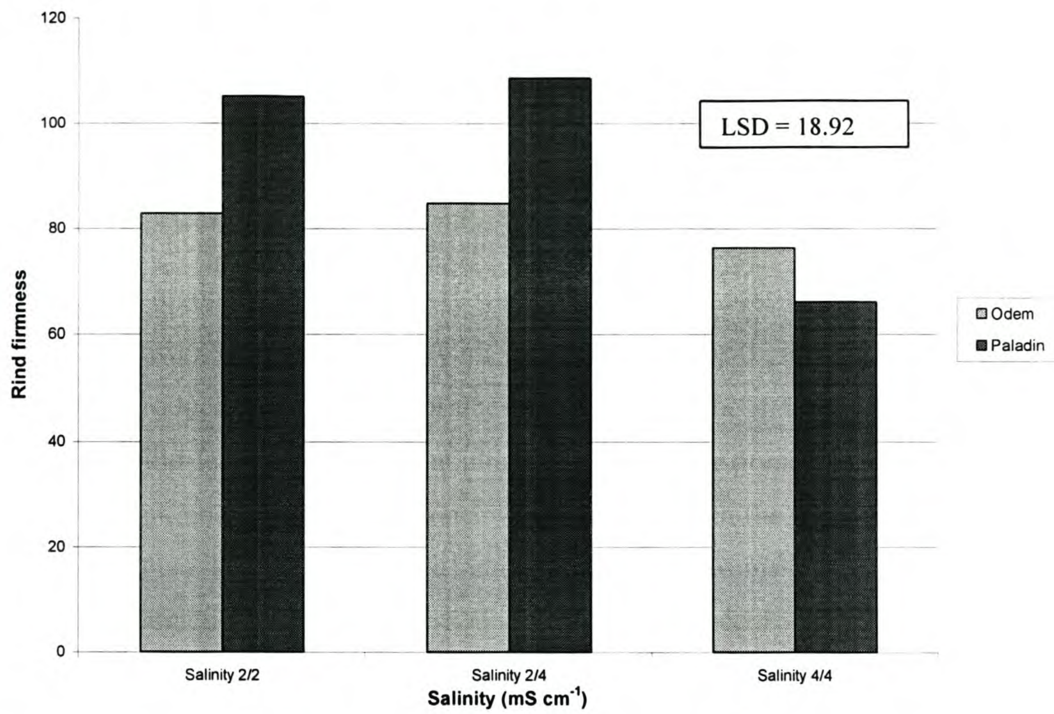

Figure 2 Salinity effect on rind firmness of Paladin and Odem watermelon cultivars.

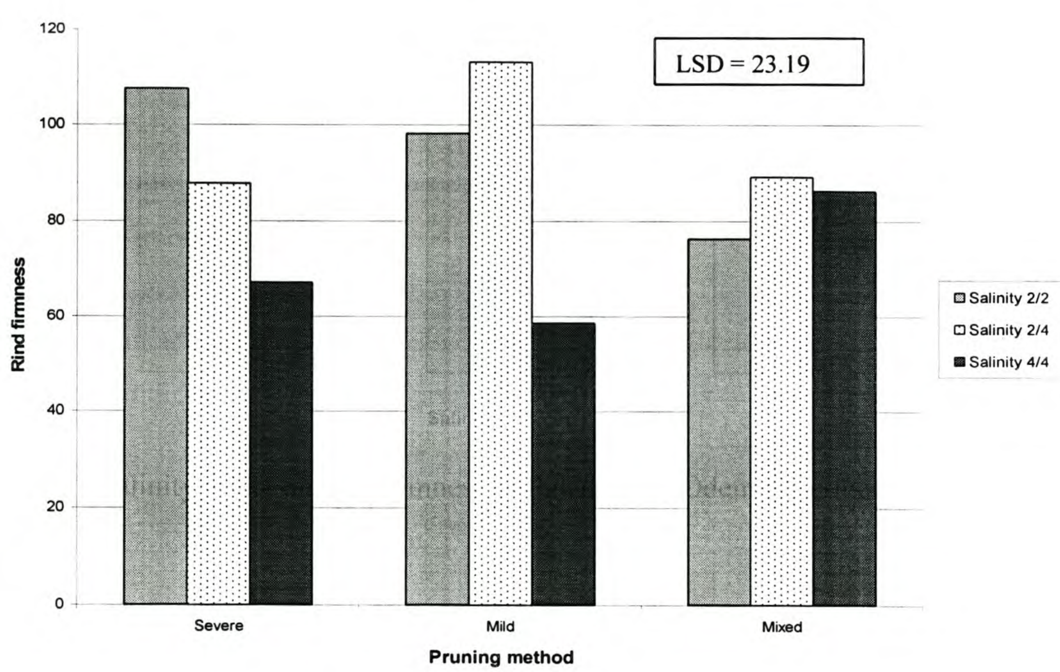

Figure 3 Pruning and salinity interaction on rind firmness in watermelon.

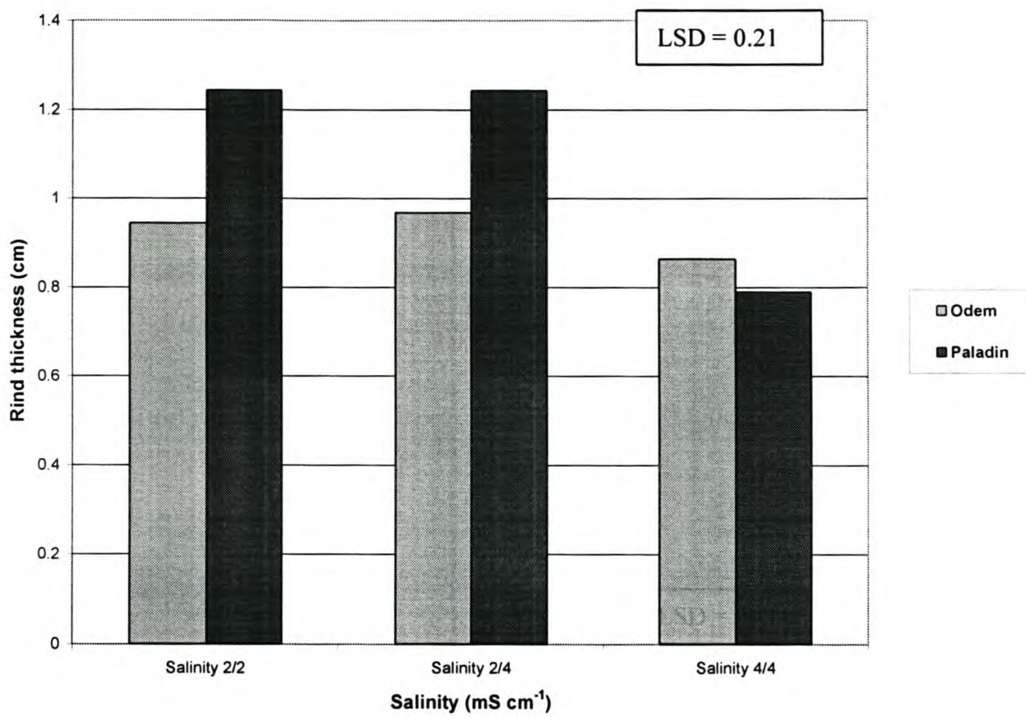

Figure 4 Salinity effect on rind thickness of Paladin and Odem watermelon cultivars.

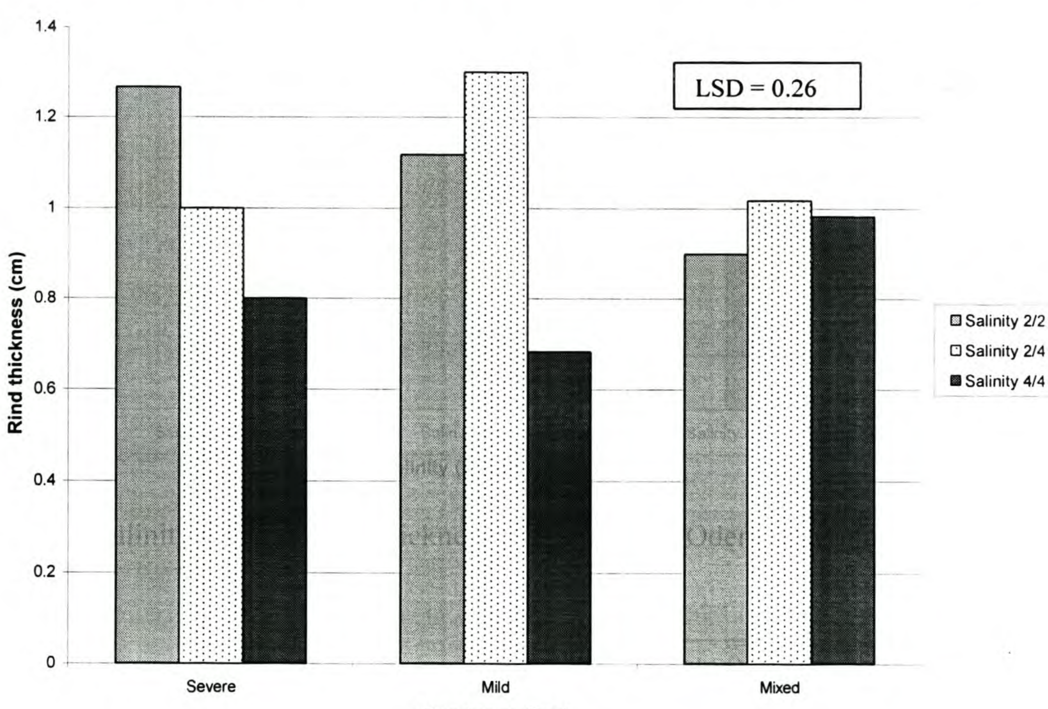

Figure 5 Pruning and salinity interactions on the rind thickness of watermelons.

Sugar yield: Paladin produced a significantly higher sugar yield ($P < 0.05$) than Odem at the low salinity treatment (Figure 6). No significant differences in sugar yield were found at the high (4/4 mS cm^{-1}) and combined (2/4 mS cm^{-1}) salinity treatments.

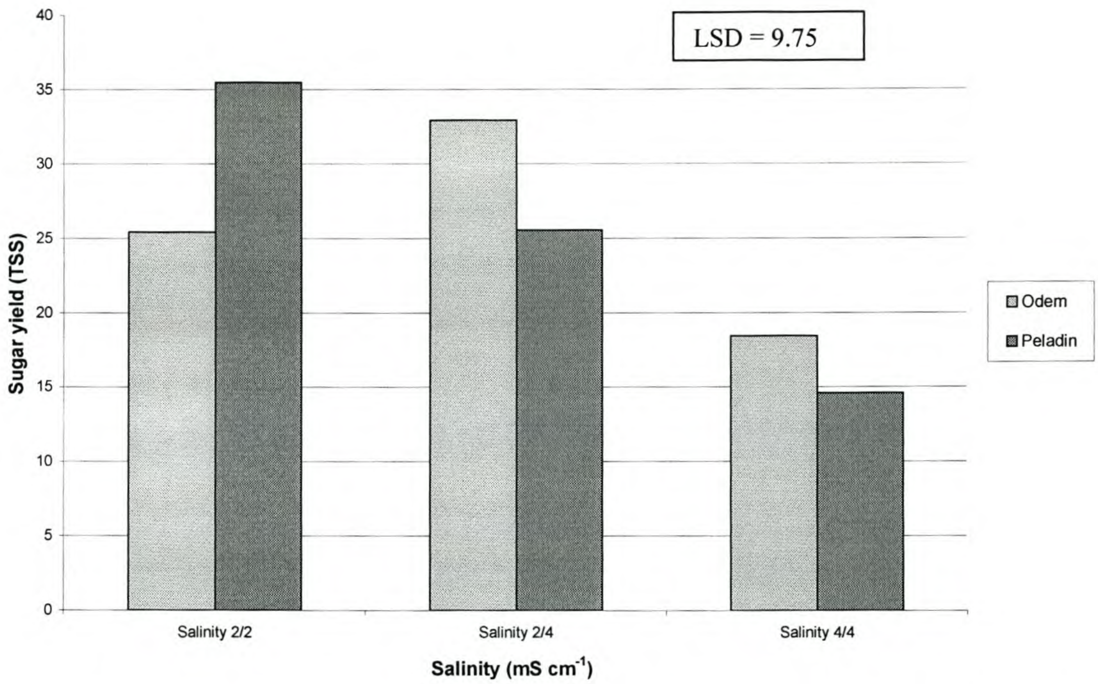

Figure 6 Effect of salinity on sugar yield of Odem and Paladin watermelon cultivars.

Seed production: Our results show that mild pruning of plants produced a greater total seed mass and more brown seeds than fruits of severely pruned plants (Table 3). The high salinity nutrient solution produced fruits with significantly less white seeds only with Paladin. Both cultivars produced fruits with about the same white seed numbers at the 2/2 and 2/4 salinity treatments (Figure 7). The cultivars had different brown:white seed ratios with no differences in total seed mass (Table 3).

Table 3 Effect of different cultivars, salinity levels and pruning methods on watermelon seed production under greenhouse cultivation at Welgevallen Experimental Farm

Treatment	Brown Seeds	Seed ratio (brown:white)	Total Seed mass (g)
Odem Cultivar	289.85	6.286	16.811
Paladin Cultivar	284.41	10.727	16.484
LSD	ns	4.161	ns
Salinity 2/2 mS cm^{-1}	302.67	7.078	15.736
Salinity 2/4 mS cm^{-1}	304.33	8.472	16.760
Salinity 4/4 mS cm^{-1}	252.29	10.186	17.484
LSD	ns	ns	ns
Severe pruning	222.18	6.288	11.462
Mild pruning	367.89	10.974	24.170
Mixed pruning	267.56	8.257	14.013
LSD	88.097	ns	9.896
CV	44.911	87.273	87.015

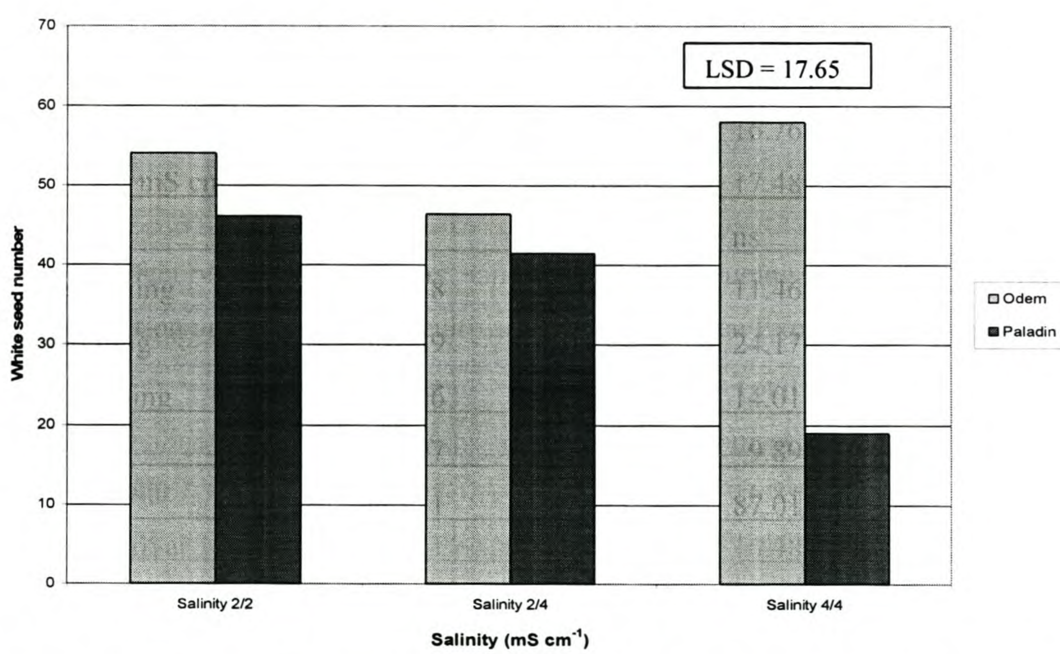

Figure 7 Odem and Paladin cultivar white seed numbers as affected by salinity treatments.

Stem and leaf disease: Figure 8 shows a severe stem disease index for Odem at constant low and high salinity treatments, an index much higher than at the combined (2/4) salinity treatment. The leaf disease index on Paladin was not significantly affected by the salinity treatment (Figure 7).

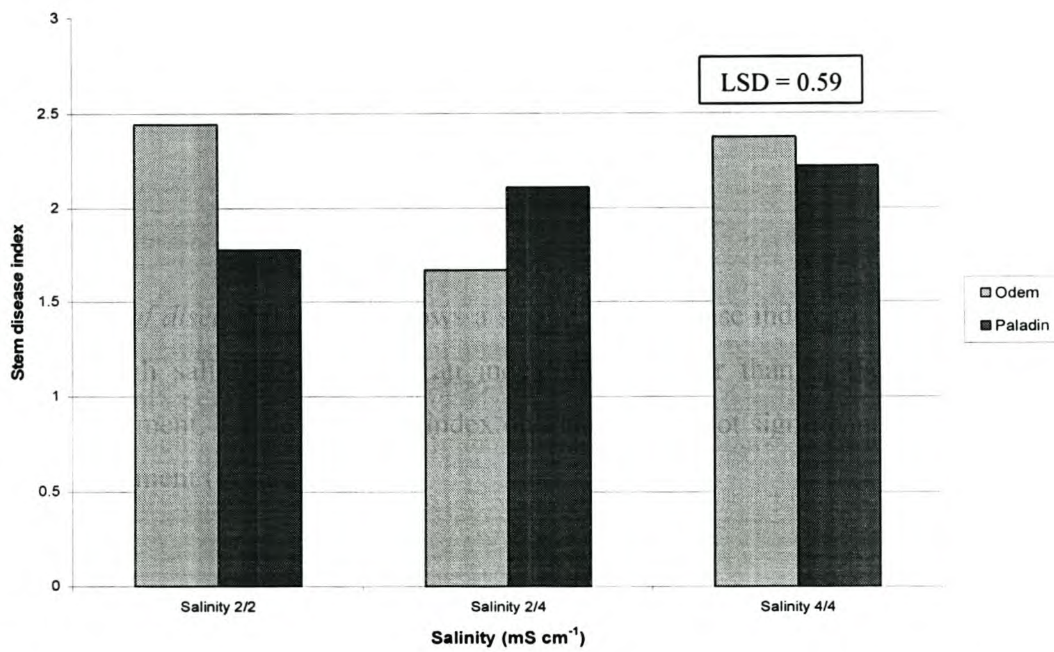

Figure 8 An interaction between cultivars and salinity treatments affecting the incidence of watermelon stem diseases

Fruit quality index: An interaction between pruning methods and salinity treatments affected the fruit quality index as illustrated in Figure 9. With the mixed pruning system, salinity treatments did not affect fruit quality. The best fruit quality indexes were found with the 2/2 and 2/4 salinity treatments where the mild and severe pruning systems were used. The detrimental effect of the high EC treatment on fruit quality was best shown with the mild pruning system (Figure 9).

Stepwise regression analysis showed that variation in rind firmness (R^2 = 99.8%) was attributed by rind thickness and fruit density ($P < 0.001$). Flesh firmness was negatively correlated (R^2 x 100 = 17.6%) to FDP ($P = 0.03$) and fruit mass ($P = 0.009$). However, rind thickness was positively correlated (R^2 x 100 = 35%) to fruit mass and sugar yield. Sugar yield was calculated as a function of TSS and fruit mass and was correlated to leaf dry weight and disease index. Results showed positive correlations between sugar yield and leaf dry weight and total foliage distal to the fruit bearing node (results not shown). Leaf and stem disease indexes were negatively correlated to sugar yield (R^2 x 100 = 9.2%, $P < 0.05$).

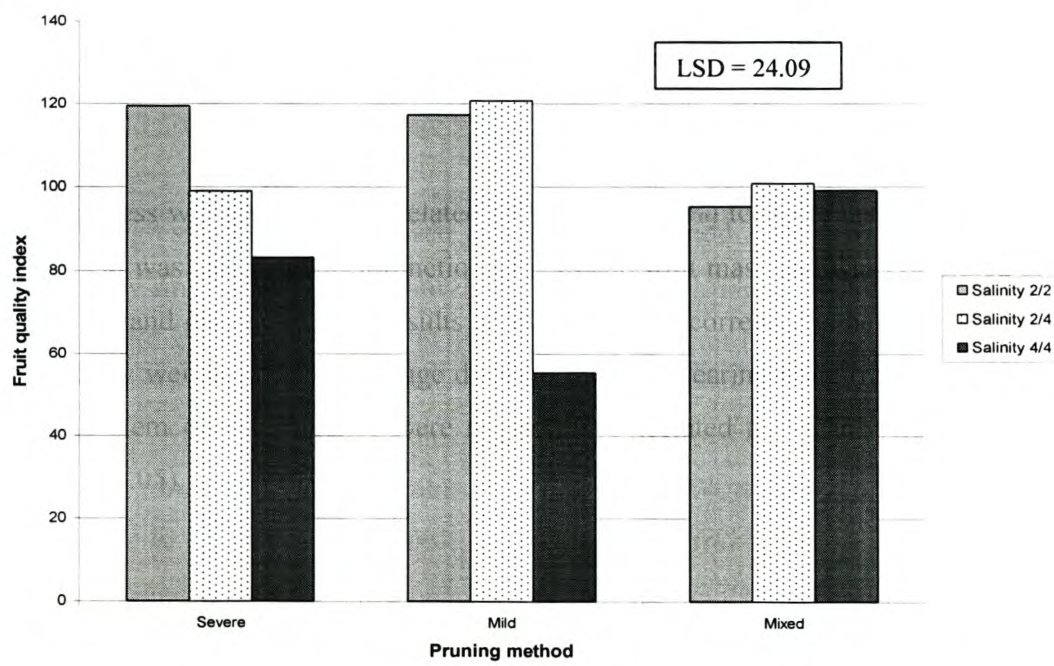

Figure 9 Fruit quality index of watermelon as influenced by salinity levels and pruning systems.

4. Discussion

4.1 Salinity effect on fruit yield

Our study confirms results obtained by other workers on the sensitivity of watermelon and other cucurbits to salinity. It is known that salts exert both general and specific effects on plants which directly influence crop growth and yield (Rhoades, Kandiah & Mashali, 1992). In our experiment, the high salinity level significantly lowered fruit mass of both watermelon cultivars. Savvas (2001) reported that the fruit growth of eggplant and melon was more severely affected by salinity than the vegetative growth. Increasing the salinity over 10 mM significantly reduced the fruit yield of both cucumber and egg-plant (Chartzoulakis, 1995).

Although salt tolerance is relatively low in most crop species (Marschner, 1995), watermelon is mildly sensitive to salinity (Rhoades *et al.*, 1992). At a low salinity level, the fruit mass of Paladin was higher than that of Odem. This is attributed to the large fruit size of Paladin compared to the small-sized Odem. The results showed that fruit mass of Odem and Paladin were the same where the salinity level was increased from EC 2 to EC 4 at the FDS. Savvas (2001) explained that the yield of smaller fruits responds less to moderate salinity levels in hydroponics since the small fruits have a lower bulk volume per fruit surface unit and are, therefore, more capable of attracting water.

Fruit size can be related to fruit width, fruit volume and fruit circumference (Table 2). Fruit enlargement was significantly suppressed by the high salinity treatment. As can be seen from Table 2, a high nutrient solution (EC 4 mS cm^{-1}) resulted in watermelons of lesser fruit volumes compared to low and combined salinity treatments. Our results are in support of Watanabe, Nahano and Okano (2001) that salinity treatments reduce watermelon fruit size. This is a well-known feature of high salinity treatments on the fruit size of the majority of vegetable crops. Similar results were obtained in several other crops, including tomato, melon and cucumber (Savvas, 2001; Watanabe *et al.*, 2001).

The hypothesis that may explain these observations states that excessive salinity reduces plant growth primarily because it increases the energy needed to acquire water from the rootzone and to make biochemical adjustments necessary to survive under stress conditions (Rhoades *et al.*, 1992). Salinity may also increase the respiration rate of the roots, which may lead to a higher carbohydrate requirement in saline substrates (Marschner, 1995).

4.2 Pruning effect on fruit yield

Our results are in contrast with Jani and Hoxha (2002) who found that pruning methods had an evident influence on total and marketable yield of melons. No significant interactions ($P<0.05$) with pruning treatments were found in our experiment. In their study on melon, Jani and Hoxha (2002) found that pruning methods had no significant effect on the average weight of fruits or the refractive index of the flesh. As discussed in the next sections, fruit quality was affected by pruning systems (Figure 9), thus affecting marketable yield in quality terms. Watanabe *et al*. (2001) found that vertically trained plants produced smaller fruit than horizontally grown plants. In cucumber, yield was increased in training the plants on wires, moreover fruit quality was affected positively (Tokatli & Ozgur, 1999).

4.3 Salinity and pruning effect on fruit quality

Fruit quality is an important criterion in the production of muskmelon, watermelon, and winter squash (Wien, 1997). As in the study of Duthie, Screfler, Roberts & Edelson (1999), the marketable quality of each fruit was assessed on the basis of ripeness, shape, size and appearance of the rind at harvest. Compared to tomato, relatively little information can be found in the literature about the quality of other fruit or leafy vegetables grown hydroponically (Savvas, 2001). Information on the effects of water salinity and/or soil salinity on crop yield is very scant although such effects are apparent and have been noticed under field conditions (Rhoades *et al.*, 1992).

4.3.1 Sugar yield

If watermelons could be produced year-round in greenhouses, fruit sweetness would be required to stimulate demand, especially in the cold season, as there are many other sweet fruits available then (Watanabe *et al.*, 2001). The culture conditions and the cultivar are important factors affecting soluble solids content (Pangiotopoulos, 2001). Although no significant differences in TSS were found between salinity and pruning treatments, the

TSS of Odem was higher than that of Paladin (Table 2). Watanabe *et al.* (2001) did not find any significant difference in TSS contents of fruits in their study with salinity treatments at the FDS. Similar findings on the TSS of watermelons are documented by Miguel, Maroto and Lopez-Galarza (2001). The favourable effects of an increased EC on the quality of tomato are due to increased dry matter content and higher sugar and titratable acid contents in the fruit (Savvas, 2001). In our trial, TSS per fruit mass significantly decreased for Paladin at the high salinity compared to the low salinity nutrient solution. In contrast, Chartzoulakis (1995) found that cucumber fruits produced at a high salinity level had higher values for soluble solids, as well as chloride and sodium concentrations.

Paladin showed a decrease in sugar yield with an increase in salinity (Figure 6). The sugar content of dry tomato fruit seems to increase slightly with increasing salinity (Savvas, 2001). As with fruit mass (Figure 1), sugar yield of Odem was not affected significantly by increasing the salinity level after the vegetative growth stage (Figure 5). The sugar yield was positively correlated to leaf dry mass and total foliage dry mass that was measured distal to the fruit bearing node. A high leaf density per plant should increase the sugar yield of fruits due to a higher photosynthetic potential. Negative correlations between sugar yield and stem and leaf disease indexes were found. The high disease incidence in our study decreased sugar yield, obviously due to a lower active leaf area as source of carbohydrates for partitioning. Watermelons should have a sugar content of 10% to be acceptable (Wien, 1997). All salinity treatments produced fruits with >10% sugar yields (Figure 6). Therefore, greenhouse watermelons do meet the market requirement for sweetness, even under high salinity (EC = 4 mS cm^{-1}) conditions and diseased leaves.

4.3.2 Rind firmness

Increasing the EC of the nutrient solution resulted in increased tomato rind firmness (Savvas, 2001). Paladin showed a decrease in rind firmness with a high EC nutrient solution compared to the low salinity treatment (Figure 2). Rind thickness of both cultivars was affected by salinity levels and pruning systems (Figures 4 & 5). These interactions were also found with rind firmness (Figures 2 & 3). The similarity between Figures 2 and 4 (cultivar x salinity) and Figures 3 and 5 (salinity x pruning) indicates that rind thickness is an important factor, determining rind firmness.

A fruit with a thin rind may be seen as an indication of good watermelon fruit quality, due to its smaller weight and size. The results of this study show, however, that a thin rind may be associated with a lack of rind firmness. Higher rind firmness in watermelon is a positive quality parameter that may be an attribute to prolonged shelf life, as reported for tomato by Savvas (2001).

Correlation analyses in our study showed that higher flesh density values as found in unripe fruit, were associated with fruits of low rind firmness. A stepwise correlation analyses ($P < 0.05$, $R^2 \times 100 = 18\%$) showed that a longer FDP and higher fruit mass were negatively correlated to flesh firmness, thus improving fruit quality.

4.3.3 Seed production

Severe and mixed pruning systems produced significantly fewer brown seeds than the mild pruning method (Table 3). The brown:white seed ratio, expressing the distribution of seeds in fruit, may serve as a reliable indicator of fruit ripeness. Generally, undeveloped fruits will have more white seeds. Paladin had a significantly higher brown:white seed ratio than Odem (Table 3). The latter produced much more white seed than Paladin, probably owing to premature harvesting and the profound differences in FDP of these cultivars. High seed number in fruits may affect fruit quality by hindering market acceptability in countries where watermelons are mostly consumed for their fruits. However, they may still be of export quality to other nations. Seed consumption of watermelon is popular in several countries such as China, India and the Mediterranean basin (Edelstein and Nerson, 2002). From genotype and plant density studies, Edelstein & Nerson (2002) suggested that the fruit number per unit area is the most important component determining watermelon seed yield.

4.3.4 Watermelon diseases

The lack of adequate control of temperatures and humidity within the greenhouse causes plant stress and encourages the growth of fungal pathogens (Passam *et al.*, 2002). Almost all plants in the greenhouse were diseased to a varying degree (Figure 8). The vines of Odem plants were more diseased than vines of Paladin, only at low salinity level (Figure 8). If the rate of leaf death approaches the rate of new leaf expansion, the photosynthetic area will become too small to support continuous growth (Marschner, 1995). It is probably for this reason that fruit mass (Fig. 1) was much lower for Odem at the low EC than Paladin.

4.3.5 Fruit quality index

According to Passam *et al.* (2002), flavour and aroma together with crispness and juiciness, will increasingly become key factors in quality assessment. In tomato, fruit quality was improved by increased salinity treatment at the FDS (Watanabe *et al.*, 2001). Increasing the nutrient solution EC at FDS (2 – 4 mS cm^{-1}) did not improve the fruit quality index as expected (Figure 9). Only with the mildly pruned plants the 2/4 treatment produced the best quality but only significantly better than the EC 4/4 treatment. Welles (1999) reported that a training system where all fruits are well exposed to natural light and enabling growers to keep a good balance between plant load with fruits and vegetative development, gives the best guarantee for good fruit quality.

5. Conclusion

Considering the extreme summer air temperatures occurring in the winter rainfall area of the Western Cape, and the difficult way of climate regulation in the plastic greenhouse used, the experience with the watermelons were satisfying. The results support reports by previous workers (Chartzoulakis, 1995; Savvas, 2001; Watanabe *et al.*, 2001; Jani & Hoxca, 2002; Passam *et al.*, 2002). Proper pruning systems increase foliage thereby creating a photosynthetic potential to produce important assimilates. Watermelons seem to offer good possibilities for growing in low-cost plastic greenhouses. A marketable class watermelon has a minimum fruit size, high content sugar and good external characteristics. However, care should be given to diseases that are likely to develop during cultivation under humid conditions.

The high salinity treatment produced smaller fruit volumes without affecting the TSS. The occurrence of diseased leaves was relatively high with the 4 mS cm^{-1} nutrient solution and the decrease in the area of healthy leaves probably caused a decline in the photosynthetic potential and could contribute to the reduction in fruit size (Watanabe *et al.*, 2001). The lower the EC of the irrigation water and the higher the leaching frequency, the higher the resultant water-uptake-weighted osmotic potential and the lower the total water stress to which a plant is exposed at steady-state (Rhoades *et al.*, 1992).

Our findings showed that minimal pruning of leaves increased sugar content of fruits. The fact that more leaves, distal to the fruit bearing node, increased the sugar yield, indicates that leaf position should be considered as part of any watermelon trellising and pruning strategy. Thicker fruit rinds increased rind firmness, thus adding to fruit mass and quality.

This study supports the hypothesis of Duthie *et al.* (1999) that the efficiency of commercial production of watermelon can be increased by increasing plant density. Under field production, watermelon plants take up much space while hindering workability due to its sprawling habit. If the correct cultivars in terms of fruit mass and size are cultivated under a greenhouse V-training system, watermelons can prove an attractive business for local consumption and develop into a high quality export product. Icebox cultivars are planted at high-density because plants are smaller (Duthie *et al.*,1999). Small size watermelons can bring a premium price as a fresh market crop, and are easy to handle. The pruning system used in this study where female flowers were allowed to develop close to soil surface, made it possible to use a low-cost structure with no need to carry the fruit mass.

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Chapter 4

SUMMARY

Planting a variety that is not suited for the available market and the particular production situation leads to lower profits or possibly crop failure. In addition to market acceptability, a variety must germinate well, produce an acceptable fruit mass, be adapted to the production area, and have the highest level of needed genetic traits and disease resistance available. Plants vary substantially in their ability to tolerate saline water, as their growth can be restricted by wasted energy, used to absorb water against an osmotic gradient thus affecting yield and quality.

Seed germination is an essential process for optimum crop establishment and harvest returns for any crop species. The ISTA procedures for accelerated ageing of watermelon seeds were adapted for a germination study. By using this technique, it was possible to expose fresh and aged seeds of two cultivars to four salinity levels and five temperature regimes. Maximum germination was achieved within 25-29 °C at salinity 4 and 8 mS cm^{-1} for Odem and Paladin respectively. The best temperature for Paladin germination was >15 °C, and the best germination was at >30 °C for Odem. At a salinity level of 8 mS cm^{-1}, germination of Odem seeds was poor and both cultivars failed to germinate at a salinity level of 12 mS cm^{-1}.

The results of the studies carried out are important because they show that components of watermelon fruit mass and quality are affected by salinity and pruning systems. Additional information on the cultural management of watermelon in greenhouses could aid efforts to increase crop production. Similarly, our study showed seeds of the two cultivars responded differently to temperature and salinity levels.

A new trellising system, with one fruit on the ground and two shoots trained vertically in a V-shape, was tested in a low-cost greenhouse. Two cultivars were exposed to three pruning systems and three salinity treatments. Moderate removal of leaves produced

fruits with thin rinds, a characteristic of good quality watermelon fruit, due to its smaller weight and size for handling and good appearance. We further found that with moderate leaf numbers, the fruit quality index was highly influenced by the high EC nutrient solution. With excessive pruning of vines, the low salinity treatment had a much higher fruit quality index than plants exposed to saline conditions. Rind thickness and rind toughness were similarly affected, giving a clear indication of a positive correlation between these two parameters. Pruning to retain more leaves per vine, represented a good system whereby fruits of a lesser weight and greater commercial acceptability were obtained. Watermelon fruits of stronger rind toughness and thicker rinds may reduce mechanical injury of fruits to maintain quality and higher prices. However, appropriate fertigation and phytosanitory techniques may contribute to superior quality.

Watermelon crop production under soil-less production systems have immense potential in southern African countries such as Namibia, where only about 10% of the land surface is considered to have medium to high potential for rainfed and irrigated crop production. The added protection by plasticulture could lead to production of higher quality fruits that will make the regional growers more competitive against imports from major world production areas. It is thus evident that for the vegetable industry in the region to prosper, there is a need to develop new cultural technologies.

The theory involved in pruning is that when the number of melons per plant is reduced towards the distal nodes of the plant, the plant's producing power will be concentrated in a smaller number of fruits, thereby increasing the size and perhaps the quality. The vertical training of vines combined with soil-less production systems could address several of the serious challenges facing the horizontal open-field production of watermelons, and could provide a new sector for the growers in the vegetable industry. These results should be helpful in developing future plant pruning systems for greenhouse watermelon production to obtain optimum yield while maintaining fruit quality.

Because of the high cash value potential of watermelons, and the wide diversity of germplasm and increasing pressure of land scarcity in southern Africa, there appears to be a need for more research on intensive cultivation techniques. As high quality water becomes scarcer, there is a growing need to use poorer quality water for agriculture. The challenge for using poor quality water profitably will depend on greater knowledge of the effects of salinity on a wide variety of crops including watermelons. Our study also confirms that all salinity effects may not be negative; it may have some favourable effects on yield and quality. Using two shoots per fruit, vertically trained in a V-shape, this study showed that moderate salinity levels and mild pruning systems were the best combination for the production of fruits of good quality.

ADDENDUM 1

ANOVA of data used in Chapter 2

Source	Df	Maximum Percentage Germination (%)	Mean Germination Time (days)
Cultivar (C)	1	ns	ns
Pre-treatment (P)	1	ns	ns
Salinity (S)	1	ns	ns
Temperature (T)	1	ns	ns
CP	1	ns	ns
CS	3	0.0087	ns
CT	4	0.014	ns
PS	3	ns	ns
PT	4	ns	ns
ST	12	ns	ns
CPS	3	ns	0.0071
CPT	4	ns	ns
PST	12	<0.0001	0.0089
CPST	12	ns	ns
CV (%)		19.9	56.3

ADDENDUM 2

ANOVA of data used in Chapter 3

Source	Df	Fruit Mass (kg)	Rind Firmness	Rind Thickness (cm)	Sugar yield	Brown seeds	White Seeds	Seed Ratio	Total Seed Mass (g)
Cultivar (C)	1		0.0349	0.0084				0.0372	
Salinity (S)	2		0.0005	0.004	0.0003				
Pruning (P)	2					0.0056			0.0323
CS	2	0.0135	0.0233	0.0248	0.0338		0.0186		
CP	2								
SP	4		0.0029	0.0021					
CSP	4								
CV		26.2	22.4	21.4	39.5	44.9	41.6	87.3	87.0

ANOVA of data used in Chapter 3 (cont.)

Source	Df	Stem Disease Index	Fruit Quality Index	Fruit Circum (cm)	Fruit Radius (cm)	Fruit Volume	Fruit Width (cm)	TSS (°Brix)
Cultivar (C)	1					0.0172		0.0041
Salinity (S)	2		<0.0001	0.0001	0.0001	<0.0001	0.0001	
Pruning (P)	2							
CS	2	0.0350						
CP	2							
SP	4		0.0010					
CSP	4							
CV		29.3	20.5	15.1	15.0	40.9	15.1	23.0