FACTORS INFLUENCING FRUIT SHAPE IN LEMONS (*Citrus limon* L.)

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.

SUMMARY

Lemons with an elongated fruit shape achieve premium prices in certain discerning markets. Factors influencing the fruit shape of lemons were investigated to find means to produce a crop with a higher percentage of elongated lemons.

Intra-plant factors were investigated to understand the variation in fruit shape within a single tree and even within the same fruit cluster. Bearing position (leafy vs. leafless inflorescences) and position in the canopy (inside vs. outside) were taken into consideration, along with the number of seeds, number of segments and rind thickness in the center of the fruit as well as stem- and stylar-ends. Bearing position and position in the canopy had no effect on fruit shape, while the number of seeds was positively correlated with elongated lemons.

Rootstocks were evaluated to determine the influence of rootstock type on fruit shape. Twelve rootstocks were evaluated in total, at Addo, Citrusdal and Nelspruit. At all three locations rootstock type had no or little influence on fruit shape. Different scions were also evaluated at both Addo and Citrusdal to determine whether a certain scion characteristically produces elongated fruit. A total of 20 different scions were evaluated, and as opposed to rootstocks, there were larger variations between scions. Of the commercially-produced scions, 'Fino' lemon had the least variation, producing elongated lemons more consistently than 'Lisbon' and 'Eureka' lemons. Of the other scions, 'Cicily' lemon produced fruit with the smallest L:D ratio, while 'Verna' lemon was the scion producing fruit with the largest L:D ratio. 'Verna' lemon is, however, not an attractive fruit, having a thick rough rind.

In the case of grapefruit, unwanted "sheepnosed" fruit with thick rinds are common in areas with a low winter temperature at night. 'Eureka' lemon fruit from six different climatic areas were compared to evaluate the difference in fruit shape. Cooler areas, such as Vaalharts, had more elongated fruit than areas with a higher winter temperature, such as Nelspruit.

Altering lemon fruit shape was also attempted by chemical manipulation, using gibberellin, cytokinin or auxin containing products. Promalin® (GA_{4+7}, BA), Accel® (GA_{4+7}, BA), Corasil E® (2,4-D), Provide® (GA_{4+7}) and ProGibb® (GA_3) were sprayed at different times and different concentrations. Promalin® was partly successful in altering fruit shape, but these changes were not large enough from a commercial point of view. Promalin® also resulted in a lower percentage fruit set. Accel®, Corasil E®, Provide® and ProGibb® were not successful in altering fruit shape favorably, with Corasil E® having a strong thinning effect.

OPSOMMING

Fakore wat die verlenging van suurlemoene beïnvloed

Suurlemoene met `n verlengde vrugvorm behaal hoë pryse in sekere markete. Faktore wat die vrugvorm van suurlemoene beïnvloed is bestudeer om praktyke te vind wat die produksie van verlengde suurlemoene kan verhoog.

Intra-plant faktore is bestudeer om die variasie in vrugvorm binne `n enkele boom en ook in dieselfde vrugtros te verstaan. Dra-posisie ("wit" en "groen" blomme) asook posisie in die boom (binnevrugte vs. buitevrugte) is in aanmerking geneem. Die invloed van die hoeveelheid sade en segmente per vrug, asook skil dikte in die middle van die vrug en aan stingel- en kelkkant is ook bestudeer. Dra-posisie en posisie van vrug in die boom, het geen invloed op vrugvorm gehad nie, terwyl die hoeveelheid sade per vrug die beste met vrugvorm gekorreleer was.

Die invloed van onderstam tipe op vrugvorm is ook geëvalueer. Vrugvorm van twaalf onderdstamme in totaal is te Addo, Citrusdal en Nelspruit ondersoek. By al drie areas is klein verskille in vrugvorm van verskillende onderstamme opgemerk. Saam met die onderstamme is 20 seleksies te Addo en Citrusdal ondersoek, om te bepaal of `n sekere seleksie `n karakteristieke verlengde vrugvorm openbaar. In teenstelling met onderstamme, is groter variasie tussen seleksies gevind. Van die kommersiële kultivars, het 'Fino' suurlemoen die minste variasie openbaar en deurgans verlende vrugte gelewer, terwyl 'Lisbon' en 'Eureka' suurlemoene groter variasie gehad het. Van die ander seleksies, het 'Cicily' suurlemoen geneig om vrugte met die kleinste L:D verhouding te lewer, terwyl 'Verna' suurlemoen deurgans vrugte met `n groter L:D verhouding gelewer het. 'Verna' suurlemoen is egter nie `n aantreklike vrug nie, aangesien dit `n dik skil het.

In die geval van pommelos word ongewenste vrugte met `n "skaapneus" vorm algemeen aangetref in areas met `n lae mininmum winter temperatuur. Vrugvorm van 'Eureka' suurlemoene van ses verskillende klimaats areas is vergelyk. Koeler areas, soos

Vaalharts, het meer verlengde vrugte gehad, terwyl Nelspruit met `n hoër winter temperatuur, ronder vrugte produseer het.

Daar is ook gepoog om suurlemoen vrugvorm te manipuleer d.m.v. chemiese bespuitings. Ouksiene, gibbereliene en sitokiniene asook kombinasies daarvan, is gebruik. Promalin® (GA_{4+7}, BA), Accel® (GA_{4+7}, BA), Corasil E® (2,4-D), Provide® (GA_{4+7}) en ProGibb® (GA_3) is by verskillende tye en verskillende konsentrasies gespuit. Promalin® was gedeeltelik suksesvol in verlenging van vrugte, maar die veranderinge was te klein uit `n kommersiële oogpunt. Promalin® het ook tot uitdunning van vrugte gelei. Accel®, Corasil E®, Provide® en ProGibb® was nie suksesvol in verandering van suurlemoen vrugvorm nie. Corasil E® het tot strawwe vruguitdunning gelei.

Dedicated to my family

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GENERAL INTRODUCTION

The South African citrus industry currently constitutes a total area of 59 280 hectares. During the 1980s annual planting rates were approximately 700 000 trees and increased to over 1 million trees per year. Citrus growing regions in South Africa are categorised as hot, intermediate, cool or cold. The citrus harvest season ranges from March to October. Citrus production South Africa exceeds 1.2 million tons, with only 90 000 tons consisting of lemons. The global leader in lemon production is Argentina, producing 942 000 tons (Anon., 2001).

The depreciation of the Rand favours export industries and the citrus industry in South Africa is export-focused, with 60 % to 65 % of the citrus crop being exported. Domestic consumption is about 10 %, with the rest being processed for juice. Lemon production in South Africa is approximately 6 % of total citrus types grown (Rabe, 2001). 'Eureka' lemon has been almost exclusively used, but 'Lisbon' and 'Fino' may be increasingly used in replants.

Premium prices are obtained in the export market for fruit of good internal and external quality. External quality includes rind texture, fruit colour and fruit shape. As with other markets, the citrus industry has to produce what the market demands. Certain discerning markets such as the Japanese market, prefer lemons with an elongated fruit shape of lemons, with more slices being cut from an elongated lemon. Fruit shape is measured by the length to diameter ratio (L:D ratio) of the fruit. Fruit with a L:D ratio of 1.25 and higher are exported to Japan (Capespan (Pty) Ltd, 1994). By increasing the percentage of elongated lemons produced per orchard, a higher percentage of fruit will be suitable for export to Japan.

The purpose of this study was to determine the intra-plant factors influencing lemon fruit shape to understand variation in fruit shape within individual trees. Factors investigated include bearing position, position of fruit within the canopy, seed count, number of segments and rind thickness. The influence of rootstock/scion combination on fruit shape was also evaluated. McDonald and Hillebrand (1980) reported on lemons from different countries differing in fruit shape, with South Africa being one of the countries with the roundest lemons. Therefore lemons from different climatic areas in South Africa were also compared. Manipulation by means of chemical sprays was investigated in an attempt to improve fruit shape of established lemon orchards.

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FACTORS INFLUENCING FRUIT SHAPE

1. Introduction

Premium prices for fresh fruit are not obtained if the fruit are not attractive in appearance. The decision to buy is often spontaneous and dependant on product quality. Product quality includes internal and external quality. In citrus, internal fruit quality is determined by total soluble solids (TSS):titratible acidity (TA) ratio and juice %, whereas external quality includes rind texture, fruit colour and fruit shape. Apples of the 'Delicious' cultivar are not competitive in some Asian markets unless they display the distinct angularity achieved with growth regulator treatment (Looney, 1993). Similarly, certain discerning markets, e.g. the high paying Japanese market, prefers lemons with an elongated fruit shape. Fruit shape is expressed by the length:diameter (L:D) ratio.

Fruit cell division and expansion and, therefore, growth are controlled by endogenous hormones. Rate of fruit growth and development as well as peel thickness also differs between climatic areas, with different temperatures and relative humidity. Different fertilisation practices also have an effect on fruit composition. Other factors such as rootstock, fruit position on the tree, and number of seeds also seem to influence fruit shape. Looney (1993) found that fruit shape has proven to be an important component of apple fruit appearance and one that can be improved with plant bioregulators. Guardiola et al. (1993) also showed that auxins on the one hand and cytokinins and GA on the other hand, influence development of different tissues in *Citrus unshiu*, which explains the different effects on final fruit size.

2. Fruit Growth

2.1 Fruit components

Spiegel-Roy and Goldschmidt (1996) described the citrus fruit as a type of berry, termed "hesperidium". The fruit arises through growth and development of the ovary, and is classified as a true fruit.

Spiegel-Roy and Goldschmidt (1996) further described the citrus fruit as made up of two morphologically distinct components. The pericarp or peel, and the endocarp, which is the edible part of the fruit and is also known as the pulp. The peel is further divided in two components. The external, coloured part known as the flavedo or epicarp, and the albedo or mesocarp, visible as the white region under the coloured flavedo. The pulp consists of segments, enclosed in a locular membrane and filled with juice sacs.

2.2 Fruit development

Bain (1958) and Holtzhausen (1965) described the sigmoidal growth curve of 'Valencia' and 'Washington Navel', oranges respectively. In a classical study by Bain (1958) on 'Valencia' orange, fruit growth was divided into three major stages: cell division (I), cell enlargement (II) and fruit maturation (III). The cell division stage (I) varied in length. Increase in fruit size at this stage was mainly due to increased peel thickness. The peel reaches its maximum width at or shortly after the end of stage I. At the end of stage I, cell division was completed in all areas except for the outermost flavedo layers. In a study done by Ford (1942) on 'Eureka' lemons, cell multiplication in the ovary wall proceeded uniformly until the fruit was 10 mm in diameter and the pericarp (peel) 3 mm thick. Bain (1958) described stage II as a period of very rapid growth. It was the critical period for growth and was distinguished as the cell enlargement period, with rapid morphological and physiological changes occurring. The peel became thinner as the pulp continued to increase in size. The growth of the pulp was responsible for most of the increase in fruit size. Stage III was the maturation and ripening period. Fruit continued to grow while on the tree, but at a reduced rate compared to stage II. It seems that Bain's division into the above mentioned three growth stages is appropriate for most citrus fruits. Gillaspy et al. (1993) also conducted a more detailed study on early fruit development of fruit in general and divided it into the following stages, which corresponds with that done by Bain (1958). Phase I, period of ovary development, fertilisation, and fruit set; phase II, period of cell division, seed formation, and early embryo development; phase III, period of cell expansion and embryo maturation. As reported by Bain (1958), cell division in citrus fruits occurs in phase I.

2.3 Seed development

Fertilisation of the ovary by a pollen grain results in the formation of seeds (Frost, 1948). When fully developed the ovary is called the fruit. Each segment of the mature citrus fruit represents that part of the ovary called the carpel. While still young, each carpel contains a cavity called the locule. The locule is later filled with juice sacs and if ovules are fertilised, seeds (Frost, 1948).

Fertilisation starts with pollination. Pollination consists of pollen transfer to the stigma, germination of the pollen tube and penetration of the embryo sac in the ovule (Spiegel-Roy and Goldschmidt, 1996). Self-pollination may occur in self-compatible genotypes by wind blown pollen or by direct contact of anthers with the stigma. (Spiegel-Roy and Goldschmidt, 1996). Pollination between clonal varieties such as 'Eureka' lemon, is equivalent to self-pollination of a single tree. Cross-pollination involves the transfer of pollen from one clonal variety or plant, to another (Frost, 1948). Honey bees are the main cross-pollinators (Spiegel-Roy and Goldschmidt, 1996).

Fertilisation consists of the fusion of a sperm nucleus with an egg nucleus (Frost, 1948). Two microgametes are produced by the generative nucleus of the pollen. One microgamete fuses with the egg nucleus producing the zygote, while the other fuses with the two polar nuclei initiating the endosperm. Fertilisation of the egg cell occurs two or three days after pollination. Cell division of the zygotes starts soon afterwards (Spiegel-Roy and Goldschmidt, 1996).

Plants producing seedless fruit are referred to as parthenocarpic. Fruit setting without external stimulation is defined as autonomic pathenocarpy. Stimulative pathenocarpy is used to describe cases where a stimulus is needed for seedless fruit set. These stimuli include pollination, pollen germination and pollen tube growth unaccompanied by fertilisation (Spiegel-Roy and Goldschmidt, 1996).

3. Controllable factors influencing fruit shape

3.1 Growth regulators

Early fruit growth is normally mediated by auxins, gibberellins and cytokinins (Famiani et al., 1999). The use of plant growth regulators (PGR's) has become important in citriculture. The use of PGR's presupposes an active regulation of growth processes by endogenous, and similar complementary or antagonistic effects of exogenous regulators (Monselise, 1979). PGR's can improve fruit size, appearance and internal fruit quality by direct effects on fruit growth and development or indirectly by regulating crop load, tree or vine vigour, and canopy architecture (Looney, 1993).

3.2 Gibberellic acid (GA)

Endogenous GA seems to play a role in citrus biology. GA is important in several processes connected with flowering and fruit development (Monselise, 1979). Goldschmidt and Monselise (1972) determined that GA is an antagonist of flower initiation. Erner et al. (1976) reported excessive levels of endogenous GA and cytokinins to cause unduly thick peels in oranges.

3.3 Cytokinins

The ban on cytokinins for fear of carcinogenic side-effects as well as difficulties with the solubilisation and translocation of applied cytokinins has hindered the search for practical uses of these compounds for a long time (Monselise, 1979). Currently cytokinins in combination with gibberellins, in compounds such as Promalin® are registered for use on apples in South Africa.

Itai et al. (1995) suggested the root to be considered the most important source of cytokinins, which are transported to other plant parts where they affect various physiological processes. El-D et al. (1979) indicated that leaves of sunflower plants have the capacity to produce cytokinins, provided that sufficient levels of inorganic nutrients reach the leaves. Greene (1993a) noted that cytokinins have been implicated in a number of physiological responses important in fruit production. The responses he includes are bud break, lateral branching, fruit size and shape, fruit set, flower bud formation, and water relations. Itai et al. (1995) described cytokinins as PGR's which stimulate cell division and expansion and can delay senescence.

Specific effects include the excessive growth of peel in oranges caused by cytokinins (Erner et al., 1976). Williams and Stahly (1969) determined that cytokinin-treated apples were elongated which indicates that cytokinins affects the direction of cell division or cell expansion.

In addition to the above observations, Greene (1989) as well as Antognozzi et al. (1993) discovered that the response to cytokinins depends on the type of compound used, and that it may also be affected by its association with other growth regulators. They found that the most effective compound used so far proved to be the substituted phenylurea, N-(2-chloro-4pyridyl)-N'-phenylurea (CPPU). It also proved to be effective in other species such as melon, potato, pepper, tomato, olive, grape and apple. Treatment with cytokinin, other than affecting fruit growth, can also influence fruit shape, ripening, and quality.

3.4. Effects of GA on apples

Bukovac and Nakagawa (1968) treated apples with localised applications of GA_4. The treatment resulted in pronounced tissue enlargement in the vicinity of the lateral treatment site, giving rise to asymmetric fruits. Length, but not width, of seeded and parthenocarpic fruit was increased. There was a pronounced increase in the cortex thickness and cell number on the treated side of seeded and parthenocarpic fruit, in comparison to the non-treated side.

Stembridge and Morrell (1972) reported that GA_{4+7} applications at 50 to 100 mg/l were effective in altering fruit shape while GA_3 at 100 mg/l was not effective. This was confirmed by Curry and Williams (1983), where Promalin® (GA_{4+7} and 6-Benzyladenine) significantly increased L:D ratio of 'Delicious' apples, compared to fruit treated with GA_3. Eccher (1983) determined that sprays containing as little as 10 mg/l GA_{4+7} applied over a 4 to 6 week period are known to increase L:D ratio of 'Golden Delicious' apples. Eccher and Boffelli (1981) applied GA_{4+7} on 'Golden Delicious' apples which resulted in an increased L:D ratio. Treatments applied over 20 days after full bloom were ineffective, whereas early treatments applied 6 days before full bloom may have had some influence. In many cases treatments caused parthenocarpy.

Looney et al. (1992) determined that GA sprays increased L:D ratio of 'Golden Delicious' apples grown in a maritime or desert climate. Fruit shape was not influenced by position of the fruit within the canopy.

3.5 Effects of cytokinins on apples

Greene (1993) realised that cytokinins differ significantly in their effect when applied as postbloom sprays in apples. The phenylurea-types represented by CPPU and N-phenyl-N'-1,2,3-thiadiazol-5-ylurea (thidiazuron) appear to be much more active than the N^6-substituted purine type cytokinins such as benzyladenine (BA). He determined that BA was the most effective N^6-substituted purine type of the several evaluated. CPPU and tiadiazuron (TDZ) increased fruit size, but as size increased, the severity of fruit shape abnormalities also increased. There was a direct linear relationship between fruit asymmetry and concentration of cytokinin applied. Greene (1993) found CPPU and TDZ to frequently inhibit flower bud formation, whereas BA usually increased it. CPPU and TDZ increased the L:D ratio of 'Delicious' apples more than BA (Greene, 1995). When comparable rates were applied, TDZ thinned most, CPPU was intermediate, and BA thinned the least (Greene, 1993).

Greene (1993) showed that rates of TDZ and CPPU between 5 and 20 mg/l increased the L:D ratio comparably, indicating that the optimal rate for both of these chemicals was less than 5 mg/l. CPPU at either 5 or 10 mg/l increased the fruit L:D ratio more than 25 mg/l Promalin®, whereas TDZ was intermediate (Greene 1995). More asymmetry was caused when sprays were applied at the 10 mm fruit size stage than when the same treatments were applied either earlier or later (Greene, 1993). Fruit from both full bloom and 22 days after full bloom applications were irregularly shaped. There was a treatment by time interaction for fruit L:D ratio. The fruit L:D ratio increased at both full bloom and 22 days after full bloom applications, but the greatest increase occurred with the full bloom treatment (Greene, 1995).

Greene (1995) further discovered that both CPPU and TDZ are strong promoters of cell division and cell number with fruit size increasing in the immediate area of application. Fellman et al. (1987), Biasi et al. (1993) as well as Neri et al. (1993) suggested that the asymmetry caused by CPPU was due to extremely limited mobility of and redistribution from the application site. They suggested that asymmetry may be overcome by more uniform distribution over the fruit surface, using a uniform application of small droplets or multiple sprays at low concentrations.

3.6 Effects of GA and BA combinations on apples

Williams and Stahly (1969) used Promalin® (GA_{4+7} and 6-BA) to elongate 'Delicious' apples. They discovered that application of cytokinins and GA alone and in combination to 'Delicious' apples just after full bloom affected fruit shape by increasing the L:D ratio, this was confirmed by other researchers (McLaughlin and Green, 1984; Burak and Büyükyilmaz, 1997). It was also discovered that cytokinins caused fruits to be longer with prominent, well-developed calyx lobes. GA_{4+7} caused fruit to be longer, but did not affect the development of the calyx lobes (Williams and Stahly, 1969). Stembridge and Morrel (1972) found that BA was most effective in altering fruit L:D ratio when compared to GA_{4+7}, but a combination of the two PGR's was the most effective in altering fruit shape. Curry and Williams (1983) found Promalin® to be more effective than GA_3 in altering fruit shape. Curry and Williams (1983), Stembridge and Morrell (1972), Unrath (1974) as well as McLaughlin and Greene (1984) found that GA_{4+7} and BA at high doses, alone or in combination reduced fruit set. Burak and Büyükyilmaz (1997) found high doses of Promalin® to cause adverse effects on fruit shape and also caused overthinning.

Looney (1979) determined that the increase in fruit weight with GA_{4+7} can be attributed to an increase in fruit length, whereas neither length or diameter was influenced by BA. Unrath (1978) also proposed that the improved fruit shape increased fruit weight because of the added fruit length generated.

In contrast to the above mentioned increase of fruit weight thought to be the result of the increase in fruit length, Letham and Williams (1969) observed increases in fruit weight without any effect on the L:D ratio of 'Jonathan' apples. The increase in weight was attributed to an increase in cell density in the cortex area of the fruit.

Bound et al. (1993) found in their trials of assessing the interactive effects between Promalin® and ethephon on cropping of 'Red Delicious', that there was evidence that

ethephon thinning sprays reduced the L:D ratio of fruit but the addition of Promalin® can restore fruit shape by increasing the L:D ratio and "typiness".
Unrath (1974) applied GA_{4+7} and BA to 'Starkrimson Delicious' apples from 1969 to 1972. He noticed that in the initial tests, GA_{4+7} and BA (50 to 200 mg/l) increased fruit length, fruit weight and L:D ratio, but it did not alter fruit diameter. Calyx lobe length stimulation showed a trend at 50 and 100 mg/l and became significant at the 200 mg/l level. Stembridge and Morrell (1972), further applied BA alone or in combination with GA_{4+7} at 100 mg/l. Both GA_{4+7} and BA applications increased L:D ratio and the prominence of calyx lobing. Application of either GA_3 or Promalin® at 25 mg/l increased L:D ratio, fruit size, pedicle length and leaf size on paclobutrazol (GA-inhibitor)-treated trees, but that GA_3 was less effective.

The time of application of GA_{4+7} + BA had a marked effect on L:D ratio. Application between full king bloom and petal fall resulted in approximately 75% or more of the maximum response (Unrath, 1974). Stembridge and Morrell (1972), Curry and Williams (1983) and Burak and Büyükyilmaz (1997) confirmed this by reporting that spays during bloom were more effective than sprays pre- or post-bloom. McLaughlin and Greene (1984) found that BA increased fruit weight, length and diameter on 'Golden Delicious' apples when treatments were started at 4 days after full bloom. GA_{4+7} increased fruit length but weight was only increased when treatments started at 11 days after full bloom. Looney (1979) reported that GA_{4+7} + BA sprays increased L:D ratio for at least 5 weeks after bloom.

Unrath (1974) found that air blast applications of GA_{4+7} + BA were as effective as hand-gun applications even when the amount of spray mixture was substantially reduced. Fruit length was affected at all concentrations, while calyx lobe length was directly related to concentration. Unrath (1974) realised that it was apparent that only a small numerical increase in lobe length was necessary to substantially change the visual appearance and prominence of the calyx lobes.

Unrath (1974) further detected that split applications were significantly less effective than a single application at the same concentration. Single applications were thus preferable to split applications. Unrath (1974) noted that it was of interest that these results differ from reports that split applications were more effective. He concluded that improved fruit shape and increased fruit mass justified the use of GA_{4+7} and BA in apple producing areas where post bloom temperature conditions reduced "typiness". Neither a single application nor a split application significantly increased fruit weight (Unrath, 1974).

3.7 Effects of cytokinin on kiwifruit

Investigating the effects on kiwifruit, Costa et al. (1993) applied CPPU at 20 mg/l 15 days after full bloom. They found that CPPU modified fruit shape or caused minor changes like fruit distal end extroversion, which could pose commercial problems. In Central Italy it was found, however, that CPPU did not influence the L:D ratio but only caused a distal-end extroversion. Antognozzi et al. (1997) found that CPPU treatment on *Actinidia deliciosa* significantly increased fruit size. An increase in growth of all different fruit tissues, e.g. outer pericarp, inner pericarp and core was promoted by CPPU without modifying their relative proportions. CPPU stimulated both cell division and cell elongation. In further investigations on kiwifruit, Famiani et al. (1999) found TDZ treatments to increase fruit size, and caused modification in fruit shape. Famiani et al. (1999) concluded that TDZ increased the length and diameter of fruit. It increased the percentage of fruits having a protruded-distal end, and tended to decrease the fruit L:D ratio. The effects on fruit shape were more marked at the higher concentrations.

Patterson et al. (1993) only found an increase in the size of the small cells in the outer pericarp of kiwifruit when CPPU was applied, whereas Woolley et al. (1991) observed an increase in cell number in the core and both cell number and size in the outer pericarp. It is thus still not clear whether the larger size of CPPU-treated fruits is a result of an increased number of cells and/or cell-size and what modifications are induced in the different tissues of the kiwifruit.

Antognozzi et al. (1997) also mentioned that, given the similarity between TDZ and CPPU, it is likely that TDZ increases fruit size, stimulating both cell multiplication and expansion as reported for CPPU-treated kiwifruits.

3.8 Effects of cytokinins on persimmons

Itai et al. (1995) studied the effects of three synthetic cytokinins on fruit development of persimmon by spraying flowers or young fruitlets with 10 or 100 mg/l 4PU-30 and TDZ, and 100 or 1000 mg/l BA. At 100 mg/l, 4PU-30 produced flatter fruit, by promoting transverse growth. BA and TDZ had no effect on the L:D ratio. The promotion of lateral fruit growth by cytokinins in persimmon fruit is in contrast with the elongation of apples as reported by other researchers.

3.9 The effect of growth regulators on citrus

Goldschmidt (1983) applied lanolin pastes containing 0.02-1.0% GA_{4+7} on one side of developing citrus fruitlets and caused thickening of the peel in the area of the application. It involved the enlargement of the albedo cells. Cells of albedo from GA_{4+7}-treated fruit had larger intercellular spaces than control fruit. The flavedo and the pulp were not affected. Except for the thickening of the albedo, there was no change in the fruit shape as expressed in the L:D ratio. Goldschmidt (1983) also mentioned that growth of the albedo seemed to be strongest in cultivars which naturally have a well-developed albedo.

Erner et al. (1976) investigated the reduction of peel roughness of 'Shamouti' orange with PGR's. 'Shamouti' oranges are associated with thick peels, that result in large fruit sizes. This condition was overcome by early anti-gibberellin sprays of succinic acid-2,2-dimethylhydrazide (SADH) and 2-chloroethyltrimethylammonium chloride also known as Cycocel® or chlormequat.

3.10 Auxins

Westwood and Blaney (1963) stated that cell elongation is mediated by auxins, and proposed that the factors affecting fruit shape do so by regulating the auxin available to them. Auxins promote cell elongation, via loosening of the cell walls and making them more susceptible to turgor-derived extension (Shoseyov and Dekel-Reichenbach, 1993). Late fruit growth and final fruit size of 'Satsuma' mandarin, were increased by the application of the synthetic auxin 2,4,5-trichlorophenoxyacetic acid. The auxin had a specific effect on the enlargement of the juice vesicles (Guardiola et al., 1993).

3.11 Seed activity in relation to endogenous hormones

Partially seeded apple fruit are lob-sided, the less fleshy side being adjacent to seedless carpels (Westwood and Blaney, 1963).

In a study done by Dennis (1976), it was determined that seeds are a major source of GA. Hoad (1978) indicated that GA originating from developing seeds migrate to the subtending bud and inhibit flower bud induction. Stembridge and Morrell (1972) compared GA_{4+7} to GA_3 by applying it to 'Delicious' apples. GA_{4+7} successfully altered fruit shape, while GA_3 was not effective. This supports the idea that GA_4 and GA_7 occur in immature apple seeds. Vanoli et al. (1993) confirmed GA presence during cell enlargement; which seemed to be initially linked with seed activity, but was directly synthesised in the fruit flesh.

Unrath (1974) applied GA_{4+7} and BA to 'Starkrimson Delicious' apples and discovered that there was a decreasing trend in number of developed seeds/fruit, which became significant at the 200 mg/l level. This was confirmed by McLaughlin and Greene (1984). Buban et al. (1993) treated 'Starking Delicious' apples with 5 to 10 mg/l GA_{4+7} at anthesis and also at petal fall. The percentage elongated fruit increased in treated trees up to 71% from 36% in the untreated controls. No relationship was detected between number of seeds and fruit shape. Looney et al. (1992) found that in general, seed number related more strongly to fruit diameter and weight than to fruit length.

Letham and Williams (1969) showed that cytokinin activities from extracts of developing seeds in apples, were much more active than extracts from fruitlet flesh. Investigations on the relationship between fruit size or shape and seediness of citrus was done on 'Valencia' oranges and 'Marsh' grapefruit. Cameron et al. (1960) showed that there is an association between fruit size and seed number in 'Valencia' oranges. Larger fruit were clearly associated with greater number of seeds. Smith and Rasmussen (1960) determined that increased K fertilisation resulted in increased seediness of 'Marsh' grapefruit.

3.12 Fertilisers

Various researchers investigated the effect of nitrogen (N), phosphorus (P) and potassium (K) on the peel thickness of citrus fruit, that may also result in the alteration of fruit shape. Reuther and Smith (1952) stated that large fruit tended to have thicker peels with less juice than smaller fruits. This was confirmed by Wallace et al. (1955) as well as Smith (1963). Koseoglu et al. (1995) found that N and K increased fruit weight, fruit size, and rind thickness of 'Satsuma' mandarins. It did not elongate the fruit.

Koo and Sites (1956) studied the mineral composition of citrus fruit, as associated with position on the tree. They discovered that N, P and K contents of the fruit varied according to height zones and light exposures in the tree. Fruit in the lower zone were higher in these three elements than in the middle zone, while fruit from the top of the tree were lowest in these three elements. Inversely, the Ca content increased from the lower to the higher parts of the tree. Magnesium (Mg) content in the fruit was not affected by height of fruit borne on the tree. N, P and K contents of fruit were highest, taken from fruit inside the tree, and lowest in the outside fruit. No significant differences were found in the Ca or Mg content of fruit due to light exposure.

3.12.1 Nitrogen (N)

Jones and Embleton (1967) determined that as N fertilisation increased, the peel of 'Valencia' oranges was rougher and thicker, and extractable juice decreased. Low levels of N produced fruit with thinner peels than at higher rates (Reuther and Smith, 1952). On 'Marsh' grapefruit, Smith et al. (1969) found low rates of N to produce slightly larger fruit with thinner peels, but lower juice content. Reitz and Hunziker (1961) noted that 'Marsh' grapefruit developed slight coarsening of the fruit, as evidenced by wrinkling around the stem-end or the development of a "shoulder" around the stem, as a result of high N application. The high N application also resulted in a slight decrease in flatness of the fruit.

In contrast to the above, Lynch et al. (1953) determined that there was a trend for percentage of juice to increase as the N applications were increased to 'Persian' limes. At low N fertilisation, fruit were of rough thick-skinned type. In 'Prior Lisbon' lemons, Jones et al. (1970) determined that N had no effect on fruit shape or juice content.

When foliar applications were compared to soil application of N, foliage sprays produced thin-peeled, smooth-textured fruit of 'Valencia' oranges (Jones and Embleton, 1959).

Smith and Rasmussen (1961) showed that the source of N (calcium nitrate, ammonium nitrate or ammonium sulphate) had no effect on peel thickness or juice content when applied to 'Marsh' grapefruit.

3.12.2 Potassium (K)

Embleton et al. (1956) investigated the influence of K on the quality of 'Valencia' oranges. Potassium did not significantly influence peel thickness even though the amounts of K in the peel increased. In contrast, Smith and Rasmussen (1960) found K fertilisation to increase peel thickness, as well as fruit diameter and increased seediness of 'Marsh' grapefruit. Reuther and Smith (1952) determined that peel thickness increased as K increased in 'Valencia' oranges. They found that there was a significant interaction between N and K on peel thickness. The level of K had a greater effect on peel thickness at the high than at the low N level.

Embleton and Jones (1966) showed that an increase of K in the lemon tree had an opposite effect as that which occurs in the orange and grapefruit tree. An increase in K level in orange and grapefruit trees generally increases the thickness of the peel and reduces the percentage of juice in the fruit. According to them an increase in K level resulted in thinner, smoother peels and a higher percentage of juice. Embleton et al. (1967) confirmed the above results and added that massive applications of K also increased the L:D ratio of 'Eureka' lemons.

3.12.3 Phosphorus (P), Calcium (Ca) and Magnesium (Mg)

Phosphorus, Ca, and Mg resulted in a reduction in peel thickness, while P also resulted in a reduction in the L:D ratio of 'Valencia' oranges (Embleton et al. 1956). Jones et al. (1971) concluded that foliar applied Mg had no effect on peel thickness or juice content.

3.13 Effect of cultivar and rootstocks on fruit shape.

Letham (1969) showed that the application of cytokinin to flowers and fruitlets of apples can alter apple shape, and can promote, surpress, or not affect fruit elongation, depending on the variety of apple, and the amount of cytokinin applied.

Westwood and Blaney (1963) determined that rootstock significantly influenced fruit shape of 'Red Delicious' apple. Fruits from trees with non-dwarfing rootstocks were relatively more elongated than those from dwarfing rootstock. This was confirmed by Barritt et al. (1994).

Barritt et al. (1994) showed that fruit L:D ratio for 'Starkspur Supreme' and 'Redchief Delicious' apples varied with rootstocks and season. Fruit were more elongated during a cooler season. Trees on the most dwarfing rootstocks had the lowest fruit L:D ratio. As rootstocks increased in vigour from extremely dwarfing to semi-dwarfing, fruit L:D ratio was higher. Rootstocks accounted for 40 to 83% of the variation in the fruit L:D ratio, depending on the season and 'Delicious' strain. Greenhalgh and Godley (1976) found that when semi-vigorous and vigorous rootstocks were evaluated, it did not influence fruit shape.

Curry and Williams (1983) as well as Williams and Stahly (1969) explained the reduction in transport of GA across the rootstock/scion union as roughly proportional to the dwarfing effect of the rootstock. Given that 1) foliar- applied PGR's, GA and BA as well as other materials with PGR's-like or PGR's-inhibiting qualities can affect fruit shape, 2) that roots are a site of PGR's production, and 3) that rootstocks influence the transport of PGR's across the rootstock/scion union, it is possible that rootstocks may influence fruit shape by regulating PGR levels.

Avilàn et al. (1997) found that rootstocks modified the fruit dimension, weight and shape of mango's. These changes varied according to the scion/rootstock combination used. Observed differences in fruit shape and fruit size were more accentuated in certain cultivars.

In terms of citrus, Economides and Gregoriou (1993) found rootstock differences on 'Marsh' grapefruit affecting fruit size and weight, rind thickness, juice content, total soluble solids concentration and total acids, but the differences were not large enough to affect the market value of the fruit. Georgiou and Gregoriou (1999) confirmed this for 'Shamouti' orange. The effect of rootstocks on fruit shape of citrus was not reported.

4. Non-controllable factors influencing fruit shape

4.1 Climatic effects on fruit shape

In a study done by McKenzie (1971) in New Zealand, it was found that fruit shape in some apple varieties, notably 'Delicious', varied consistently with locality. He realised that the close correlation between spring soil temperature and mature fruit shape in some apple varieties suggests that factors controlling fruit development may be most influenced during the flower and fruitlet stage.

Shaw (1914) (cited by Barritt et al.,1994) reported that cooler periods shortly after bloom resulted in more elongated apples while Westwood (1962) (cited by Barritt et al.,1994) found that final fruit shape was determined within 100 days after full bloom.

Cohen et al. (1972) investigated the relationship between peel thickness and fruit shape of 'Marsh Seedless' grapefruit and various climatic factors. It was found that peel thickness was affected most by winter temperature preceding flowering. Low winter temperature resulted in fruits with thick peel in the following year. Fruit shape was affected to a similar degree by low winter temperature and summer air humidity. Summer temperature and the differences between maximum and minimum temperature in the spring (flowering period) and autumn (maturation period), had little effect on fruit shape and peel thickness. Cooper et al. (1963), as well as Reuther et al. (1969) found that attempts to determine the differences between thicker, rougher peel and fruit shape in different climatological regions, revealed that both temperature and humidity affect peel thickness, and that air and soil humidity had a greater effect than temperature. This might explain why fruit shape and rind thickness differ in coastal regions when compared to inland regions.

Results indicate that effects of low winter temperature are not on the fruits which are already on the tree, but rather on those which the tree will produce the following year (Cohen et al., 1972). Cohen et al. (1972) further suggested that low winter temperature

cause an increase in growth vigour of the tree and its shoots and thus affect peel thickness, while fruit shape was also affected by relative humidity. Cohen et al. (1967) (cited by Cohen et al., 1972) found fruit shape to change continuously throughout the growing season and therefore may also be affected by summer conditions.
Reuther et al. (1969) conducted a study comparing maturation and composition of 'Valencia' oranges in some major subtropical zones of the United States. Fruit differed in peel thickness, smoothness of the peel, fruit size, juice percentage and time of colouring. In general, rinds were thinner and smoother with larger, juicier fruit in regions where the minimum temperatures were the highest during the winter months. This suggests that with milder winter temperatures rinds are thinner and smoother. Seediness of the fruit was influenced by both location and season.

Wutscher (1976) found that for unknown reasons, varying from year to year and with geographical location, part of the grapefruit crop has an ovoid shape with high collared and depressed bases, giving the fruit a snoutlike appearance, more commonly known as "sheepnosing". It is more of a problem in inland than in coastal regions. Large fruit are also more likely to be "sheepnosed" than smaller fruit. Wutscher (1976) investigated effects of controlled environments on fruit shape of 'Redblush' grapefruit. It was found that day and night temperature played a significant role. Fruit grown under a 32°/30°C day/night temperature regime had creased stem-ends, while a 32°/24°C regime resulted in normal fruit, and 32°/7°C induced severe "sheepnosing". Reducing daylength from 14 to 11 hours had no influence on fruit shape.

Tucker and Reuther (1967) also discovered that juice content differed between the coastal and interior southern areas compared to central interior valleys and the low desert regions. The central interior and desert areas had distinctly less juice than the coastal and southern intermediate areas.

4.2 Seed-activity in relation to climate

Tromp (1995) found that it appeared for apples in New Zealand grown in regions with warmer, more humid conditions to be more flattened than apples grown in regions with cooler and drier conditions. Tromp (1995) also did studies in America that showed a difference in fruit shape between fruit on the north and south side of the tree. He found no difference in fruit shape for trees grown in indoor conditions with controlled air and soil temperature. This was in contrast to field studies where climate played a definite role in fruit shape. Tromp (1995) explained in saying that fruit shape is associated with the number of seeds per fruit. The association of fruit shape with temperature was the clearest when looking at the temperature in the time shortly after bloom. He said that this was the reason why climate had an influence on fruit shape only in the period of bloom and shortly thereafter via the influence of the number of seeds. In the controlled conditions there were no differences between the number of seeds at different conditions.

4.3 Positional differences

Webster and Crowe (1971) studied the effect of shade treatments on 'McIntosh' apples. It was indicated that the terminal fruit in a cluster in 'Delicious' apples is more elongated than the lateral fruits, and fruit on trees with a light crop load are more elongate than fruit from trees with a heavy crop load.

According to Watson and Gould (1993) kiwifruit shape is established early in the development of the floral bud. Lai et al. (1990) reported that fruit shape and size vary considerably both within and among kiwifruit vines.

4.4 The influence of light on fruit shape

Eccher (1986) realised that the shape and quality of apple fruit are greatly influenced by environmental factors. Apples grown on hills are more elongated and also less russeted than those grown in low valleys (Eccher, 1986; Eccher and Noe, 1993). Eccher (1986) found treatments with exogenous GAs to have the same effects on the elongation and russeting of apples at high altitudes. The opposite occurs when apple trees are treated with GA-inhibitors. It was concluded that apples grown in different light conditions showed slight, but significant differences in shape. It was hypothesised that light can interact with GA synthesis or activation, likely by involving photoreceptors. Eccher (1986) did not investigate the possible influence of temperature on fruit shape as opposed to light.

Noe and Eccher (1996) further found that shading increased the L:D ratio of the fruit and decreased the incidence of russeting. Natural light produced the lowest L:D ratio and the greatest amount of russeting. Blue/UV-B ratio had no consistent effect on fruit shape. The Red/Far-red ratio did not vary greatly among treatments and was not related to differences among fruit. The greatest elongation resulted from shading alone. Supplementary lighting antagonised the effects of shading. According to Noe and Eccher (1996) it is not yet clear which wavebands are involved and how light quality brings on these effects.

5. Conclusions

Growth regulators such as cytokinins, gibberellins and auxins seem to successfully alter fruit shape of apples, kiwifruit and persimmons. No known work has been reported on the effects of growth regulators on citrus fruit shape.

A relationship was found between 'Valencia' orange fruit size and the number of seeds per fruit, with more seeds resulting in larger fruit. The effect of the number of seeds on citrus fruit shape has not been reported.

Certain fertilisers had an effect on the rind thickness of orange or grapefruit, by either resulting in a rough, thick rind or a smoother, thinner rind.

Rootstocks affected apple and mango fruit shape. Rootstocks differences were also found on 'Marsh' grapefruit, affecting fruit size, rind thickness, juice content and total soluble solids.

Non-controllable factors influencing fruit shape include climatic effects, positional differences within the tree, and light conditions. Apple fruit were more elongated when temperatures after bloom were cooler. The "sheepnosing" effect of grapefruit was more common in cooler inland regions. In the case of 'Delicious' apples, terminal fruit in a cluster was more elongated than lateral fruit. Shading also increased the L:D ratio of apple fruit, while natural light produced fruit with the smallest L:D ratio.

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Paper I: Fruit shape of 'Eureka' lemon (*Citrus limon* L.): fruit growth, seeds count, number of segments, rind thickness and positional differences in the tree canopy.

Abstract

A study was undertaken to understand the fruit growth characteristics of 'Eureka' lemons which might determine final fruit shape. The length and diameter of fruit was measured regularly, starting from 2 weeks after full-bloom until harvest, to determine the critical growth period in which fruit increases in length and/or diameter. The fruit growth curve, illustrates 'Eureka' lemon fruit growth as sigmoidal. The change of length length:diameter (L:D) ratio of fruit over time shows fruit L:D ratio decreasing over the fruit growth period.

Factors speculated to influence final fruit shape measured by the L:D ratio, was also taken into account. This included number of segments, number of seeds and rind thickness at stylar and stem ends as well as rind thickness in the centre of the fruit. These factors were evaluated to determine their influence on final fruit shape. Fruit maturing early in the season had a smaller L:D ratio and had less or no seeds, whereas later maturing fruit were longer and had more seeds, with a larger L:D ratio. Fruit with more seeds had thicker rinds at all three areas measured. Number of seeds correlated with rind thickness at both stylar and stem end, resulting in fruit with a larger L:D ratio. At time of harvest, the position of fruit on the tree was also taken into account to determine whether there is a difference in fruit shape between fruit from leafy inflorescences and fruit from leafless inflorescences. Fruit from inside the canopy was compared to fruit outside the canopy. No significant differences of fruit shape were found between fruit from different positions in the tree.

Introduction

Early during fruit growth lemons have an elongated fruit shape, but this shape changes during the growing season (per. obs.), with some fruit being almost round at time of harvest. The length:diameter (L:D) ratio is calculated as an index of fruit shape. Bain (1958) divided 'Valencia' orange fruit growth into three major stages, viz. cell division (Stage I), cell enlargement (Stage II) and fruit maturation (Stage III). The rind reaches its maximum width at or shortly after the end of stage one. At the end of Stage I, cell division was completed in all areas except for the outermost flavedo layers. Bain (1958) described Stage II as a period of very rapid growth when cell enlargement takes place. Stage III was the maturation and ripening period. Fruit continued to grow while on the tree, but at a reduced rate compared to Stage II. It seems as though Bain's division into the above mentioned three growth stages is appropriate for most citrus fruits, although times and duration of developmental stages may vary, according to cultivar, climate and other factors (Spiegel-Roy and Goldschmidt, 1996).

Lemons from the same tree can differ distinctly from each other in terms of fruit shape. In a study done by Dennis (1976), it was determined that seeds are a major source of gibberellins. Vanoli et al. (1993) confirmed GA presence during cell enlargement in apples fruit, which seem to be initially linked with seed activity, and then directly synthesized in the fruit flesh. After reviewing literature in this field, Bukovac (1963) concluded that seedless apple fruit, induced to set by GA_3 and GA_4, were distinctly more elongate than normal-seeded fruit. Westwood and Bjornstad (1968) presented data showing fully-seeded apples to respond to GA_3 in producing longer fruit. In contrast to this, Buban et al. (1993) found no relationship between number of seeds and fruit shape in apples. Looney et al. (1992) found that, in general, seed number related more strongly to apple fruit diameter and weight than to fruit length. Goldschmidt (1983) applied lanolin pastes containing 0.02 to 1.0% GA_{4+7} on one side of developing citrus fruitlets at 30 days after anthesis which caused thickening of the rind in the treated zone involving the enlargement of the albedo cells. Cameron et al. (1960) showed that there is a positive relationship between fruit size and seed number in 'Valencia' oranges. Larger fruit size was clearly associated with greater number of seeds. Webster and Crowe (1971) concluded that the terminal fruit in a cluster in 'Delicious' apples is more elongated than the lateral fruits, and fruit on trees with a light crop load are more elongate than fruit from trees with a heavy crop load. Eccher (1986) concluded that apples grown in different light conditions showed slight but significant differences in shape. It was hypothesised that light can interact with GA synthesis or activation, likely by involving photoreceptors.

In this study it was attempted to determine the critical time of fruit shape change during the growing season, as this could help in determining the best time to manipulate fruit shape e.g. by means of chemical sprays. The influence of seed number, number of segments and rind thickness at three different parts of the fruit was investigated to determine their influence on L:D ratio. Fruit from leafy inflorescences were compared to fruit from leafless inflorescences, and fruit picked from inside the tree canopy were also compared to fruit picked from outside the canopy to determine whether inflorescence type and bearing position influence fruit shape.

Materials and Methods

Fruit growth

To determine fruit growth, 100 fruit were randomly selected and tagged on 25 trees (4 fruit per tree), two weeks after full-bloom. Fruit were measured weekly with a hand-held caliper, from early October 2000 until end of February 2001, and then every two weeks thereafter until harvest in early June 2001. At first, only fruit diameter was measured as the style was still attached to the fruit which made measurement of the fruit length difficult. As soon as the style abscised, fruit length was also measured. Some of the tagged fruit abscised as physiological fruit drop proceeded, and a total of 31 fruit persisted to harvest and were used to determine average length and diameter values for presentation as a fruit growth curve.

Rind thickness, number of seeds and number of segments and L:D ratio

Fifty trees were randomly selected in an orchard located in the Stellenbosch area in the Western Cape, South Africa (34°S 19°E, 146 m.a.s.l., Mediterranean-type climate). Nine-year-old 'Eureka' lemon trees grafted to rough lemon rootstock were used. One branch per tree was tagged and picked selectively three times during the 2001 cropping season. Measurements taken included the length, diameter, rind thickness in the centre of the fruit, as well as rind thickness at the stylar- and stem-ends of the fruit, with a hand-held caliper. Rind thickness included measurement of the albedo and the flavedo. The number of seeds as well as the number of segments per fruit were counted. All fruit per branch were picked as soon as they were mature, and thus fruit number per branch varied according to the number of fruit being mature at the time of harvest. At the first pick 708 fruit were harvested. Fruit from the first pick were the early fruit, not harvested by the producer, but were used in this study because of the high number of seedless fruit. 1082 fruit were picked at the second pick and 351 for the third pick. For data-analysis, fruit were divided into three groups; fruit with L:D ratio of 1.0 to

1.24 were classified as round, fruit with L:D ratio of 1.25 to 1.35 were classified as medium elongated whereas fruit with L:D ratio of 1.36 and higher were classified as elongated fruit. Data were analysed by using the STEPDISC (Stepwise Discriminant Analysis), as well as the CANDISC (Canonical Discriminant Analysis) procedures in the SAS (Statistical Analysis System) programme (SAS Institute Inc., 1990).

Position of fruit on the tree

To evaluate fruit shape from fruit of different positions in the tree, 500 fruit from 25 randomly selected trees were picked from a position inside the canopy and 500 fruit were picked from outside the canopy of the same tree. Fruit from leafy (1206 fruit) and leafless (935 fruit) inflorescences were picked. Data were analysed by the PROC GLM procedure in the SAS programme.

Results and Discussion

Fruit growth

Figure 1 and Figure 2 illustrate growth curves of 'Eureka' lemon and the change in L:D ratio, respectively. The length and diameter increased, (Figure 1) following a sigmoidal growth pattern as also described by Bain (1958). However there was a decrease in L:D ratio over time (Figure 2). This suggests that fruit increase more in diameter than in length over time. A reason for this can be that the calyx of the fruit was also measured at each measurement date and, while the fruit was still small, this constituted a large percentage of the length of the fruit. The calyx contribution decreased relatively in size (length) as the fruit continued to grow (per. obs).

Fruit shape as influenced by number of seeds, number of segments and rind thickness

Fruit with more seeds had thicker rinds at the stylar- and stem-ends as well as in the centre of fruit (Table 1). Using stepwise discriminant analysis, five variables which influence L:D ratio were selected when fruit of all three harvest dates were included in the analysis (Table 2). The first variable selected was number of seeds, followed by rind thickness at stem end, number of segments, rind thickness at stylar end and rind thickness in centre of fruit. All variables were selected. With a canonical discriminant analysis, using the five variables selected by the

Stepdisc procedure, Figure 3 shows round, medium and elongated fruit grouped together, with not a very clear distinction between the groups, although the elongated fruit are grouped slightly more to the right. The results suggest that number of seeds and rind thickness at either stylar or stem end are the major factors influencing the L:D ratio of 'Eureka' lemons. Number of seeds strongly correlates with rind thickness at either stem or stylar end. Seed number at first pick were low, and fruit had a smaller L:D ratio (Table 3), when compared to second and third pick with more seeds and a larger L:D ratio. Pollination and fertilisation is essential for seed production. Fruit from the first pick developed during cooler spring temperatures, whereas fruit from the second and third pick developed during warmer temperatures. According to Davies and Albrigo (1994), temperature has a significant effect on pollination. The effect can be direct or indirect. Bees are the primary citrus pollinators. Bee activity is minimal when temperatures are below 12.5°C. Direct effects include the rate of pollen tube growth. At temperatures below 20°C, pollen tube growth rate is reduced or totally inhibited. When seed number for different times of fruit set are compared, the latter temperature effect is more likely to be the explanation for differences in seed number. 'Eureka' lemons are self-compatible, and bee activity may have a smaller effect than pollen tube growth.

It has been reported by Dennis (1976) and Vanoli et. al. (1993) that seeds are a major source of gibberellins. Goldschmidt (1983) applied lanolin pastes containing 0.02-1.0% GA_{4+7} on one side of developing citrus fruitlets and caused thickening of the rind in the area of the treated zone. It involved the enlargement of the albedo cells. It is possible that gibberellins from seeds can result in rind thickening at either stem or stylar end resulting in fruit having a larger L:D ratio. If this is the case it means that fruit with a larger seed count has a larger L:D ratio as a result of a thickened part of the rind, rather than the endocarp (edible part) comprising a larger part of the fruit.

Position of fruit on the tree

Fruit shape from fruit that developed on leafy inflorescences and leafless inflorescences were compared (Table 4). No significant differences in length, diameter or L:D ratio were recorded. According to Ross (1991), young leaves are thought to be major sites for gibberrellin synthesis, while El-D et al. (1979) indicated that leaves have the capacity to produce cytokinins, provided that sufficient levels of inorganic nutrients reach the leaves. If fruit shape is related to endogenous hormones, fruit on leafy inflorescences supposedly be more readily supplied with endogenous hormones, should be more elongated. From the data presented this hypothesis does not seem to be true.

No differences in L:D ratio were found when fruit from inside the tree canopy was compared to fruit from outside the canopy (Table 5). Fruit from inside the canopy was however significantly larger than fruit from outside the canopy. Noe and Eccher (1996) found that shading increased the L:D ratio of the fruit and decreased the incidence of russeting of apples. Natural light produced the lowest L:D ratio. The non-significant L:D ratio difference shown in Table 5, might be due to good light distribution in lemon trees in general, with small parts of the canopy being completely shaded. The sampled trees used were open and "light friendly", and thus no big differences in light conditions existed within the canopy.

Conclusion

Fruit with a smaller L:D ratio at the first, early pick had no seeds, while fruit harvested later, had a larger number of seeds, and a thickened rind at both stem and stylar end, increasing the L:D ratio of fruit. Promoting seeded fruit development in the orchard by using cross-pollinators or bees will not be advantageous, since consumers prefer seedless fruit. Positional differences and different flowering positions does not seem to affect the L:D ratio.

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Table 1. Comparison of seed count, number of segments and rind thickness in relation to 'Eureka' fruit shape for the first, second and third pick combined.

Eureka fruit shape *	Number of fruit harvested	Averge number of seeds	Average number of segments	Rind thickness In centre of fruit	At stylar end	At stem end
Round	797	3.611 c	9.45 a	4.99 c	12.55 c	8.58 c
Medium	640	7.24 b	9.26 b	5.30 b	14.05 b	9.73 b
Elongated	704	11.06 a	9.105 c	5.76 a	15.70 a	11.37 a
Significance		0.0001	0.0001	0.0001	0.0001	0.0001
LSD (P=0.05)		0.68	0.111	0.16	0.37	0.32

*Round: L:D ratio of 1.0 to 1.24

Medium: L:D ratio of 1.25 to 1.35

Elongated: L:D ratio of 1.36 and higher

Table 2. Summary of the stepwise discriminant analysis performed on different components of 'Eureka' lemon fruit for first, second and third picks combined.

	Variable		Number	Partial	F	Prob
Step	**Entered**	**Removed**	**In**	**R**2**	**Statistic**	**>F**
1	Seeds		1	0.1838	240.731	0.0001
2	Stem		2	0.0740	85.383	0.0001
3	Segments		3	0.0374	41.484	0.0001
4	Stylar		4	0.0199	21.647	0.0001
5	Centre		5	0.0071	7.625	0.0005

Seeds: Number of seeds per fruit

Stem: Rind thickness at stem end

Segments: Number of segments per fruit

Stylar: Rind thickness at stylar end

Centre: Rind thickness measured in centre of fruit

Table 3. Mean values of length, diameter, number of seeds, number of segments and rind thickness at stylar end, stem end and in centre of fruit, for three different times of harvest.

						Rind thickness		
	Length (L)	**Diameter (D)**	**L:D**	**Average number of seeds**	**Average number of segments**	**In centre of fruit**	**At stylar end**	**At stem end**
1 Pick	68.79 c	56.43 b	1.22 c	0.4 c	9.0 b	4.79 c	12.1 c	8.65 c
2 Pick	72.57 b	55.03 b	1.33 b	9.5 b	9.0 a	5.50 b	14.42 b	10.30 b
3 Pick	73.95 a	54.78 b	1.35 a	13.5 a	9.0 ab	5.92 a	16.61 c	10.83 a
Sig.*	0.0001	0.0001	0.0001	0.0001	0.0567	0.0001	0.0001	0.0001
LSD	1.04	0.78	0.014	0.61	0.12	0.17	0.40	0.37

*Significance

LSD= (P=0.05)

Table 4. Fruit shape comparison between fruit developing on leafy inflorescences or leafless inflorescences.

	Length (L)	**Diameter (D)**	**L:D ratio**
Leafless inflorescences	71.78 a	55.51 a	1.30 a
Leafy inflorescences	71.36 a	55.40 a	1.29 a
Significance	0.3000	0.7202	0.4827
LSD (P=0.05)	0.790	0.580	0.011

Table 5. Fruit shape comparison of fruit picked from inside of canopy and fruit picked from outside the canopy.

	Length (L)	**Diameter (D)**	**L:D ratio**
Fruit from inside of canopy	81.02 a	59.15 a	1.37 a
Fruit from outside of canopy	77.53 b	57.10 b	1.36 a
Significance	0.0001	0.0001	0.162
LSD (P=0.05)	1.08	0.63	0.016

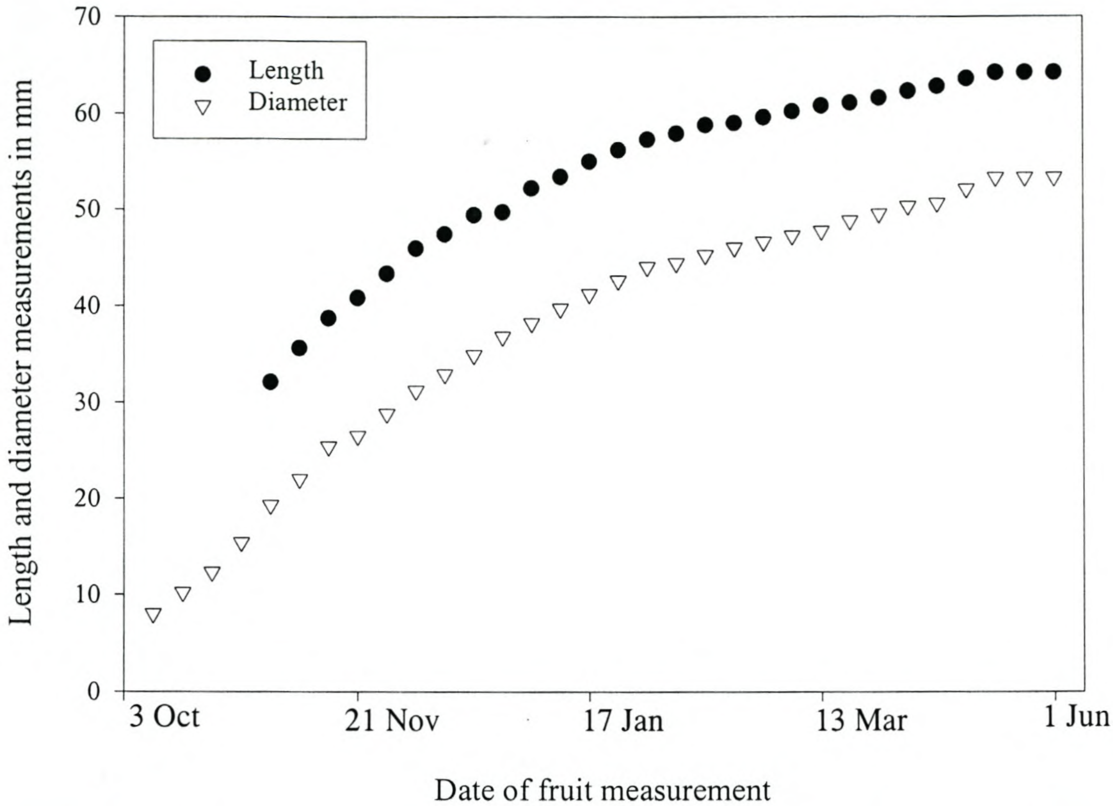


Figure 1. Length and diameter growth of 'Eureka' lemons, from 2 weeks after full-bloom to harvest in the Stellenbosch region of the Western Cape, South Africa.

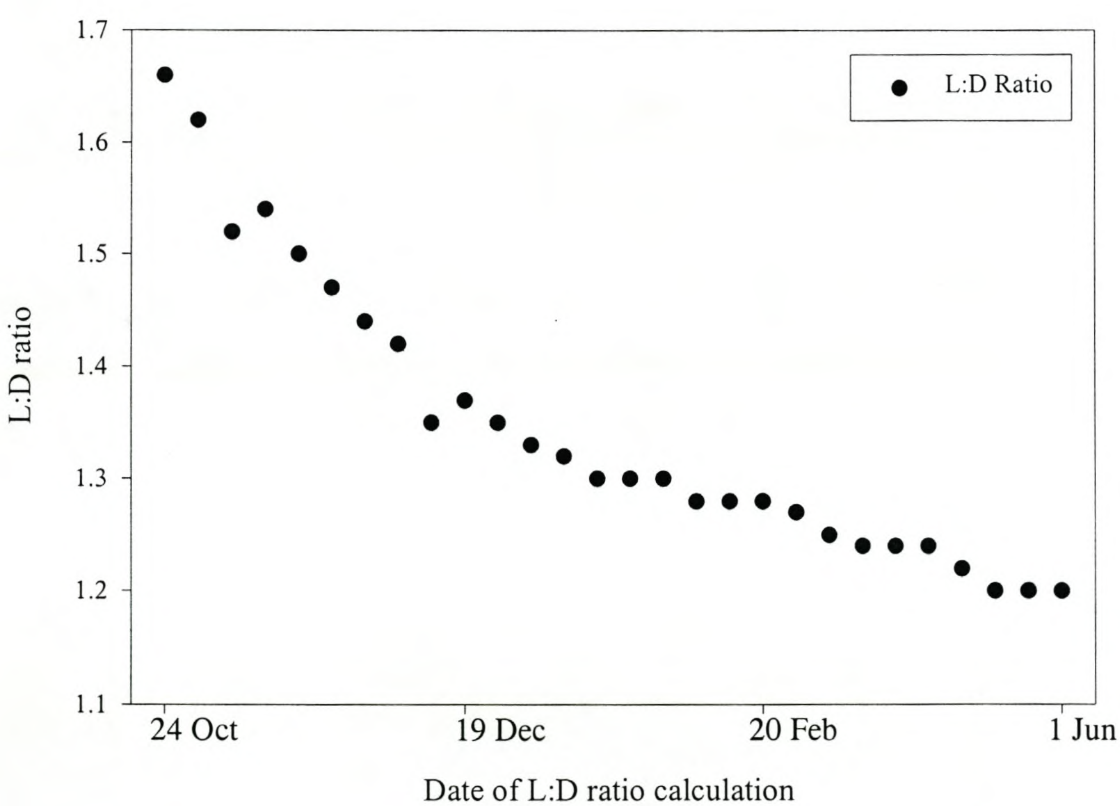
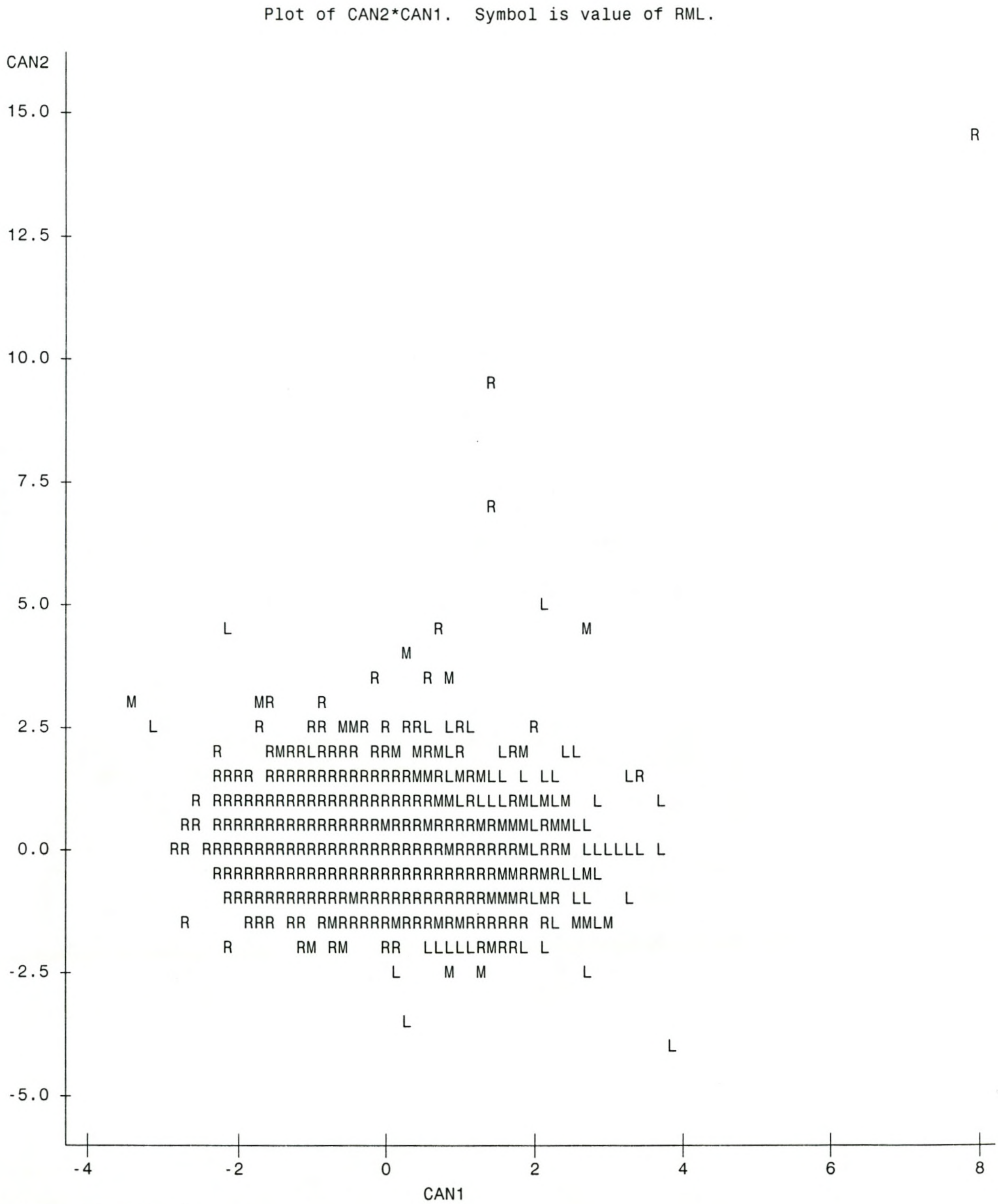


Figure 2. The change of 'Eureka' lemon fruit shape as calculated by the L:D ratio, in the Stellenbosch region of the Western Cape, South Africa.

Figure 3. Discriminant analysis of Round (R), medium (M) and elongated (L) fruit using five variables as selected in the Stepdisc procedure.



NOTE: 1809 obs hidden.

Paper II: 'Eureka'(*Citrus limon* L.) lemon fruit shape relative to different climatic regions in South Africa.

Abstract

Premium prices are obtained in the Japanese market for lemons with an elongated fruit shape. Fruit shape is expressed as the length to diameter (L:D) ratio of fruit. Fruit with a L:D ratio of 1.25 and higher are preferred in Japan. Comparisons were made of the L:D ratio of 'Eureka' lemons in six (2000) and five (2001) different climatic production areas in South Africa, to determine whether climatic differences and time of fruit initiation influenced the fruit shape of lemon fruit. Measurements were taken over two cropping seasons. Different times of harvest were also compared to determine whether time of fruit initiation has an influence on 'Eureka' lemon fruit shape. The locations were Stellenbosch, Western Cape; Citrusdal, Western Cape; Uitenhage, Eastern Cape; Addo, Eastern Cape; Vaalharts, Northern Cape and Nelspruit, Mpumalanga. Areas with the lowest winter temperature, when flowers are initiated, produced fruit with the largest L:D ratio, whereas areas such as Nelspruit with a milder winter had fruit with a rounder fruit shape. The time of harvest also influenced fruit shape. Differences between times of harvest are however smaller when compared to differences between different production areas.

Introduction

Premium prices are paid for attractive fruit. Factors influencing fruit appearance include fruit colour, rind thickness as well as fruit shape in the case of citrus. Apples of the 'Delicious' cultivar are not competitive in some Asian markets unless they display distinct angularity (Looney, 1993). Similarly the Japanese market prefers lemons with an elongated shape. Fruit shape is measured by the length:diameter (L:D) ratio. Class 1 fruit with an L:D ratio from 1.25 and higher qualifies for export to Japan. By increasing the number of fruit with a larger L:D ratio, more fruit can be exported and higher prices can be obtained. McDonald and Hillebrand (1980) compared physical and chemical characteristics of lemons from several countries. Lemons from South Africa, amongst other countries, proved to be rounder than fruit from Spain and Turkey. Cohen et al. (1972) investigated the relationship between peel thickness and fruit shape of 'Marsh Seedless' grapefruit and various climatic factors. It was found that peel thickness was affected most by winter temperature preceding flowering. Low winter temperature resulted in fruit with thick peel in the following year. Fruit shape was affected to a similar degree by low winter temperature and summer air humidity. Summer temperature and the differences between maximum and minimum temperature in the spring (flowering period) and autumn (maturation period), had little effect on fruit shape and peel thickness. Results indicate that effects of low winter temperature are not on the fruits which are already on the tree, but rather on those which the tree will produce the following year (Cohen et al., 1972). Cohen et al. (1972) further suggested that low winter temperature cause an increase in growth vigour of the tree and its shoots and thus affect peel thickness, while fruit shape was also affected by relative humidity. Wutscher (1976) found that for unknown reasons, varying from year to year and with geographical location, part of the grapefruit crop has an ovoid shape with high collared and depressed bases, giving the fruit a snoutlike appearance, more commonly known as "sheepnosing". It is more of a problem in inland than in coastal regions. Wutscher (1976) investigated effects of controlled environments on fruit shape of 'Redblush' grapefruit. It was found that day and night temperature played a significant role. Fruit grown under a 32°C/30°C day/night temperature regime had creased stem ends; a 32°/24°C regime resulted in normal fruit, and 32°C/7°C induced severe "sheepnosing". In a study done by McKenzie (1971) in New Zealand, it was found that fruit shape in some apple varieties, notably 'Delicious', varied consistently with locality. Shaw (1914) (cited by Barritt et al., 1994) reported that cooler periods shortly after bloom resulted in more elongated apples and also that Westwood (1962) found that final fruit shape was determined within 100 days after full bloom. In this paper presented, different climatic regions are compared, to determine whether some areas produce longer lemons than others based on the hypothesis that temperature during fruit initiation the previous season plays a significant role in final fruit shape. Different times of fruit set were also compared.

Materials and Methods

Six lemon orchards in South Africa were selected to measure fruit L:D ratio during all the harvest dates of each cropping season for 2000 and 2001. The six orchards are located at Stellenbosch (34°S, 19°E,146 m.a.s.l.), Western Cape, Citrusdal, (32°S 19°E, 198 m.a s.l.), Western Cape; Uitenhage, (34°S 25°E, 110 m.a.s.l.) Eastern Cape, Addo, (33°S 25°E 152 m.a.s.l.), Eastern Cape; Vaalharts (28°S 25°E 1175 m.a.s.l), Northern Cape and Nelspruit, (25°S 31°E, 660 m.a.s.l.), Mpumalanga. At least 300 'Eureka' lemon (*Citrus limon* L.) fruit samples per area were taken during each harvest time in 2000 and 2001. In some areas larger samples were taken. Where possible, specific picking dates are given in the Appendix of Paper I. The same scion/rootstock combination was not available in all areas and thus 'Eureka' lemons were sampled from trees on different rootstocks. Rough lemon was however the rootstock most readily available, and 'Eureka' lemon on rough lemon rootstock is thus also compared between areas where possible. Samples were taken randomly throughout each orchard. The same orchards were used for the 2001 cropping season, except for Citrusdal where a different orchard was used. Nelspruit was not used during the 2001 cropping season. Length and diameter of fruit were measured with a hand-held caliper and the L:D ratio was calculated. Long-term weather data was calculated by using average temperatures over 16 years (from 1984 to 2000). Plant material differed from area to area and is summarised in Table 1. Details of the number of measurements per area, rootstock and tree age is also summarised in Table 1.

Statistical analysis

Three variables were measured viz. fruit diameter (D) in mm, fruit length (L) in mm and L:D ratio. As already mentioned these variables were measured for different scions on different rootstocks for different times of fruit set, resulting in a very large data set for both the 2000 and 2001 cropping season. A multitude of combinations between area, scion, rootstock and harvest can be formed. There are a number of ways to describe data. One way is univariate descriptive methods. These methods include histograms, density plots and boxplots, where one variable at a time is described. A box plot is a pictorial display that indicates the two extreme values of the data set, where the data are centered, and how spread out the data are. It provides a five-number summary of the data. Values plotted include the largest value, the smallest value, the upper and lower quartile, and the median. Outliers, representing unusually large or small values, are also plotted.

The shape of the distribution of data can also be described in a simple way by constructing a histogram. The area of any rectangle in the frequency histogram is proportional to the relative frequency or proportion of observations falling into that class. The probability histogram is a frequency histogram that has been standardised so that the total area of all the bins equals one, and thus can be used as a density estimate. Density plots used in this paper, are based on the probability histogram. All three variables measured are continuous. Since a histogram arbitrarily splits the continuous variable into a number of non-overlapping bins it can be regarded as a crude approximation of a continuous density function unless the number of bins becomes large. Therefore a density estimate is a better approximation of the underlying density function. Furthermore two main difficulties with the probability histogram are estimating the underlying density function and choosing the bin width as well as the starting point of the first bin. Kernel density estimators combined with optimising functions for determining the bin width address these difficulties. These estimators are also smooth functions as opposed to the jagged estimators produced by the construction of histograms.

Multivariate descriptive methods include the biplot. A biplot is the simultaneous display (usually in two dimensions) of the rows (e.g. the various lemon selections) and columns (the variables) of a data matrix. Biplots allow the examination of the multivariate distribution of all continuous variables of interest for a sample as well as the structure of various categorical groupings relative to the multidimensional distribution. This is achieved by approximating the multivariate distribution in fewer, usually two, dimensions. A biplot can be regarded as the multivariate analogue of an ordinary scatter plot (Gower and Hand, 1996; Gardner, 2001). The variables (three in this paper) are represented as calibrated (in the original units) axes while the data points are interpolated onto the two dimensional display. It is to be noted that "bi-" of biplots refers to the simultaneous display of the rows and the columns of a data matrix and not to whether the resulting graph is two-or three-dimensional. The values of a paticular sample point can be read from the biplot axes by projecting onto the respective axes. Different types of biplots can be constructed. A principle componenet analysis (PCA) biplot is used for displaying variances of the multidimensional data. In this paper canonical variate analysis (CVA) biplots were constructed. A CVA biplot aims to separate group means optimally. Hence a CVA biplot is similar to a discriminant analysis. Apart from displaying the group means all sample points (using different colours or plotting symbols for the different groups) are also interpolated onto a CVA biplot. The difficulty with biplots of large data sets is overplotting, leading to uninformative graphs. To overcome the overplotting difficulties of the biplot, a bagplot (Rousseeuw et al. 1999) can be superimposed on a biplot.

The bagplot which is used to describe two-discriminant data, extends the utility of the boxplot by allowing the consideration of a bivariate distribution. Apart from the location, variation, skewness, tails and outliers of a bivariate distribution, the bagplot also gives an indication of the correlation of the two variables under consideration. The main component of the bagplot is a bag that contains 50% of the data. Inflating the bag by a factor of approximately three, the fence is obtained. The fence encloses the loop that contains points neither in the bag nor outliers. Inside the bag, the depth median is marked. The depth median visualises the location of the data. The orientation of the bag is indicitive of the correlation of the variables as well as the skewness of the data. Points near the fence give an idea of the tails of the bivariate distribution. The degree of overlap between groups displayed in a biplot can be quantified by extending the bagplot to the concept of an alpha bag (Gardner, 2001). An alpha bag is drawn to enclose the deepest 100 alpha % of the data points. It provides a quantitative measure of overlap by finding the smallest alpha for which there is no overlap.
The statistical analysis was carried out using the S-Plus package.

Results and Discussion

Figure 1 shows the length, diameter and L:D ratio boxplots for the 2000 cropping season, respectively. The notch (blue coloured part of the box) provides a non-parametric 95% confidence interval for the median (S-Plus, 2000). The notches may be compared pairwise. Non-overlapping notches mean that the hypothesis that the two population medians are the same should be rejected at an appropriate 95 % confidence level (S-Plus, 2000). It is clear that Vaalharts is the area standing out with the notches not overlapping with the other areas (Figure 1). For the 2001 cropping season it is again Vaalharts having notches not overlapping with other areas (Figure 2). Vaalharts is however joined by Addo in the 2001 cropping season. Data was at first analysed by using traditional analysis of variance (AVOVA) (data not presented). With *P* approaching 0 in all cases, H_0 is rejected at a very small significance level. Therefore, further analysis was done using simultaneous Scheffe 99 % confidence intervals (data not presented). The hypothesis that the difference between the respective population means is zero, is rejected at a 1 % significance level with intervals excluding zero. Highly significant differences were found for the majority of comparisons made. These differences are however measured relative to zero. From a commercial point of view these differences are not always large enough to significantly alter the fruit shape appearance of lemons. It was difficult to compare areas as almost all comparisons made differed significantly. For this reason, it was decided to make use of more unconvensional statistical analysis, to provide a better insight into the areas and overlapping of data from different areas, by using density plots and alpha bags.

Vaalharts was the area with fruit having the largest L:D ratio for the first pick of the 2000 cropping season with the spread of the data lying towards the larger L:D ratio (Figure 3). For the second pick Addo and Uitenhage were the two areas having fruit with largest L:D ratio, with Vaalharts being absent, but the difference was small when compared to other areas (Figure 3). Table 2 shows the mean and standard deviation for all 'Eureka' lemons measured in an area for the 2000 cropping season. Vaalharts had the largest mean L:D ratio (Table 2). The overlap of fruit measured from the different areas are shown in

Figure 4. All three variables (L, D and L:D) can be compared at once by using alpha bags. Vaalharts clearly having the most fruit with a large L:D ratio, and the Nelspruit fruit having the smallest L:D ratio. Fruit from Nelspruit and Vaalharts did not overlap over a large area, showing that the majority of fruit from Vaalharts are elongated, which was not the case for Nelspruit. It is also clear that Vaalharts did not have fruit with a larger L:D ratio because of a smaller diameter. In the 2001 cropping season, Vaalharts was again the area having fruit with the largest L:D ratio for the first pick, followed by Addo (Figure 5). Vaalharts had fruit with a smaller L:D ratio than in the 2001 cropping season, and fruit was not as significantly elongated as in the 2000 cropping season when compared to other areas. Citrusdal was the area with fruit having the smallest L:D ratios. Vaalharts and Addo had the largest L:D ratios for the second pick (Figure 5). Citrusdal was the area standing out as the area with the smallest L:D ratio (Figure 5). Table 3 shows the mean and standard deviation, showing Vaalharts to have the largest mean L:D ratio, followed by Addo, and Citrusdal having the smallest mean L:D ratio.

All three variables can be compared in the 95% alpha bag (Figure 6). As in the 2000 cropping season, fruit did not have a larger L:D ratio because of a smaller diameter, with Vaalharts and Addo having fruit spread more towards the larger L:D ratio for both first and second pick.

Figure 7 shows the different areas for the first and second pick, respectively, of the 2000 cropping season, with 'Eureka' lemon budded on rough lemon rootstock. Vaalharts is again clearly the area with fruit having the largest L:D ratio, with Citrusdal and Nelspruit having the roundest fruit (Figure 7). This was also the case for 'Eureka' lemon budded on a variety of rootstocks. For the second pick (2000), Addo was the area with longest fruit (Figure 7) and Nelspruit having the roundest fruit. Vaalharts (first pick) having the largest mean L:D ratio, while Addo (second pick) having the largest mean L:D ratio and Stellenbosch was the area having fruit with smallest mean L:D ratio (Table 4). From Figure 8, it is clear that fruit from Vaalharts and Nelspruit overlaps over a small area only, with Nelspruit being the area with fruit having the smallest L:D ratio.

Figure 9 shows the different areas for the first and second pick respectively (2001 cropping season), with 'Eureka' lemon budded on rough lemon rootstock. Vaalharts and Addo is the area with fruit having the largest L:D ratio, while Uitenhage had the roundest fruit for the first pick (Figure 9). Vaalharts also had the most elongated fruit for the second pick (Figure 9). Table 5 shows the mean and standard deviation for 'Eureka' lemon budded on rough lemon rootstock. The overlapping of fruit measured from different areas can be compared when studying Figure 10. Vaalharts (first and second pick) and Addo (first pick) lying towards the areas with a larger L:D ratio. It is again clear that the elongated lemons had a larger L:D ratio because of a larger length and not because of a smaller diameter. All trees were budded on rough lemon rootstock, but this did not influence the results, with Vaalharts still having fruit with the largest L:D ratio.

Figure 11a compares fruit shape of different times of harvest for the 2000 and 2001 cropping season in Addo. Fruit from the first pick in both cropping seasons had a larger L:D ratio and decreased for later harvests. Fruit from the 2001 cropping season was slightly longer than in the 2000 season. Uitenhage had little difference in fruit shape from different picking dates as well as between different cropping seasons (Figure 11b).

Figure 11c shows Vaalharts having fruit with largest L:D ratio for the first pick in 2000 cropping season. As was the case in most areas, fruit from the first pick was slightly more elongated than fruit from the second pick in the 2001 cropping season. Figure 12a shows the situation for the Stellenbosch area. The second pick of 2001 having longer fruit than the first pick. Fruit from 2000 seemed to be longer than fruit from the 2001 season. Figure 12b shows the same data for the Citrusdal area. Fruit from later harvests being rounder than for the first harvest. The differences was small however, fruit from the 2000 season being longer than for 2001 season. It must be kept in mind that different orchards were used for measurements in the 2000 and 2001 cropping seasons at Citrusdal, and also that the orchards received no fertilization. In the case of Nelspruit, fruit from the first pick was longer than from the second pick (Figure 12c). No fruit were measured in Nelspruit in the 2001 season.

Table 6 shows Vaalharts had the largest percentage of fruit exportable to Japan, with fruit having the largest L:D ratio. Nelspruit had a high percentage of fruit suitable for export, but mean values of L:D ratios was low (Table 2). Fruit from Nelspruit was thus suitable for export, but fruit from Vaalharts was more elongated and thus more suitable for export to the Japanese market. From Table 6, it is also clear that a larger percentage of fruit from first pick are suitable for export, when compared to second and third picks. The difference is marginal however.

Flower induction involves the events directing the transition from vegetative growth to the production of inflorescences (Davenport, 1990). Cold temperatures and water stress are the primary inductive factors, with cold being the primary factor in subtropical climates (Davies and Albrigo, 1994). Fruit from later picks are initiated at higher winter temperatures, while fruit from the first pick are initiated around July, when it is the coldest. Cohen et al. (1972) investigated the relationship between peel thickness and fruit shape of 'Marsh Seedless' grapefruit and various climatic factors. It was found that peel thickness was affected most by winter temperature preceding flowering, i.e. lower winter temperatures resulted in fruits with thicker peel in the following year. Fruit shape was affected to a similar degree by low winter temperature and summer air humidity. Summer temperature and the differences between maximum and minimum temperature in the spring (flowering period) and autumn (maturation period), had little effect on fruit shape and peel thickness. The colder winter temperature during initiation of first pick fruit, might be the reason for more fruit having a desirable L:D ratio.

Colder winter temperatures, differing from area to area, also seems to be the reason for some areas producing longer lemons than others. From Figures 4, 6, 8 and 10 it is clear that Vaalharts was the area with fruit having the largest L:D ratio for both 2000 and 2001 cropping season with the spread of the data being more towards the larger L:D ratio. Nelspruit was the area with fruit having the smallest L:D ratio. Based on the hypothesis that fruit produced in areas with a lower winter temperature when fruit are initiated, it seems that winter temperature plays a significant role in lemon fruit shape. In the 2001 cropping season, large L:D ratios of fruit from Vaalharts was followed by fruit from

Addo. Figure 13 shows the long-term minimum and maximum temperatures for 16 years. Vaalharts clearly has the lowest minimum winter temperature, differing from the other areas by at least 5°C. Addo had the second lowest winter temperature. Nelspruit and Stellenbosch are the two areas having the mildest winter temperatures, with Nelspruit having the roundest fruit. Uitenhage and Citrusdal were intermediate areas relative to fruit shape. With the exception of Citrusdal, this agrees with the hypothesis that cooler winter temperatures produces fruit with a larger L:D ratio.

Comparing fruit shape of two cropping seasons, fruit from Vaalharts, Citrusdal, Uitenhage, Stellenbosch were more elongated in the 2000 cropping season. Addo however had more elongated fruit in the 2001 cropping season. The difference in fruit shape between the 2000 and 2001 was however very small when studying the mean L:D ratio (data not presented). Comparing the average maximum and minimum temperatures for the three winter months of June, July and August of the 2000 and 2001 cropping season, there are small differences in minimum as well as maximum temperatures. This might explain the marginal difference in fruit shape of the 2000 and 2001 cropping season for all areas. The difference in mean maximum temperatures for the two years did not exceed 1.3°C and the difference in mean minimum temperatures did not exceed 0.7°C (Table 7). Uitenhage was an exception with minimum temperatures differing by as much as 3.6°C. In spite of this relative large temperature difference, Uitenhage did not have a large difference in fruit shape when 2000 and 2001 cropping season were compared.

The difference in fruit shape linked to minimum winter temperature agrees with findings of other researchers, showing winter temperature to influence fruit shape of citrus fruit as well as apples (Mckenzie, 1971; Cohen et al. 1972; Wutscher, 1976; Barritt et al. 1994). Natural gibberellins accumulate in cold-requiring species during exposure to low temperature (Salisbury, 1991). Gibberellins are known to promote elongation of intact plants and alter leaf shape (Ross, 1991). Gibberellins also have a thickening effect on the rind of citrus fruit (Goldschmidt, 1983). It might be possible that the colder winter temperatures result in build-up of gibberellins. The increase in gibberellins can result in elongation of fruit by an increase of fruit growth in the right direction or by the thickening of the rind at the stylar- or stem-ends, resulting in fruit with a larger L:D ratio. It also seems that the difference in minimum and maximum temperatures are not the only factor influencing fruit shape and that factors such as number of seeds may also play an important role in 'Eureka' lemon fruit shape (Paper I).

Embleton et al. (1967) used high levels of K to increase the L:D ratio of 'Eureka' lemons. It must be kept in mind that orchards in Citrsudal did not receive any fertilisation. Trees were in a bad condition and this might have had an effect on fruit shape.

Conclusions

It is clear that Vaalharts had the most elongated lemons and also having the lowest winter temperatures. Nelspruit had fruit with the smallest L:D ratio, and also had the highest winter temperatures. Fruit shape can thus be linked to minimum winter temperatures, areas with a lower winter temperature having fruit with a more elongated shape. There was a marginal difference of fruit shape from the first pick when compared to fruit from the second pick. This might be due to fruit of the first pick being initiated at the coldest time of year, while fruit of later picks are initiated at a time of slightly higher minimum temperatures, resulting in a small fruit shape difference.

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Table 1. Summary of rootstocks, tree age and number of measurements per rootstock/scion combination measured for Addo, Citrusdal, Stellenbosch, Nelspruit, Uitenhage and Vaalharts for both 2000 and 2001 cropping season. (Rosehaugh = Rosehaugh Empress, Carrizo = Carrizo citrange).

Area	Pick	Year	Rootstock	Tree age	Number of measurements
Addo	1	2000	Rosehaugh	8	75
	1	2000	Volckameriana	8	80
	1	2000	Carizzo	8	80
	1	2000	Rough lemon	8	80
	2	2000	Rosehaugh	8	79
	2	2000	Volckameriana	8	80
	2	2000	Carizzo	8	80
	2	2000	Rough lemon	8	75
	1	2001	Rosehaugh	9	180
	1	2001	Volckameriana	9	180
	1	2001	Carizzo	9	180
	1	2001	Rough lemon	9	170
	2	2001	Rosehaugh	9	150
	2	2001	Volckameriana	9	240
	2	2001	Carizzo	9	120
	2	2001	Rough lemon	9	120
	3	2001	Rosehaugh	9	160
	3	2001	Volckameriana	9	190
	3	2001	Carizzo	9	150
	3	2001	Rough lemon	9	120
Uitenhage	1	2000	Rough lemon	8	150
	2	2000	Volckameriana	8	150
	1	2001	Rough lemon	9	150

	2	2001	Volckameriana	9	150
Citrusdal	1	2000	Carizzo	8	103
	1	2000	Citremon	5	43
	1	2000	Rosehaugh	8	75
	1	2000	Volckameriana	8	68
	1	2000	Rough lemon	8	73
	2	2000	Carizzo	8	41
	2	2000	Citremon	5	46
	2	2000	Rosehaugh	8	58
	2	2000	Volckameriana	8	104
	2	2000	Rough lemon	8	89
	1	2001	Rangpur	9	300
	2	2001	Rangpur	9	313
Nelspruit	1	2000	Minneola trifoliate	2	318
	1	2000	Rough lemon	2	186
	1	2000	Sour orange	2	210
	1	2000	X639	2	200
	2	2000	Minneola trifoliate	2	200
	2	2000	Rough lemon	2	200
	2	2000	Sour orange	2	200
	2	2000	X639	2	194
Stellenbosch	1	2000	Rough lemon	8	495
	2	2000	Rough lemon	8	310
	1	2001	Rough lemon	9	300
	2	2001	Rough lemon	9	301
Vaalharts	1	2000	Rangpur	5	250
	1	2000	Rough lemon	5	100
	1	2001	Rangpur	6	560
	1	2001	Rough lemon	6	370

2	2001	Rangpur	6	300
2	2001	Rough lemon	6	300

Table 2. Mean and standard deviation values of the length (L), diameter (D) and L:D ratio measured on 'Eureka' lemon fruit from six different areas in the 2000 cropping season.

Pick	Area	Length	Diameter	L:D Ratio
1	**Addo**	83.89 ± 9.45	63.09 ± 5.74	1.33 ± 0.11
1	**Citrusdal**	71.78 ± 8.31	55.55 ± 4.83	1.29 ±0.11
1	**Nelspruit**	77.18 ± 7.19	58.96 ± 4.68	1.31 ±0.08
1	**Stellenbosch**	77.29 ± 8.81	57.48 ± 5.21	1.35 ±0.13
1	**Uitenhage**	76.53 ± 9.60	56.99 ± 6.53	1.35 ±0.13
1	**Vaalharts**	98.11 ± 8.78	63.23 ± 5.20	1.55 ±0.11
2	**Addo**	80.68 ± 9.18	61.53 ± 6.11	1.31 ±0.12
2	**Citrusdal**	79.10 ± 10.77	61.97 ± 6.11	1.28 ±0.11
2	**Nelspruit**	76.46 ± 7.09	59.40 ± 4.82	1.29 ±0.07
2	**Stellenbosch**	73.64 ± 8.10	58.47 ± 6.22	1.27 ±0.11
2	**Uitenhage**	72.97 ± 9.43	55.73 ± 6.35	1.31 ±0.12

Table 3. Mean and standard deviation values of the length (L), diameter (D) and L:D ratio measured on 'Eureka' lemon fruit from five different areas in the 2001 cropping season.

Pick	Area	Length	Diameter	L:D Ratio
1	**Addo**	77.70 ± 8.75	55.54 ± 6.20	1.41 ± 0.13
1	**Citrusdal**	64.64 ± 5.66	50.61 ± 3.70	1.28 ±0.10
1	**Stellenbosch**	71.47 ± 9.15	53.80 ± 5.65	1.33 ±0.12
1	**Uitenhage**	75.97 ± 8.63	57.82 ± 6.48	1.32 ±0.15
1	**Vaalharts**	91.49 ± 8.84	63.65 ± 5.07	1.44 ±0.10
2	**Addo**	82.06 ± 8.84	60.06 ± 5.79	1.37 ±0.13
2	**Citrusdal**	67.93 ± 6.69	54.97 ± 3.84	1.24 ±0.10
2	**Stellenbosch**	73.35 ± 7.92	55.15 ± 5.13	1.33 ±0.10
2	**Vaalharts**	91.09 ± 12.24	64.79 ± 6.39	1.41 ±0.12
3	**Addo**	83.30 ± 10.16	61.65 ± 6.19	1.35 ±0.10

Table 4. Mean and standard deviation values of the length (L), diameter (D) and L:D ratio measured on 'Eureka' lemon fruit on rough lemon rootstock from six different areas in the 2000 cropping season.

Pick	Area	Length	Diameter	L:D Ratio
1	**Addo**	86.33 ± 9.85	65.34 ± 6.40	1.32 ± 0.10
1	**Citrusdal**	70.78 ± 8.31	55.34 ± 4.59	1.28 ±0.10
1	**Nelspruit**	79.92 ± 7.31	60.29 ± 4.44	1.32 ±0.08
1	**Stellenbosch**	77.29 ± 8.81	57.48 ± 5.21	1.35 ±0.13
1	**Uitenhage**	71.55 ± 7.31	54.65 ± 7.09	1.32 ±0.14
1	**Vaalharts**	97.82 ± 8.53	62.17 ± 0.11	1.58 ± 0.11
2	**Addo**	78.67 ± 8.86	60.28 ± 5.36	1.31 ±0.11
2	**Citrusdal**	82.91 ± 9.74	63.88 ± 4.99	1.30 ±0.11
2	**Nelspruit**	80.45 ± 8.22	62.47 ± 4.78	1.29 ±0.07
2	**Stellenbosch**	73.64 ± 8.10	58.47 ± 6.22	1.27 ±0.11
2	**Uitenhage**	70.78 ± 8.59	53.93 ± 0.12	1.32 ±0.12

Table 5. Mean and standard deviation values of the length (L), diameter (D) and L:D ratio measured on 'Eureka' lemon fruit on rough lemon rootstock from five different areas in the 2001 cropping season.

Pick	Area	Length	Diameter	L:D Ratio
1	**Addo**	79.44 ± 9.04	55.33 ± 6.04	1.44 ± 0.14
1	**Stellenbosch**	71.47 ± 9.15	53.80 ± 5.65	1.33 ±0.12
1	**Uitenhage**	73.50 ± 8.29	57.16 ± 6.01	1.29 ±0.16
1	**Vaalharts**	93.13 ± 8.02	64.60 ± 5.10	1.44 ±0.09
2	**Addo**	82.76 ± 9.06	60.82 ± 6.31	1.36 ±0.11
2	**Stellenbosch**	73.35 ± 7.92	55.15 ± 5.13	1.33 ±0.10
2	**Vaalharts**	96.48 ± 10.52	67.69 ± 5.78	1.43 ±0.12
3	**Addo**	82.90 ± 9.87	61.38 ± 5.76	1.35 ±0.10

Table 6. Percentage fruit suitable for export from six different climatic areas for 2000 and 2001 cropping season.

Area	Year	Pick	% Fruit suitable for export
Addo	2000	1	76.51 %
Citrusdal	2000	1	66.66 %
Nelspruit	2000	1	79.76 %
Stellenbosch	2000	1	78.18 %
Uitenhage	2000	1	81.00 %
Vaalharts	2000	1	99.14 %
Addo	2000	2	75.48 %
Citrusdal	2000	2	61.54 %
Nelspruit	2000	2	73.05 %
Stellenbosch	2000	2	53.78 %
Uitenhage	2000	2	75.00 %
Addo	2001	1	90.99 %
Citrusdal	2001	1	62.67 %
Stellenbosch	2001	1	75.00 %
Uitenhage	2001	1	68.44 %
Vaalharts	2001	1	96.56 %
Addo	2001	2	84.92 %
Citrusdal	2001	2	45.69 %
Stellenbosch	2001	2	76.67 %
Vaalharts	2001	2	91.17 %
Addo	2001	3	86.09 %

Table 7. Comparison of minimum and maximum temperatures for six different production areas in 2000 and 2001 cropping season for June, July and August when lemon flower initiation takes place.

Area	Month	Maximum temperature		Minimum temperature	
		1999	2000	1999	2000
Addo					
	June	25.7	25.2	6.5	6.5
	July	24.8	26.8	5.2	5.2
	August	25.1	27.4	6.2	6.7
	Mean	**25.2**	**26.5**	**6.0**	**6.1**
Citrusdal					
	June	21.7	21.3	7.2	6.5
	July	20.0	20.7	6.7	5.4
	August	20.80	21.9	6.9	7.9
	Mean	**20.8**	**21.3**	**6.9**	**6.6**
Stellenbosch					
	June	20.1	20.3	9.0	9.4
	July	18.3	18.2	7.5	7.8
	August	19.0	19.4	8.9	9.6
	Mean	**19.1**	**19.3**	**8.5**	**8.9**
Uitenhage					
	June	21.3	23.9	10.3	4.7
	July	23.0	22.7	6.8	4.7

	August	24.1	23.9	6.7	4.7
	Mean	**22.8**	**23.5**	**7.9**	**4.7**
Vaalharts					
	June	20.4	21.3	0.4	1.2
	July	20.7	19.3	1.5	-0.4
	August	22.3	24.2	0.6	2.4
	Mean	**21.1**	**21.6**	**0.8**	**1.1**

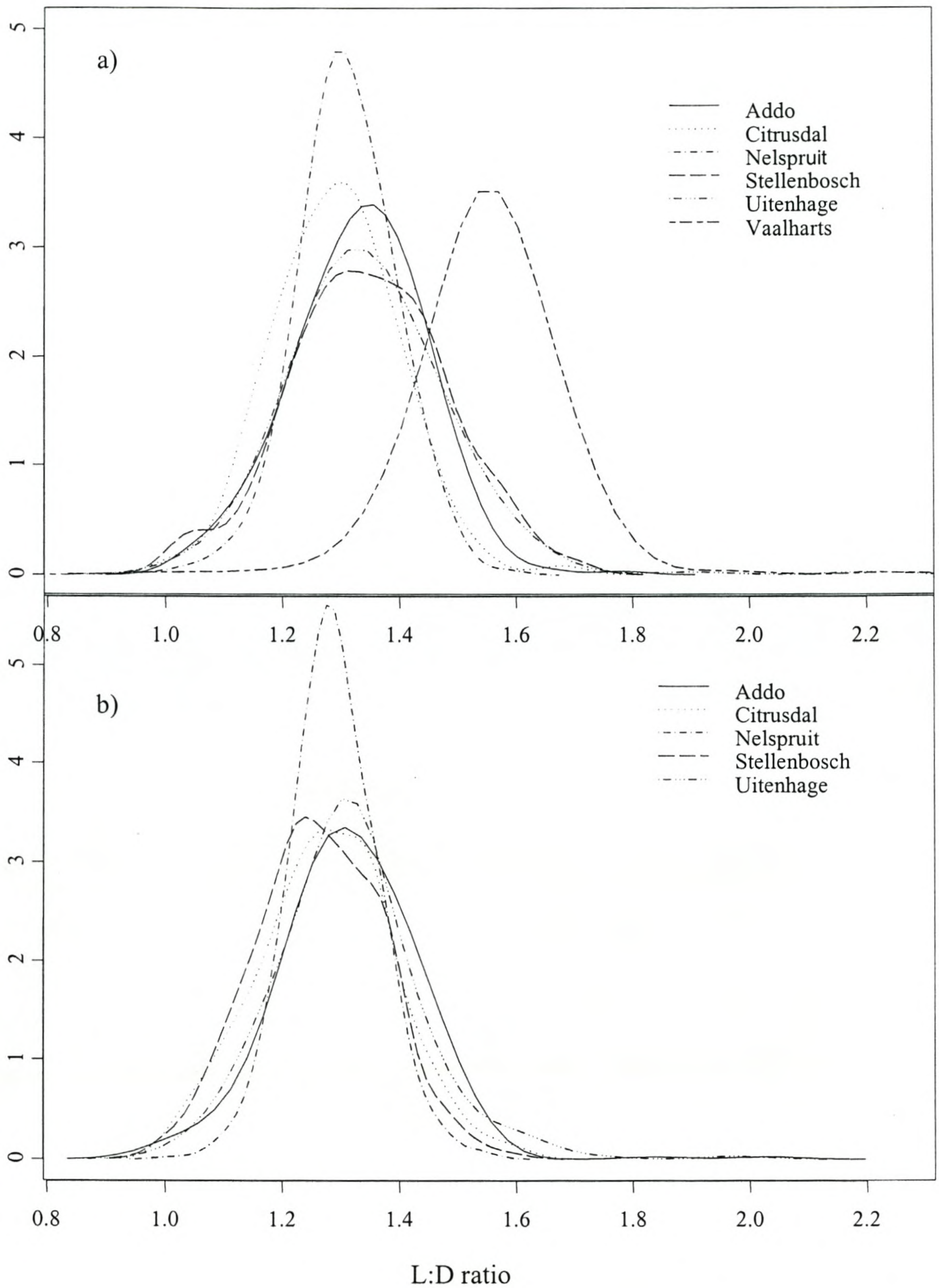


Figure 3. Density plot showing the L:D ratio of 'Eureka' lemons from different climatic areas, South Africa. 2000 Cropping season. a) First pick b) Second pick.

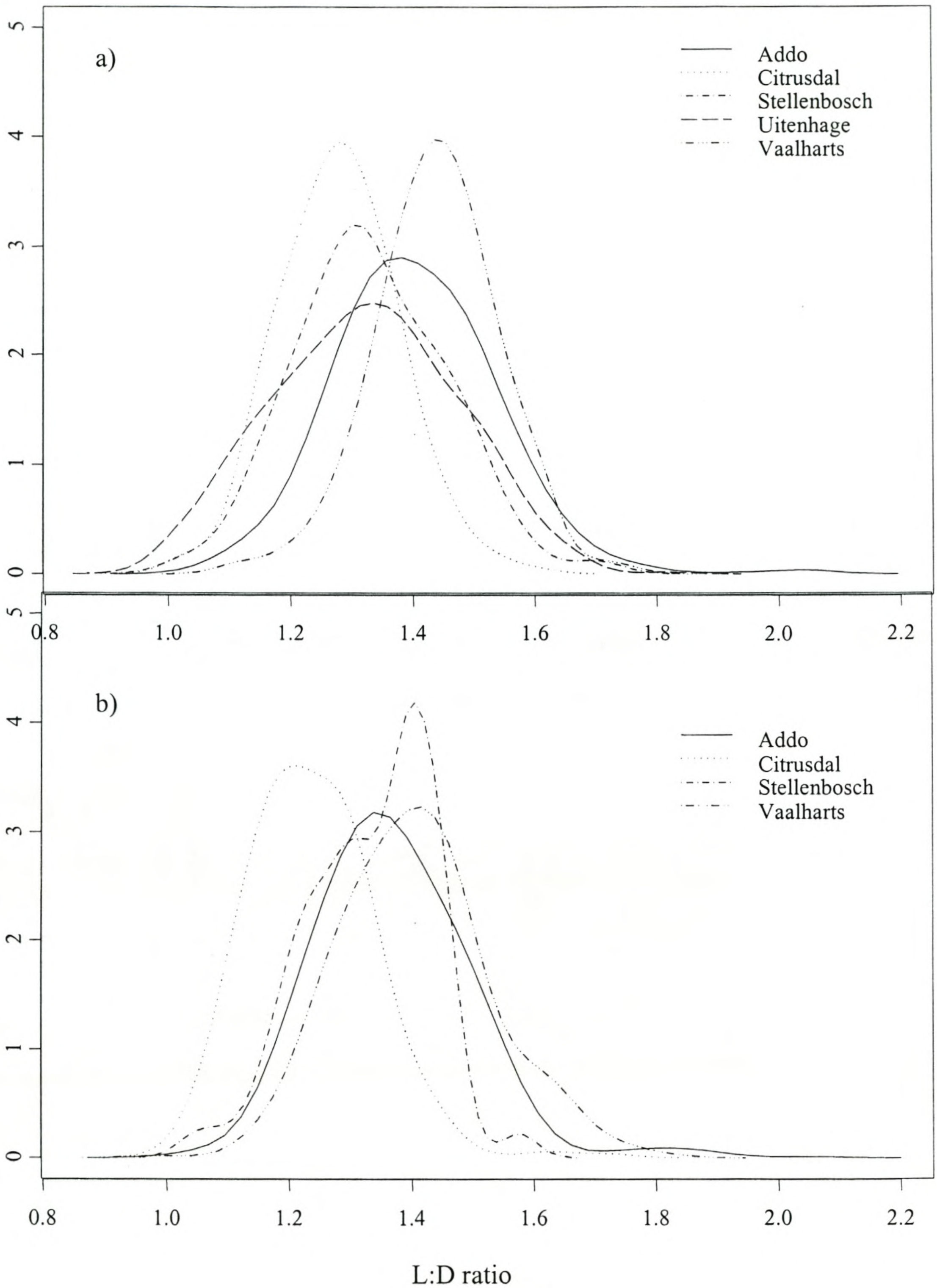


Figure 5. Density plot showing the L:D ratio of 'Eureka' lemons from different climatic areas, South Africa. 2001 Cropping season. a) First pick b) Second pick.

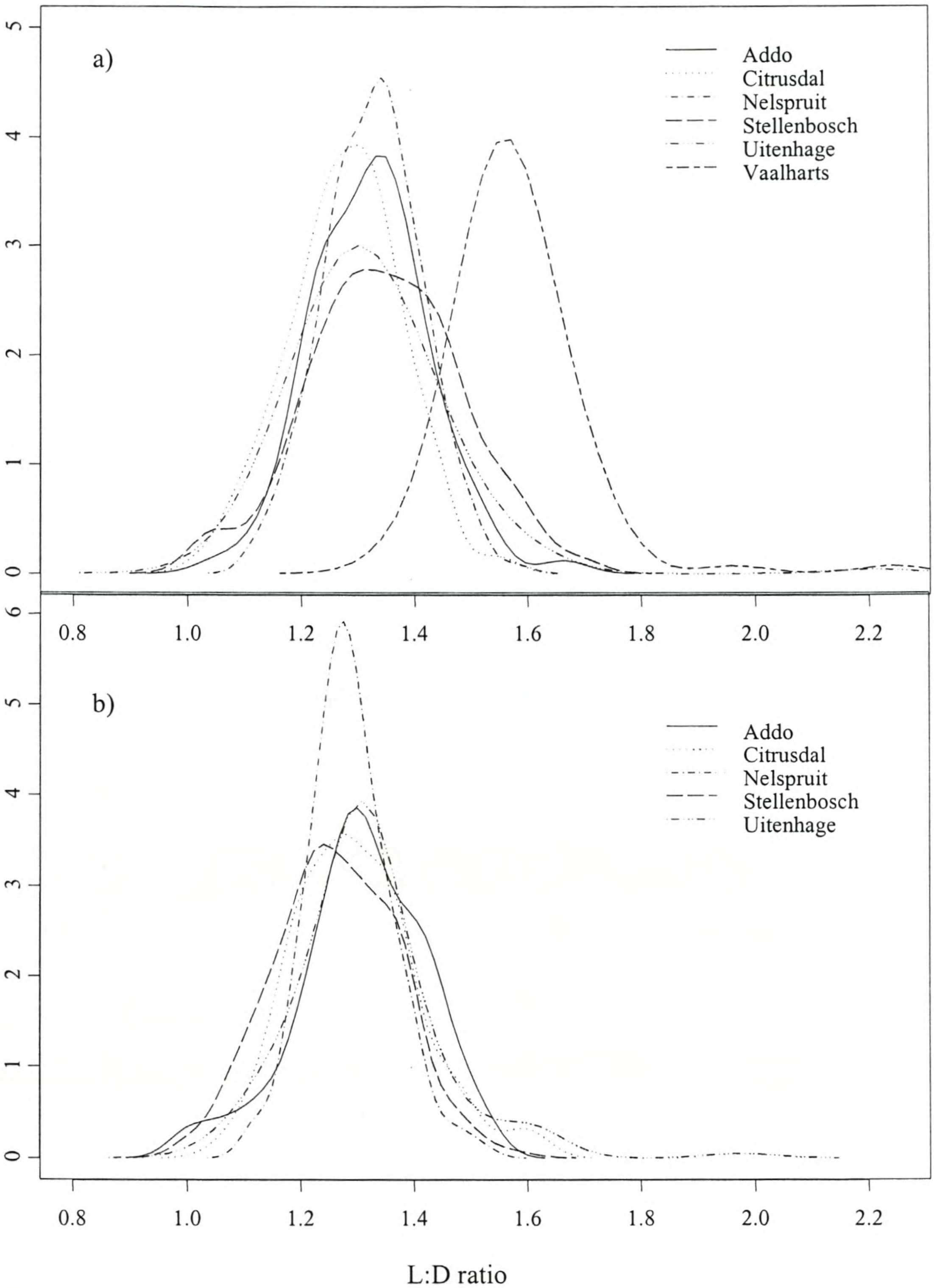


Figure 7. Density plot showing the L:D ratio of 'Eureka' lemons on rough lemon rootstock from different climatic areas, South Africa. 2000 Cropping season.
a) First pick b) Second pick

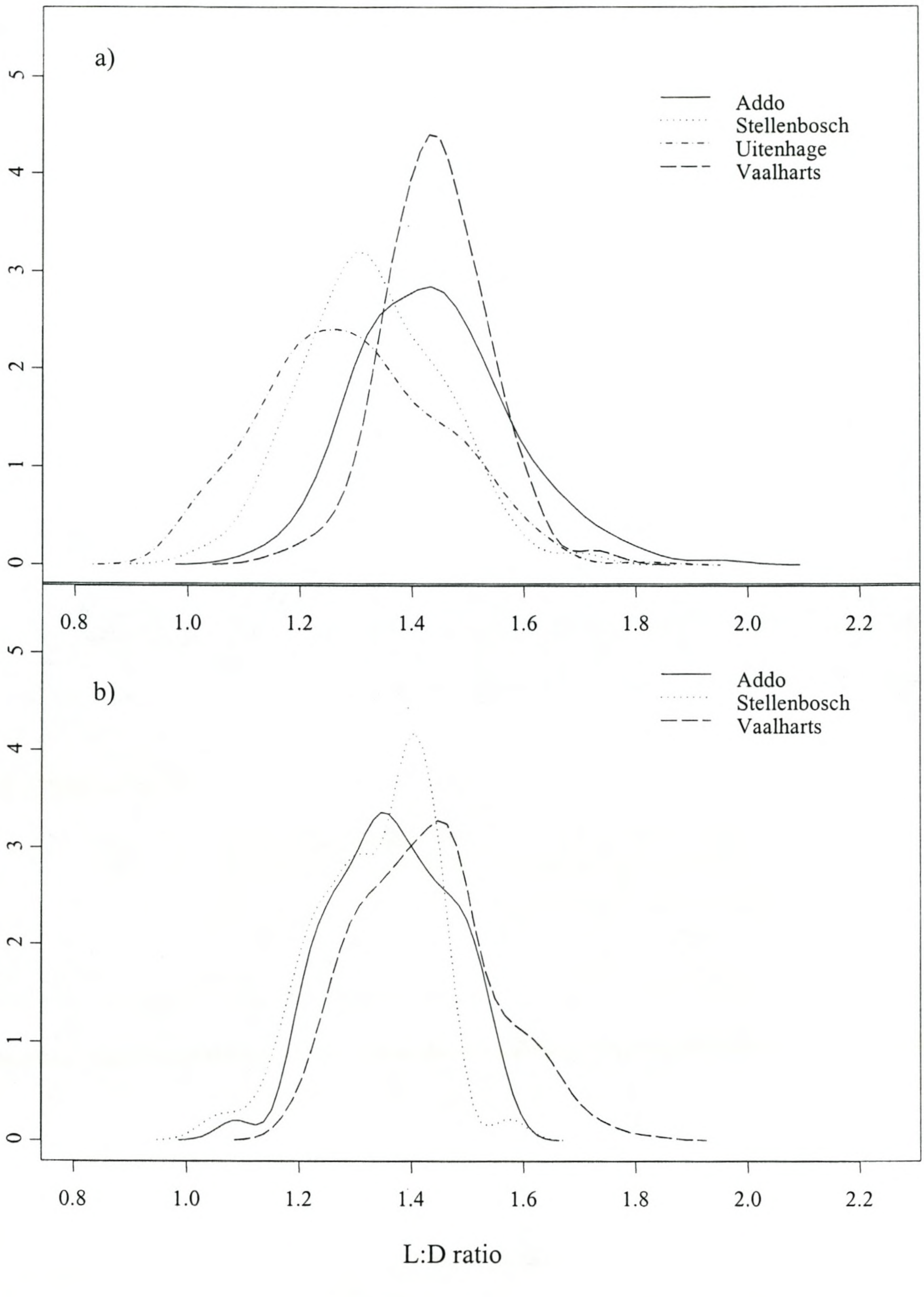


Figure 9. Density plot showing the L:D ratio of 'Eureka' lemons on rough lemon rootstock from different climatic areas, South Africa. 2001 Cropping season.
a) First pick b) Second pick

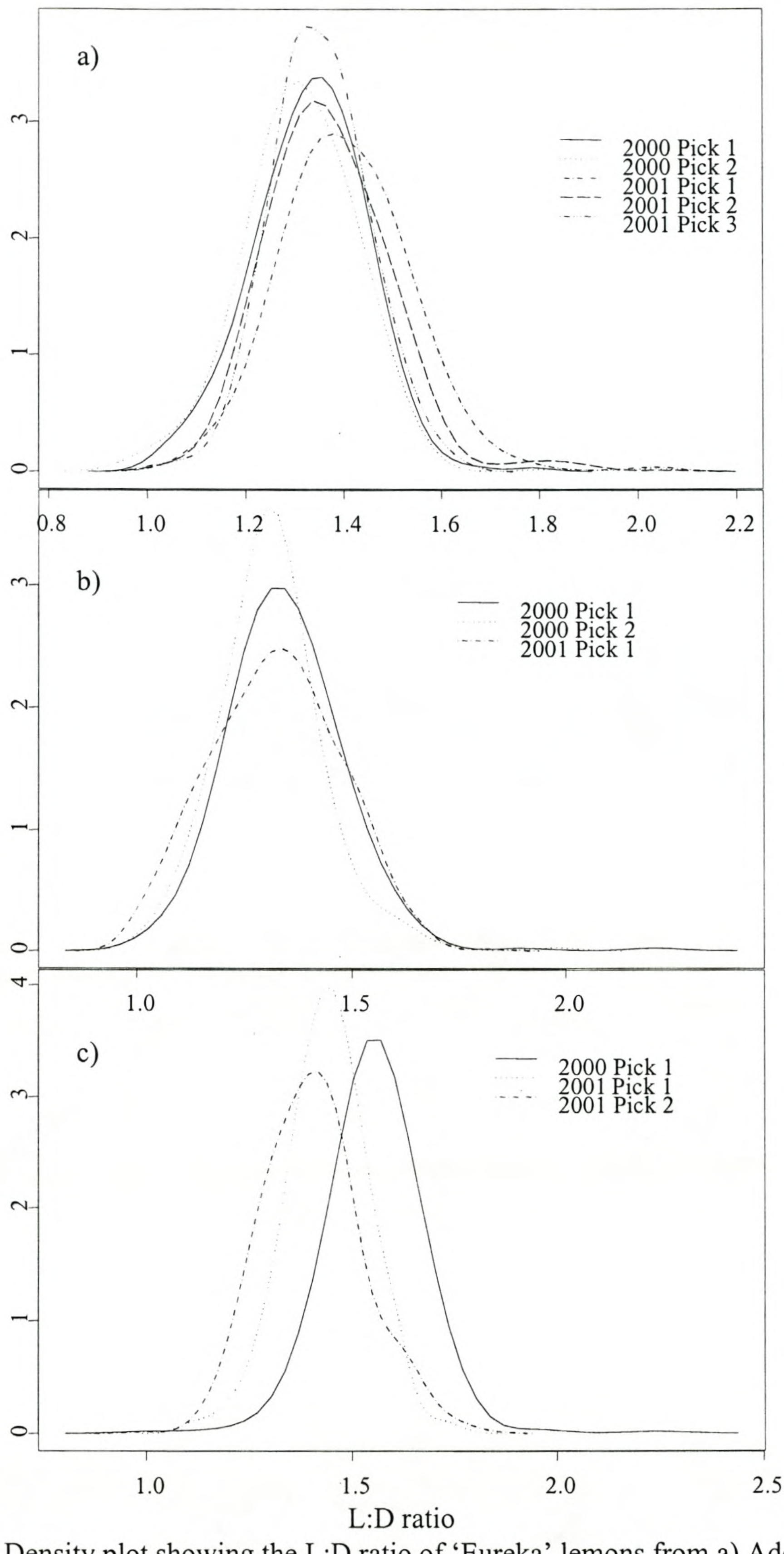


Figure 11. Density plot showing the L:D ratio of 'Eureka' lemons from a) Addo, b) Uitenhage in the Eastern Cape and c) Vaalharts in the Northern Cape, comparing fruit shape for the 2000 and 2001 cropping season for different picking dates.

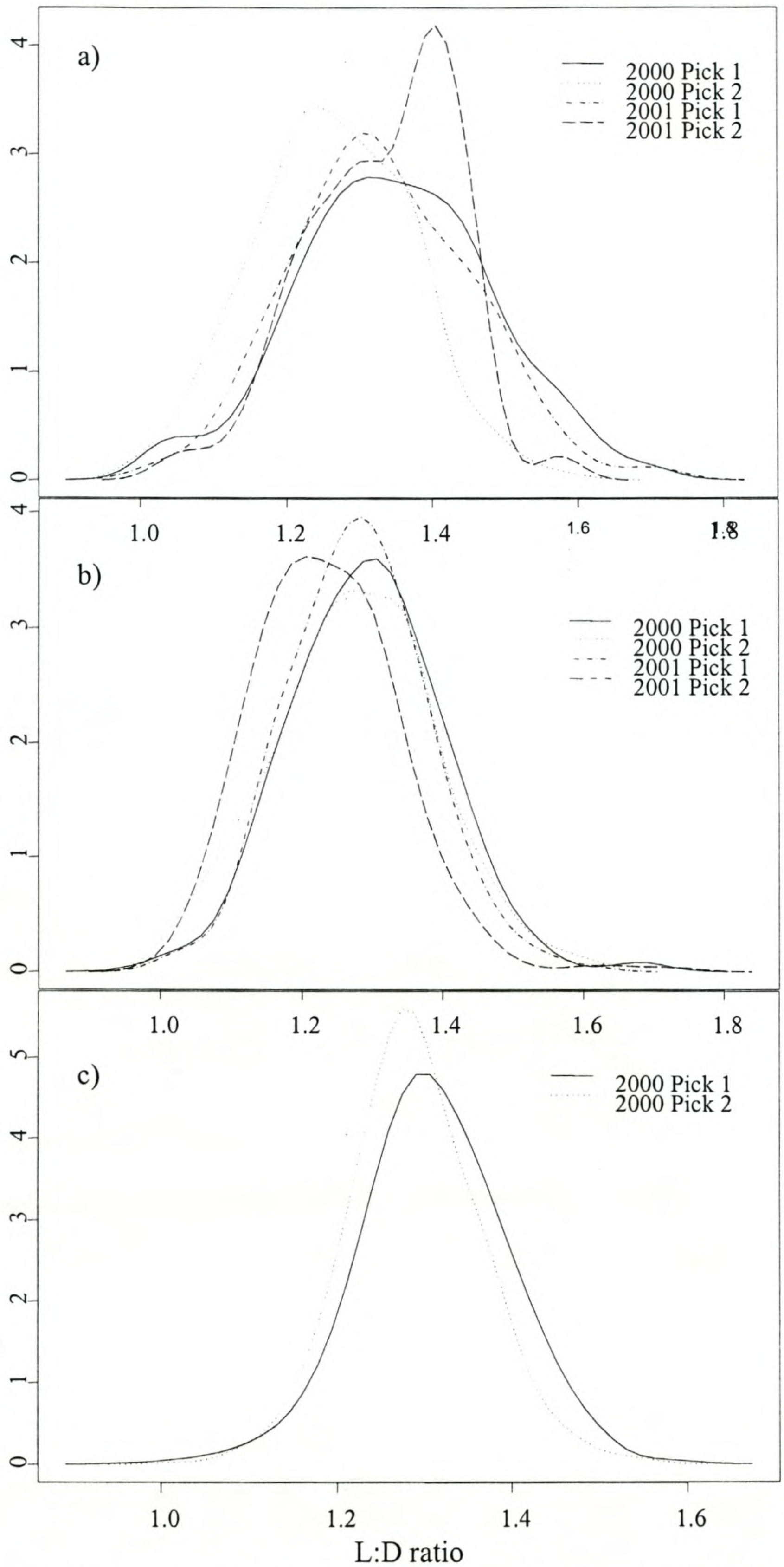


Figure 12. Density plot showing the L:D ratio of 'Eureka' lemons from a) Stellenbosch, b) Citrusdal in the Western Cape and c) Nelspruit in Mpumalanga, comparing fruit shape for the 2000 and 2001 cropping season for different picking dates.

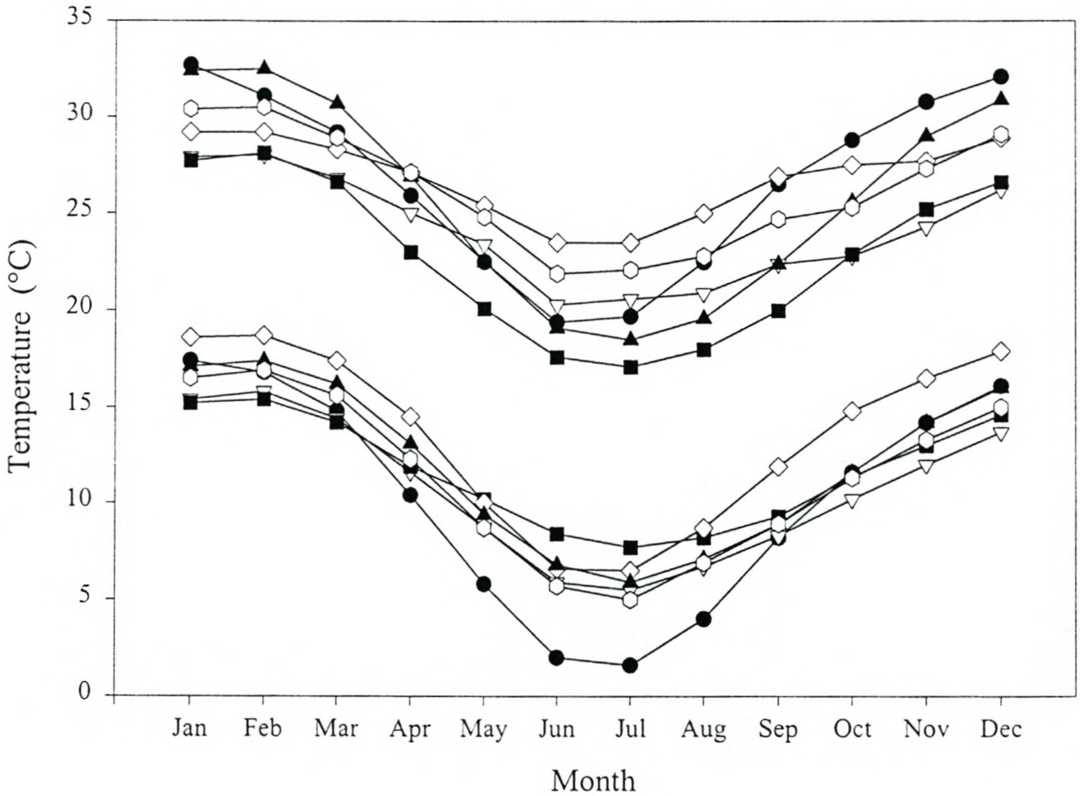
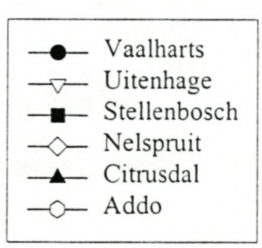


Figure 13. Long term maximum and minimum temperatures over sixteen years for six climatic areas in South Africa.



Paper III: The effect of scion and rootstock on the fruit shape of lemons.

Abstract

Fruit appearance is an important factor in fruit quality. Elongated lemons are preferred over rounder fruit in certain markets. Fruit shape, measured by length:diameter (L:D) ratio of fruit was evaluated to determine the effect of rootstock and cultivar selection on fruit shape. In total 20 selections and 12 rootstocks were evaluated. Areas offering different rootstock/scion combinations include Addo, Citrusdal and Nelspruit. Rootstocks had no or little influence on fruit shape, while cultivar selection resulted in a larger difference in fruit shape, with scions such as 'Verna' lemon consistently having the largest L:D ratio. Of the commercial scions currently being planted, 'Fino' lemon had the least variation and consistently produced fruit with large L:D ratios when compared to other commercial varieties such as 'Eureka' and 'Lisbon' lemons.

Introduction

Premium prices are obtained in the Japanese market for lemons with an elongated fruit shape. More slices are cut from an elongated lemon, and the fruit is also more attractive. Fruit shape is measured by the length:diameter (L:D) ratio of the fruit. Given that a certain rootstock is suitable for the particular environment, the choice of scion or rootstock is a controllable factor that might influence lemon fruit shape. This may result in a larger percentage of fruit from an orchard being exportable to Japan. Commercial lemon cultivars currently produced in South Africa include 'Eureka', 'Fino' and 'Lisbon'. Until the 1990's 'Eureka' lemon has been exclusively used. Due to 'Eureka' lemon's manipulability, a number of rootstocks, such as rough lemon, 'Volckameriana' lemon and 'X639' hybrid were preferred (Rabe et al. 1992), but there are a number of other rootstocks available to be used when 'Lisbon' and 'Fino' lemons are selected as scions.

In the case of citrus, work has been done on the influence of rootstock on fruit size. No known work has been done on scion or rootstock effects on fruit shape but rootstock type significantly influenced fruit shape of 'Red Delicious' apple (Westwood and Blaney, 1963).

Westwood and Blaney (1963) and Barritt et al. (1994) found fruit from trees with non-dwarfing rootstocks to be relatively more elongated than those from dwarfing rootstocks. By contrast, Greenhalgh and Godley (1976) found that when semi-vigorous and vigorous rootstocks were evaluated, it did not influence fruit shape.

Avilàn et al. (1997) found that rootstocks modified the fruit dimension, weight and shape of mangos. These changes varied according to the scion/rootstock combination used. Observed differences in fruit shape and fruit size were more accentuated in certain cultivars.

This paper presents the differences in fruit shape of lemons, as influenced by the type of scion and rootstock used.

Materials and Methods

Three orchards were available for scion and rootstock evaluation. The orchards were situated in Addo (33°S 25°E 152 m.a.s.l.), Eastern Cape; Citrusdal, (32°S 19°E, 198 m.a s.l.) Western Cape; and Nelspruit, (25°S 31°E, 660 m.a.s.l.), Mpumalanga. Fruit were harvested at all possible harvest times representing different times of fruit set. Fruit length and diameter was measured with a hand-held caliper and the L:D ratio was calculated.

Addo: Four trees per scion/rootstock combination were available. In the 2001 cropping season 15 fruit per tree were measured for the first pick and 10 fruit per tree for the second and third picks. Tree spacing was 3 m x6 m.

Citrusdal: Four trees per scion/rootstock combination were available. Citrusdal was used only in the 2000 cropping season for measurements, due to termination of the orchard in 2001. 15 fruit per tree were measured. Tree spacing was 4 m x 6 m.

Nelspruit: Fourteen trees per scion/rootstock combination were available. Two hundred fruit per scion/rootstock combination were measured. Fruit was only measured for the 2000 cropping season. Tree spacing was 2 m x 5.8 m.

Variation in number of fruit measured was due to some trees having a light fruit set, in which case all fruit available was used. Other factors resulting in less fruit per scion/rootstock combination being measured included sick and dead trees. The exact number of measurements per scion/rootstock combination is summarized in Table 1. Fruit from the same time of set was used for measurement. Fruit selected were distributed uniformly in all four sectors of the tree. Detailed description of available combinations per orchard as well as tree age in 2000 is presented in Table 2.

Results and Discussion

Influence of rootstock on lemon fruit shape

Small differences were evident in the mean L:D ratio of fruit from different rootstocks at Addo (Table 3). Fruit from all four rootstocks had a larger length and diameter for the second and third pick. There was small variation for all four rootstocks in the fruit shape distribution of 'Eureka' lemons budded on the four different rootstocks evaluated at Addo (Figure 1a,b,c). None of the rootstocks resulted in fruit with a larger L:D ratio. From the 95 % alpha bags it is possible to compare all three variables at once. Fruit shape distribution overlapped for a large area. 'Volckameriana' lemon was the rootstock producing fruit with the largest diameter for all three harvest dates (Figure 2). Rough lemon produced fruit with the largest L:D ratio at the time of first pick, followed by 'Carrizo' citrange for the second pick, and 'Rosehaugh Empress' mandarin for the third pick. There was therefore no rootstock consistently producing more elongated fruit in the Addo region.

'Lisbon' lemon budded on nine rootstocks at Nelspruit showed a maximum difference of 0.10 between L:D ratios of 'Minnelola x Trifoliate' and 'Swingle' citrumelo (Table 4), but comparing the nine rootstocks by means of a density plot there are small differences evident between fruit shape from different rootstocks (Figure 3a,b). First pick (Figure 3a) shows fruit from different rootstocks having a larger variation than for the second pick (Figure 3b). The rootstock with the smallest L:D ratio at the first pick was rough lemon, but the difference was small. As was the case for Addo, no significant differences between fruit shape of different rootstocks was found. The 95 % alpha bag shows rough lemon of the second pick to produce lemons with a larger length and diameter than other rootstocks. The other rootstocks produced fruit with a length and diameter not differing significantly from each other (Figure 4).

At Citrusdal, fruit from 'Volckameriana' lemon, second pick, produced fruit with the smallest mean L:D ratio of 1.23, resulting in the fruit not being suitable for export (Table 5), while 'Rosehaugh Empress' mandarin produced fruit with a slightly larger L:D ratio. The variation between different rootstocks was larger when compared to Addo and Nelspruit (Figure 5a,b). The 95 % alpha bag shows larger differences in fruit diameter and length (Figure 6). Fruit from 'citremon' rootstock, (first pick) had smaller diameters and lengths than all other fruit, while fruit from 'Carrizo' citrange and 'Volckameriana' from the second pick had the largest diameters and lengths (Figure 6).

From the rootstock evaluation of all three areas, it is clear that no rootstock influences fruit shape by consistently producing fruit with a larger L:D ratio. 'Volckameriana' together with 'rough lemon' and 'Carrizo' seemed to be the rootstocks producing fruit with a larger diameter, as also described by Rabe et al. (1992). No known work has been done on citrus fruit shape as influenced by rootstock. The small differences in fruit shape as influenced by rootstock, is however in contrast to other researchers investigating apple fruit shape (Westwood and Blaney, 1963), who determined that rootstock type significantly influenced fruit shape of 'Red Delicious' apple. Fruit from trees with non-dwarfing rootstocks were relatively more elongated than those from dwarfing rootstocks. This was confirmed by Barritt et al. (1994). Curry and Williams (1983) as well as Williams and Stahly (1969) explained the reduction in transport of GA across the rootstock/scion union as roughly proportional to the dwarfing effect of the rootstock. Given that 1) foliar-applied PGR's, GA and BA as well as other materials with PGR-like or PGR-inhibiting qualities can affect fruit shape, 2) that roots are a site of PGR production, and 3) that rootstocks influence the transport of PGR's across the rootstock/scion union, it is possible that rootstocks may influence fruit shape by regulating PGR levels. In this paper however, only small differences were found in lemon fruit shape as influenced by rootstock.

Fruit shape characteristics of different scions on lemon fruit shape

Comparing the density plots of rootstock evaluation to that of scion evaluation, it is clear that there are larger differences when comparing scions as when comparing rootstocks. 'Verna' lemon was the selection having the largest mean L:D ratio for all picking dates (Table 6). 'Fino' lemon was the commercial selection having the most fruit with a larger L:D ratio, the least variation and the largest mean L:D ratio in comparison to 'Eureka' and 'Lisbon' lemons in the Addo region (Figure 7). Figure 8a,b compared the commercially important selections, budded on 'Volckameriana' lemon rootstock from the Citrusdal region. For the first pick it was again clear that 'Fino' lemon was the selection having the smallest variation in fruit shape (Figure 8a). For the second pick, 'Fino' and 'Lisbon' lemons had very similar fruit shape distribution (Figure 8b). 'Fino' lemon was the commercial selection with the largest mean L:D ratio (Table 7).

'Cicily' and 'Eureka Seedless' lemons are the non-commercial selections having a lot of fruit with small L:D ratios, while 'Verna' and 'Eureka Addo' lemons were the scions producing fruit with the largest L:D ratios, for the first pick (Figure 9a). In the case of the second pick, 'Eureka Ryan' lemon had a lot of fruit with a smaller L:D ratio (Figure 9b). 'Verna' lemon was the selection having a larger L:D ratio. In contrast to the first pick, 'Eureka Addo' lemon had more fruit with a smaller L:D ratio at second pick. For the third pick, 'Cicily' and 'Lisbon Rosenberger' lemons were the two selections having the most fruit with a smaller L:D ratio (Figure 9c). As with the first pick, 'Verna' and 'Eureka Addo' lemons were the two selections with a lot of fruit having a larger L:D ratio.

Comparing other non-commercial selections from the Citrusdal region, budded on 'Carrizo' citrange rootstock, 'Verna' lemon was the selection with a lot of fruit having a large L:D ratio for the first as well as the second pick (Figure 10a,b). For the first pick, 'Cicily' and 'Eureka Ryan' lemons were the selections having a lot of fruit with smaller L:D ratios (Figure 10a). For the second pick 'Feminnello Continella' lemon was the selection having significantly rounder fruit, followed by 'Eureka Thornless' lemon (Figure 10b). In contrast to the first pick, 'Cicily' lemon had more fruit with a larger L:D ratio (Figure 10b).

95 % alpha bags

The 95 % alpha bag for all Addo scions showed that 'Verna', 'Lisbon Prior' and 'Lisbon Yen-Ben' lemons had the smallest diameter, while 'Eureka Seedless' lemon had the largest diameter (Figure 11). For the second pick, 'Genoa' and 'Lisbon Yen-Ben' lemons produced fruit with the smallest diameter and length, while 'Fino' lemon was the scion with the largest length and diameter. 'Verna' lemon had a large length, but a smaller diameter as in the first pick, resulting in fruit with the largest L:D ratio (Figure 12). 'Eureka Addo', 'Fino', 'Lisbon Rosenberger' and 'Verna' lemons had the largest L:D ratios for the third pick, with 'Verna', 'Eureka Addo' and 'Eureka Ryan' lemons having the smallest diameters (Figure 13). From Figure 14 (showing scions from Citrusdal), it is clear that 'Eureka Addo', 'Eureka Ryan' and 'Eureka Thornless' lemons had the smallest diameters for the first pick. This may explain the larger L:D ratio for 'Eureka Addo'. 'Eureka Addo', 'Verna' and 'Eureka Cook's' were the scions having the largest L:D ratio for the second pick (Figure 15). 'Eureka Ryan' and 'Lisbon Thornless' lemons had the smallest diameters (Figure 15).

Table 8 shows the percentage of fruit with a L:D ratio larger than 1.25 and thus suitable for export to Japan. Measurements were taken from Addo and Citrusdal. Scions were budded on 'Volckmeriana' lemon, 'Carrizo' citrange, 'Rosehaugh Empress'mandarin and rough lemon rootstocks. Comparing 'Eureka', 'Lisbon' and 'Fino' lemons, the latter was the scion with the largest percentage fruit suitable for export from both Addo and Citrusdal. The difference was small however. For both Addo and Citrusdal, 'Verna'lemon had the largest L:D ratio, with 'Cicily' lemon being one of the least exportable from both Addo and Citrusdal.

Conclusion

It is clear that rootstocks play a minor role in determining lemon fruit shape. 'Volckameriana' lemon was the rootstock that seemed to produce larger fruit with a larger diameter, without influencing L:D ratio.

In contrast to rootstocks, scions varied more in producing fruit of different fruit shapes. 'Fino' lemon was the commercial scion having the least variation, and consistently produced fruit with a larger L:D ratio. 'Lisbon' and 'Eureka' lemons differed more in having a range of rounder fruit as well as more elongated fruit. With other scions, 'Verna' lemon seemed to consistently produce fruit with a larger L:D ratio. 'Verna' lemon is, however, a large fruit with a thick rind, and not very attractive (per. obs.). 'Verna' and 'Eureka Addo' lemons tended to have smaller diameters, resulting in a larger L:D ratio. 'Eureka Addo' lemon was, however, prone to have large variation, and not consistently producing longer fruit. Other scions varied a lot in fruit shape between times of harvest and areas and was not consistent in producing elongated fruit. Scions with the largest variation included 'Eureka Addo', 'Eureka Ryan', 'Verna' and, to a lesser extent, 'Eureka Thornless' lemons.

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Table 1. Number of fruit measured per scion/rootstock combination for each region.

Scion	Rootstock	Year of harvest	Number of measurements Picking time		
			1	2	3
Addo					
Cicily	Carrizo citrange	2001	60	60	40
Eureka	Carrizo citrange	2001	180	120	150
	Volckameriana	2001	180	240	160
	Rosehaugh Empress	2001	180	150	190
	Rough lemon	2001	170	120	120
Eureka Addo	Carizzo citrange	2001	59	40	40
Eureka Cook`s	Carrizo citrange	2001	60	40	60
Eureka Frost	Carrizo citrange	2001	76	50	50
Eureka Ryan	Carrizo citrange	2001	45	30	30
Eureka Thornless	Carrizo citrange	2001	60	40	40
Eureka UCLA	Carrizo citrange	2001	60	40	35
Fino	Carrizo citrange	2001	60	40	40

Genoa	**Carrizo citrange**	2001	45	30	31
Lisbon	**Carrizo citrange**	2001	119	80	80
Lisbon Frost	**Carrizo citrange**	2001	60	40	40
Lisbon Prior	**Carrizo citrange**	2001	60	40	40
Lisbon Rosenberger	**Carrizo citrange**	2001	60	40	40
Lisbon Thornless	**Carrizo citrange**	2001	59	40	40
Verna	**Carrizo citrange**	2001	60	40	40
Eureka seedless	**Carrizo citrange**	2001	60	-	-
Israel Eureka seedless	**Carrizo citrange**	2001	60	-	-
Lisbon Yen-Ben	**Carrizo citrange**	2001	60	40	-
Villa Franca	**Carrizo citrange**	2001	60	-	-
Citrusdal					
Cicily	**Volckameriana**	2000	75	49	
Eureka	**Carrizo citrange**	2000	103	41	
	Citremon	2000	43	46	
	Rosehaugh Empress	2000	75	58	

	Volckameriana	2000	68	104
	Rough lemon	2000	73	89
Eureka Addo	**Volckameriana**	2000	42	56
Eureka Cook`s	**Volckameriana**	2000	75	49
Eureka Frost	**Volckamereiana**	2000	39	54
Eureka Ryan	**Volckameriana**	2000	45	47
Eureka Thornless	**Volckameriana**	2000	58	37
Eureka UCLA	**Volckameriana**	2000	75	52
Feminello Continella	**Volckameriana**	2000	-	70
Fino	**Volckameriana**	2000	75	52
Genoa	**Volckameriana**	2000	55	-
Lisbon	**Volckameriana**	2000	144	55
Lisbon Frost	**Volckameriana**	2000	44	50
Lisbon Prior	**Volckameriana**	2000	94	59
Lisbon Thornless	**Volckameriana**	2000	4	-
Verna	**Volckameriana**	2000	71	49

Nelspruit

Lisbon	**C-35**	2000	188	200
	Carrizo citrange	2000	170	191
	Flying dragon	2000	162	189
	Minneola x Trifoliate	2000	98	188
	Rough lemon	2000	75	175
	Swingle citrumelo	2000	173	175
	Sour orange	2000	189	199
	Terra Bella citrange	2000	188	190
	X639	2000	164	195

Table 2: Details of plant material used in different areas. Tree age for Citrusdal and Nelspruit applied for the 2000 cropping season. Tree age for Addo applied for the 2001 cropping season (Carrizo = Carrizo citrange)

Selection	Rootstocks	Tree Age
Addo		
Cicily	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Eureka	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo,	8
Eureka Addo	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Eureka Cook's	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Eureka Frost	Rough lemon, Volckameriana, Carrizo	7
Eureka Ryan	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	7
Eureka Thornless	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Feminello Continella	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	7
Fino	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Genoa	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Lisbon	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Lisbon Frost	Rough lemon, Volckameriana, Carrizo	7
Lisbon Prior	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Lisbon Rosenberger	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Lisbon Thornless	Rough lemon, Rosehaugh Empress, Volckameriana, Citremon	8
Verna	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Citrusdal		
Cicily	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Eureka	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo, Citremon	8
Eureka Addo	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Eureka Cook's	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Eureka Frost	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8

Eureka Ryan	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	5
Eureka Thornless	Rough lemon, Rosehaugh Empress, Volckameriana, Citremon	5
Eureka UCLA	Rough lemon, Volckameriana, Carrizo	8
Feminello Continella	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Fino	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Genoa	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Lisbon	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Lisbon Frost	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Lisbon Prior	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	5
Lisbon Rosenberger	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
Lisbon Thornless	Rough lemon, Rosehaugh Empress, Volckameriana, Citremon	5
Verna	Rough lemon, Rosehaugh Empress, Volckameriana, Carrizo	8
<u>Nelspruit</u>		
Eureka	Rough lemon, Sour Orange, Minneola x Trifoliate, X639	2
Lisbon	Sour Orange, Rough lemon, Minneola x Trifoliate, X639,	2
	Swingle citrumelo, Flying dragon, Rangpur troyer,	2
	Carrizo citrange, C-35, Terre Bella citrange	2

Table 3. Mean and standard deviation values of the length (L), diameter (D) and L:D ratio measurements of 'Eureka' lemon fruit on four different rootstocks from Addo, Eastern Cape, South Africa.

Pick	Rootstock	Length	Diameter	L:D Ratio
1	**Carrizo citrange**	76.59 ± 8.79	55.18 ± 6.48	1.39 ± 0.14
1	**Rosehaugh Empress**	74.98 ± 8.24	54.39 ± 6.02	1.38 ± 0.12
1	**Rough lemon**	79.44 ± 9.04	55.33 ± 6.04	1.44 ± 0.14
1	**Volckameriana**	79.90 ± 8.06	57.25 ± 5.92	1.40 ± 0.14
2	**Carrizo citrange**	84.64 ± 9.51	59.75 ± 6.13	1.42 ± 0.16
2	**Rosehaugh Empress**	80.13 ± 8.11	59.71 ± 5.11	1.35 ± 0.13
2	**Rough lemon**	82.76 ± 9.06	60.82 ± 6.31	1.36 ± 0.11
2	**Volckameriana**	81.63 ± 8.83	60.05 ± 5.75	1.36 ± 0.11
3	**Carrizo citrange**	82.82± 10.66	61.44 ± 6.37	1.35 ± 0.09
3	**Rosehaugh Empress**	82.00± 9.79	60.45 ± 6.20	1.36 ± 0.10
3	**Rough lemon**	82.90± 9.87	61.38 ± 5.76	1.35 ± 0.10
3	**Volckameriana**	85.60± 10.05	63.49 ± 5.96	1.35 ± 0.10

Table 4. Mean and standard deviation values of the length (L), diameter (D) and L:D ratio measurements of 'Lisbon' lemon fruit on nine different rootstocks from Nelspruit, Mpumalanga, South Africa.

Pick	Rootstock	Length	Diameter	L:D Ratio
1	**C-35**	81.04 ± 6.59	62.82 ± 5.17	1.29 ± 0.09
1	**Carrizo citrange**	81.51 ± 9.67	61.97 ± 5.56	1.32 ± 0.11
1	**Flying dragon**	82.21 ± 7.07	62.70 ± 5.11	1.31 ± 0.09
1	**Minneola x Trifoliate**	76.81 ± 6.20	61.59 ± 4.81	1.25 ± 0.09
1	**Rough lemon**	81.19 ± 7.54	62.34 ± 4.18	1.30 ± 0.08
1	**Swingle citrumelo**	82.13 ± 7.96	61.01 ± 4.80	1.35 ± 0.09
1	**Sour orange**	82.87 ± 7.57	62.31 ± 4.91	1.33 ± 0.09
1	**Terra Bella citrange**	79.73 ± 7.05	61.31 ± 5.36	1.30 ± 0.09
1	**X639**	81.35 ± 8.08	61.86 ± 5.13	1.32 ± 0.09
2	**C-35**	80.61 ± 6.86	62.59 ± 4.14	1.29 ± 0.08
2	**Carrizo citrange**	79.90 ± 8.18	62.76 ± 5.27	1.27 ± 0.07
2	**Flying dragon**	82.74 ± 8.08	64.60 ± 5.39	1.28 ± 0.08
2	**Minneola x Trifoliate**	83.30 ± 7.87	64.51 ± 5.36	1.29 ± 0.07
2	**Rough lemon**	90.53 ± 9.08	71.25 ± 4.46	1.27 ± 0.09
2	**Swingle citrumelo**	83.24 ± 7.37	63.55 ± 5.75	1.31 ± 0.09
2	**Sour orange**	80.28 ± 7.52	61.96 ± 4.65	1.30 ± 0.08
2	**Terra Bella citrange**	78.12 ± 6.00	61.36 ± 4.56	1.27 ± 0.07
2	**X639**	86.58 ± 8.09	66.78 ±5.10	1.30 ± 0.09

Table 5. Mean and standard deviation values the length (L), diameter (D) and L:D ratio measurements of 'Eureka' lemon fruit on four different rootstocks from Citrusdal, Western Cape, South Africa.

Pick	Rootstock	Length	Diameter	L:D Ratio
1	**Carrizo citrange**	74.65 ± 8.51	57.27 ± 4.22	1.30 ± 0.11
1	**Citremon**	64.31 ± 7.99	51.35 ± 4.44	1.25 ± 0.12
1	**Rosehaugh Empress**	72.04 ± 6.23	53.78 ± 3.76	1.34 ± 0.10
1	**Rough lemon**	70.78 ± 8.31	55.34 ± 4.59	1.28 ± 0.10
1	**Volckameriana**	72.96 ± 7.34	57.77 ± 4.83	1.26 ± 0.10
2	**Carrizo citrange**	81.59 ± 11.29	64.59 ± 7.66	1.26 ± 0.10
2	**Citremon**	77.01 ± 11.97	60.13 ± 6.02	1.28 ±0.13
2	**Rosehaugh Empress**	77.17 ± 9.62	58.22 ± 5.54	1.32 ±0.10
2	**Rough lemon**	82.91 ± 9.74	63.88 ± 4.99	1.30 ±0.11
2	**Volckameriana**	76.86 ± 10.54	62.21 ± 5.47	1.23 ±0.12

Table 6. Mean and standard deviation values of the length (L), diameter (D) and L:D ratio measurements of fruit from different lemon selections on 'Carrizo' citrange rootstock from Addo, Eastern Cape, South Africa.

Pick	Selection	Length	Diameter	L:D Ratio
1	**Cicily**	69.04 ± 5.85	56.03 ± 5.58	1.24 ± 0.14
1	**Eureka seedless**	85.05 ± 11.06	62.50 ± 7.82	1.37 ± 0.16
1	**Eureka**	76.59 ± 8.79	55.18 ± 6.48	1.39 ± 0.14
1	**Eureka Addo**	83.18 ± 10.00	56.16 ± 6.22	1.49 ± 0.16
1	**Eureka Cook`s**	72.97 ± 7.04	53.35 ± 5.48	1.37 ± 0.12
1	**Eureka Frost**	76.43 ± 8.43	55.88 ± 5.48	1.37 ± 0.13
1	**Eureka Ryan**	69.45 ± 5.91	52.52 ± 4.91	1.32 ± 0.12
1	**Eureka Thornless**	74.93 ± 7.21	54.59 ± 5.46	1.38 ± 0.13
1	**Eureka UCLA**	78.60 ± 9.28	62.28 ± 6.83	1.27 ± 0.49
1	**Fino**	79.15 ± 7.41	56.17 ± 4.47	1.41 ± 0.14
1	**Genoa**	74.47 ± 7.40	54.94 ± 6.64	1.36 ± 0.13
1	**Israel Eureka Seedless**	82.06 ± 8.28	58.98 ± 5.73	1.40 ± 0.12
1	**Lisbon**	74.34 ± 8.76	55.03 ± 6.08	1.36 ± 0.15
1	**Lisbon Yen-Ben**	60.81 ± 6.89	44.75 ± 5.80	1.36 ± 0.12
1	**Lisbon Frost**	71.79 ± 6.14	52.71 ± 5.95	1.38 ± 0.18
1	**Lisbon Prior**	68.65 ± 5.47	48.75 ± 3.71	1.41 ± 0.10
1	**Lisbon Rosenberger**	74.41 ± 8.12	54.41 ± 4.11	1.37 ± 0.14
1	**Lisbon Thornless**	73.31 ± 6.93	58.24 ± 6.74	1.27 ± 0.18
1	**Verna**	76.37 ± 7.20	48.05 ± 4.81	1.60 ± 0.50
1	**Villafranca**	75.06 ± 6.72	59.97 ± 4.32	1.25 ± 0.10
2	**Cicily**	83.43 ± 6.62	60.35 ± 4.80	1.39 ± 0.11
2	**Eureka**	84.64 ± 9.51	59.75 ± 6.13	1.42 ± 0.16
2	**Eureka Addo**	82.17 ± 8.69	59.81 ± 8.36	1.38 ±0.44

2	**Eureka Cook`s**	82.07 ± 6.98	58.88 ± 5.91	1.40 ± 0.09
2	**Eureka Frost**	79.93 ± 8.07	56.70 ± 4.23	1.41 ±0.34
2	**Eureka Ryan**	77.95 ± 5.77	57.68 ± 4.40	1.35 ±0.08
2	**Eureka Thornless**	83.72 ± 8.69	59.35 ± 5.91	1.41 ±0.37
2	**Eureka UCLA**	84.69 ± 8.86	63.33 ± 6.48	1.34 ±0.09
2	**Fino**	88.70 ± 8.93	62.92 ± 5.02	1.41 ±0.10
2	**Genoa**	77.44 ± 7.74	55.75 ± 4.53	1.40 ±0.16
2	**Lisbon**	81.98 ± 8.22	59.33 ± 6.13	1.39 ±0.12
2	**Lisbon Yen-Ben**	66.84 ± 5.64	49.40 ± 4.36	1.35 ± 0.09
2	**Lisbon Frost**	78.46 ± 8.20	54.43 ± 5.70	1.44 ± 0.09
2	**Lisbon Prior**	78.86 ± 6.67	57.72 ± 4.03	1.37 ± 0.10
2	**Lisbon Rosenberger**	86.52 ± 8.04	61.09 ± 4.68	1.42 ± 0.09
2	**Lisbon Thornless**	81.68 ± 7.43	58.73 ± 4.96	1.40 ±0.14
2	**Verna**	86.87 ± 9.42	53.19 ± 5.58	1.64 ±0.14
3	**Cicily**	84.70 ± 9.68	62.67 ± 4.50	1.35 ± 0.12
3	**Eureka**	82.82 ± 10.66	61.44 ± 3.37	1.34 ± 0.09
3	**Eureka Addo**	82.05 ± 9.90	57.48 ± 5.86	1.43 ± 0.12
3	**Eureka Cook`s**	82.46 ± 9.32	58.86 ± 5.46	1.40 ± 0.11
3	**Eureka Frost**	86.36 ± 8.27	62.63 ± 4.97	1.38 ± 0.10
3	**Eureka Ryan**	76.61 ± 7.25	57.41 ± 5.11	1.34 ± 0.09
3	**Eureka Thornless**	83.38 ± 11.53	60.95 ± 6.76	1.37 ± 0.12
3	**Eureka UCLA**	93.17 ± 8.99	69.28 ± 4.44	1.34 ± 0.09
3	**Fino**	93.01 ± 10.97	65.35 ± 5.99	1.42 ± 0.08
3	**Genoa**	81.94 ± 10.39	59.98 ± 4.58	1.37 ± 0.15
3	**Lisbon**	81.35 ± 7.72	57.66 ± 5.36	1.41 ± 0.11
3	**Lisbon Frost**	83.62 ± 10.00	58.99 ± 5.90	1.42 ± 0.08
3	**Lisbon Prior**	80.12 ± 5.64	58.04 ± 4.24	1.38 ± 0.10
3	**Lisbon Rosenberger**	91.89 ± 8.24	64.75 ± 4.55	1.42 ± 0.10
3	**Lisbon Thornless**	87.30 ± 10.49	62.81 ± 5.49	1.39 ± 0.10
3	**Verna**	89.16 ± 9.26	56.41 ± 4.14	1.58 ± 0.11

Table 7. Mean and standard deviation values of the length (L), diameter (D) and L:D ratio measurements of fruit from different lemon selections on 'Volckameriana' rootstock from Citrusdal, Western Cape, South Africa.

Pick	Selection	Length	Diameter	L:D Ratio
1	**Cicily**	72.30 ± 7.86	57.89 ± 4.88	1.25 ± 0.10
1	**Eureka**	72.96 ± 7.34	57.77 ± 4.83	1.26 ± 0.10
1	**Eureka Addo**	66.93 ± 7.82	49.36 ± 4.88	1.36 ± 0.12
1	**Eureka Cook`s**	72.27 ± 6.98	55.98 ± 4.18	1.29 ±0.09
1	**Eureka Frost**	69.44 ± 8.35	53.12 ± 4.53	1.31 ± 0.10
1	**Eureka Ryan**	65.92 ± 7.20	51.58 ± 4.60	1.28 ± 0.10
1	**Eureka Thornless**	66.60 ± 7.64	51.62 ± 4.84	1.29 ± 0.09
1	**Eureka UCLA**	73.01 ± 8.61	56.64 ± 5.59	1.29 ± 0.10
1	**Fino**	72.66 ± 6.71	56.73 ± 3.46	1.28 ± 0.08
1	**Genoa**	77.64 ± 9.44	55.73 ± 4.92	1.39 ± 0.11
1	**Lisbon**	71.84 ± 7.07	56.24 ± 4.01	1.28 ± 0.11
1	**Lisbon Frost**	73.46 ± 8.06	55.48 ± 4.92	1.33 ± 0.10
1	**Lisbon Prior**	75.40 ± 9.96	57.30 ± 6.87	1.32 ± 0.11
1	**Lisbon Thornless**	65.01 ± 9.52	51.77 ± 4.74	1.25 ± 0.10
1	**Verna**	88.85 ± 9.94	57.82 ± 4.35	1.54 ± 0.14
2	**Cicily**	82.83 ± 11.69	65.11 ± 8.34	1.28 ± 0.13
2	**Eureka**	76.86 ± 10.54	62.21 ± 5.47	1.23 ± 0.36
2	**Eureka Addo**	79.09 ± 10.70	59.28 ± 6.46	1.34 ± 0.41
2	**Eureka Cook`s**	79.21 ± 13.95	59.40 ± 10.77	1.34 ± 0.12
2	**Eureka Frost**	77.75 ± 10.05	62.27 ± 6.19	1.25 ± 0.08
2	**Eureka Ryan**	69.08 ± 9.67	54.01 ± 6.47	1.28 ± 0.10
2	**Eureka Thornless**	72.65 ± 12.01	58.27 ± 5.98	1.24 ± 0.13
2	**Eureka UCLA**	82.60 ± 9.17	65.81 ± 5.80	1.26 ± 0.09
2	**Feminnelo Continella**	68.66 ±7.13	59.62 ± 3.89	1.15 ± 0.10

2	**Fino**	82.25 ± 8.64	63.34 ± 4.37	1.30 ± 0.09
2	**Lisbon**	77.66 ± 9.15	60.72 ± 5.25	1.28 ± 0.09
2	**Lisbon Frost**	84.84 ± 8.20	63.94 ± 4.58	1.33 ± 0.10
2	**Lisbon Prior**	83.10 ± 10.17	63.50 ± 6.99	1.31 ± 0.11
2	**Verna**	86.59 ± 13.47	59.78 ± 7.09	1.45 ± 0.13

Table 8. Percentages of exportable fruit from different scions, budded on 'Carrizo' citrange, 'Volckmeriana' lemon, 'Rosehaugh Empress' mandarin and rough lemon rootstocks. Measurements taken from Addo (2001) and Citrusdal (2000).

Area	Scion	Percentage fruit exportable		
		Pick 1	Pick 2	Pick 3
Addo	Cicily	65.5 %	85.3 %	82.0 %
Addo	Eureka	91.0 %	84.7 %	85.6 %
Addo	Eureka Addo	95.2 %	88.0 %	92.7 %
Addo	Eureka Cook`s	83.1 %	95.6 %	92.4 %
Addo	Eureka Frost	83.2 %	95.0 %	80.7 %
Addo	Eureka Ryan	79.0 %	93.3 %	86.3 %
Addo	Eureka Thornless	92.9 %	90.6 %	86.9 %
Addo	Eureka UCLA	68.8 %	85.0 %	83.7 %
Addo	Fino	88.4 %	94.7 %	92.7 %
Addo	Genoa	88.9 %	90.0 %	84.2 %
Addo	Lisbon	79.4 %	98.1 %	91.3 %
Addo	Lisbon Frost	74.7 %	95.0 %	90.6 %
Addo	Lisbon Prior	86.7 %	88.6 %	91.5 %
Addo	Lisbon Rosenberger	75.4 %	95.4 %	93.8 %
Addo	Lisbon Thornless	65.1 %	87.9 %	87.1 %
Addo	Verna	96.3 %	98.1 %	100.0 %
Addo	Eureka Seedless	81.7 %	-	-
Addo	Israel Eureka seedless	88.3 %	-	-
Addo	Lisbon Yen-Ben	78.3 %	87.5 %	-
Addo	Villafranca	46.7 %	-	-
Citrusdal	Cicily	53.0 %	55.6 %	
Citrusdal	Eureka	66.6 %	61.5 %	
Citrusdal	Eureka Addo	80.7 %	79.5 %	

Citrusdal	Eureka Cook's	70.5 %	72.4 %
Citrusdal	Eureka Frost	67.9 %	63.6 %
Citrusdal	Eureka Ryan	39.9 %	51.6 %
Citrusdal	Eureka Thornless	61.3 %	42.4 %
Citrusdal	Eureka UCLA	67.0 %	63.6 %
Citrusdal	Feminnelo Continella	12.5 %	16.1 %
Citrusdal	Fino	72.9 %	66.3 %
Citrusdal	Genoa	86.6 %	78.9 %
Citrusdal	Lisbon	69.1 %	65.4 %
Citrusdal	Lisbon Frost	76.3 %	65.2 %
Citrusdal	Lisbon Prior	73.3 %	74.3 %
Citrusdal	Lisbon Thornless	71.4 %	57.1 %
Citrusdal	Verna	87.6 %	95.7 %

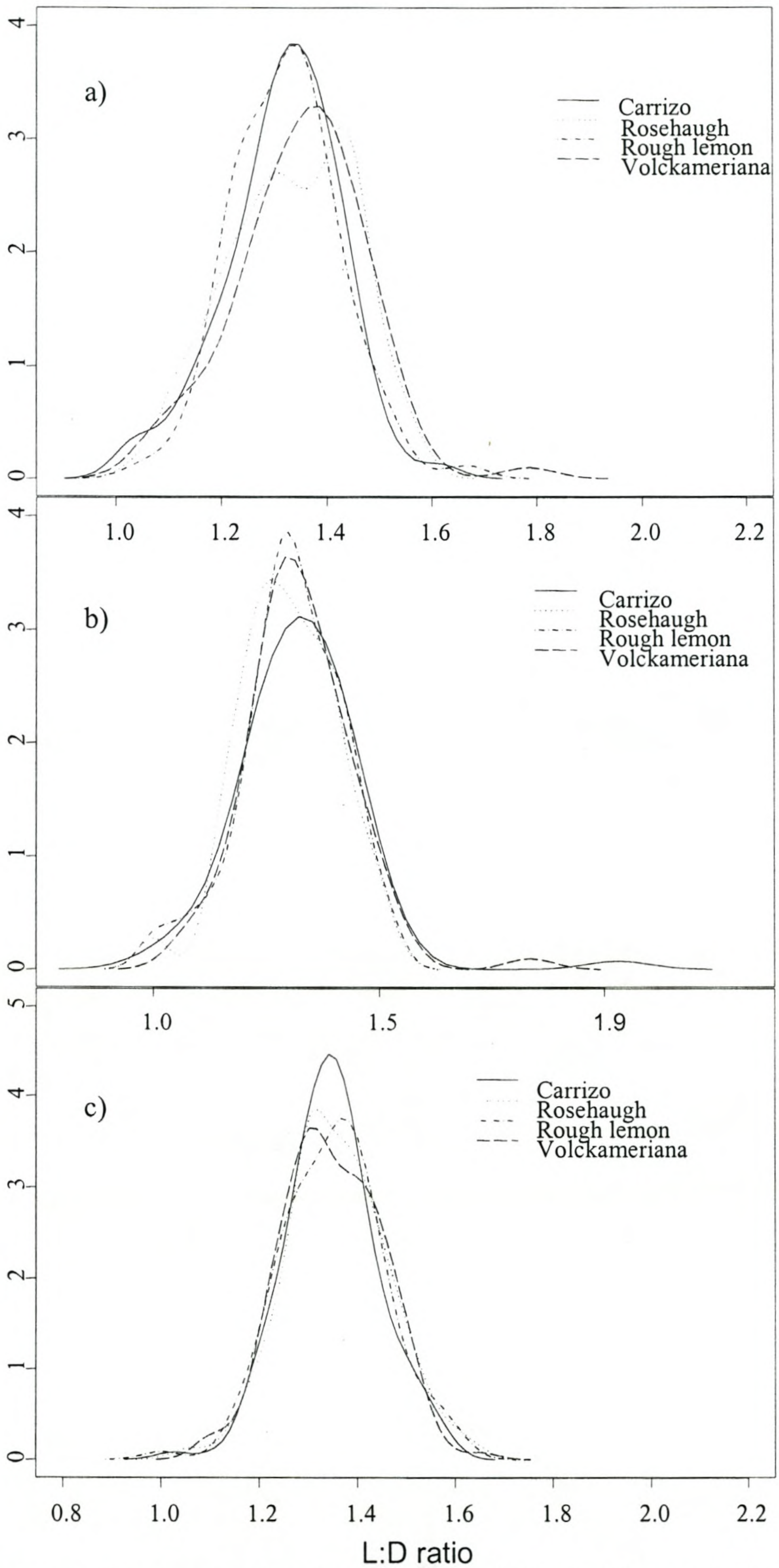

Figure 1. Density plot showing L:D ratio of 'Eureka' lemons budded on different rootstocks from Addo, 2001 cropping season.
a) First pick b) Second pick c) Third pick.

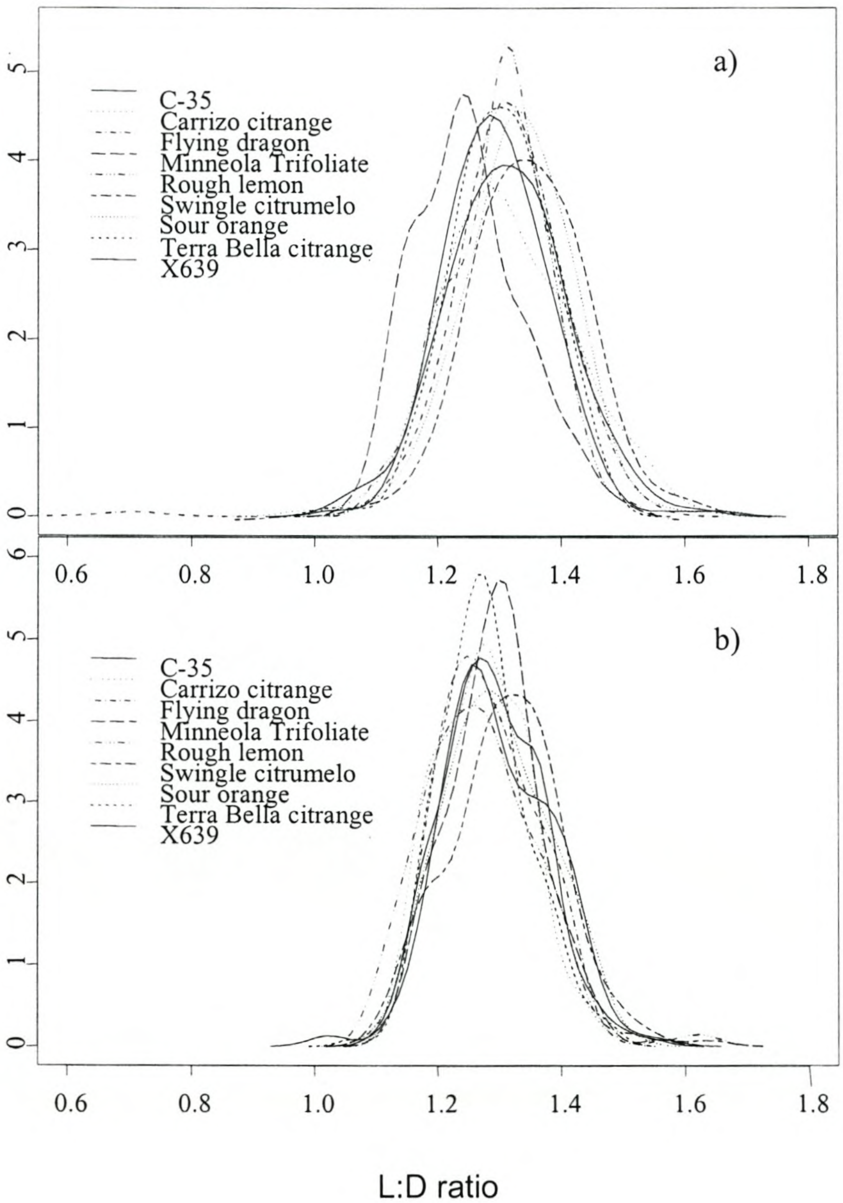

Figure 3. Density plot showing L:D ratio of 'Lisbon' lemon budded on different rootstocks from Nelspruit, 2000 cropping season.
a) First pick b) Second pick.

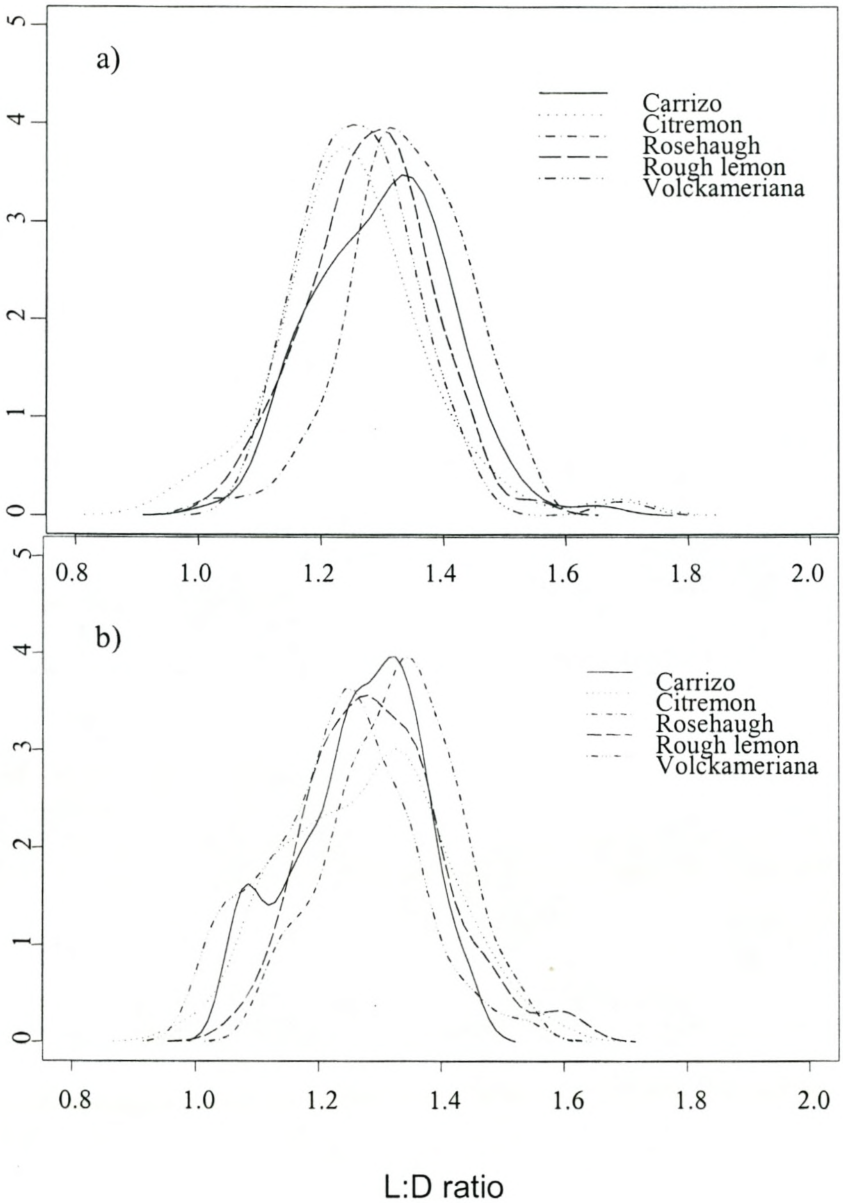

Figure 5. Density plot showing L:D ratio of 'Eureka' lemon budded on different rootstocks from Citrusdal, 2000 cropping season.
a) First pick b) Second pick.

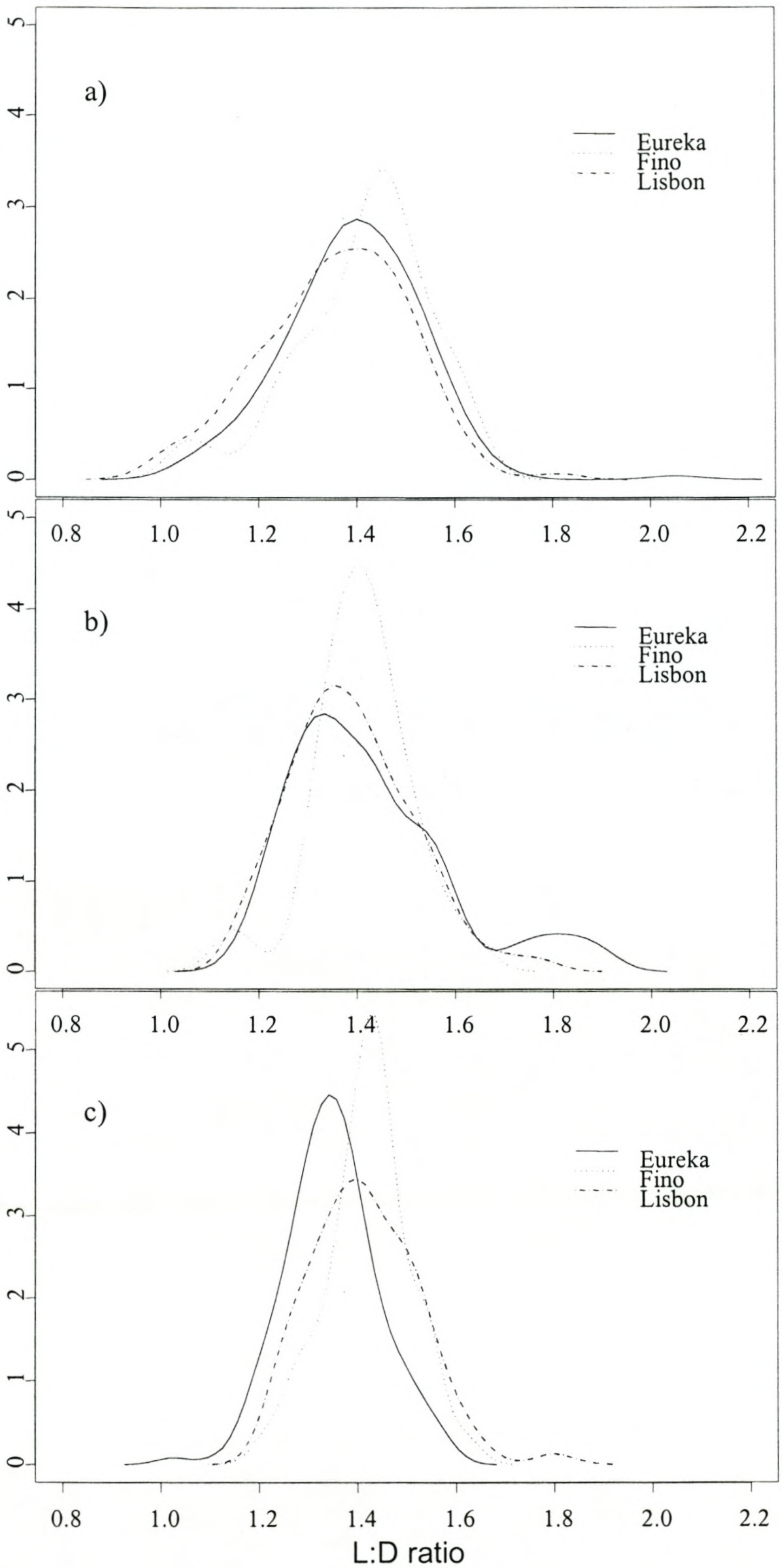

Figure 7. Density plot comparing fruit L:D ratio of 'Eureka', 'Fino' and 'Lisbon' lemons budded on 'Carrizo' citrange for three harvest dates at Addo, 2001 cropping season. a) First pick b) Second pick c) Third pick.

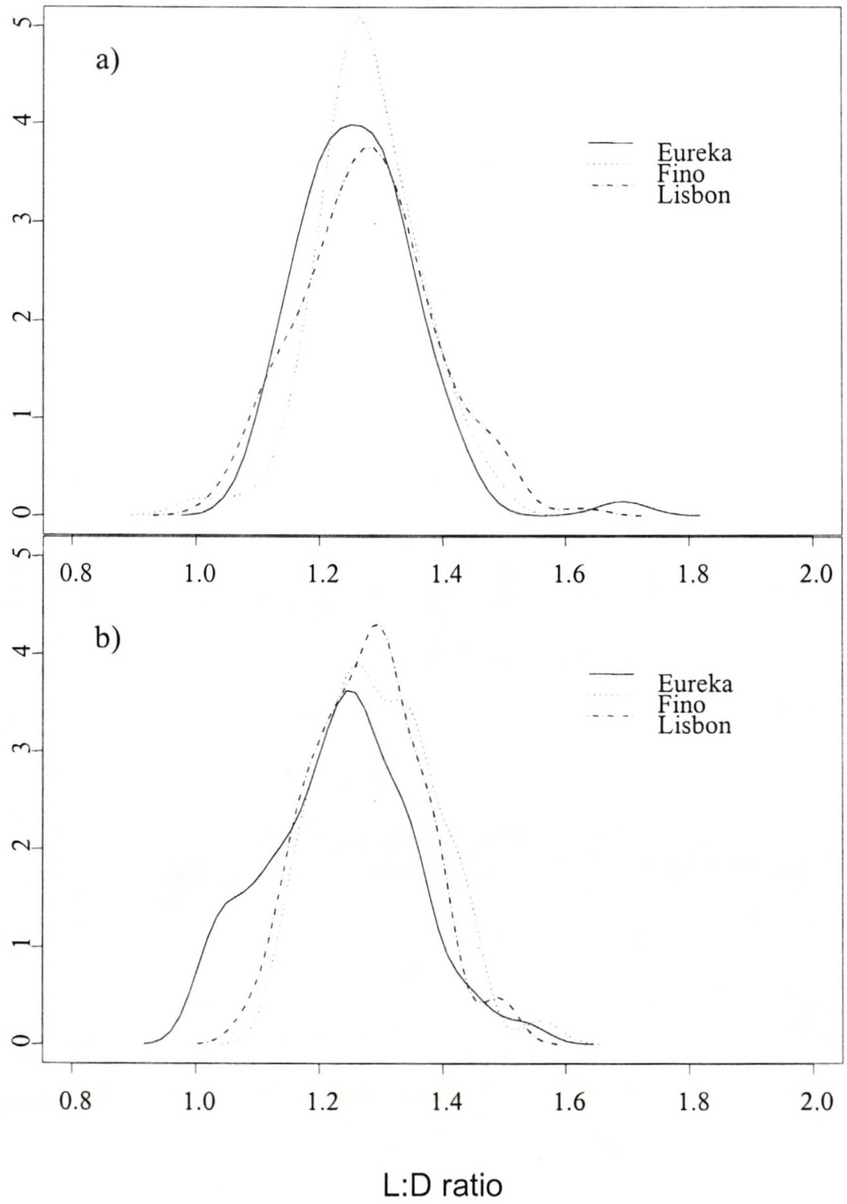

Figure 8. Density plot comparing fruit L:D ratio of 'Eureka', 'Fino' and 'Lisbon' lemons budded on 'Volckameriana' rootstock at Citrusdal, 2000 cropping season. a) First pick b) Second pick.

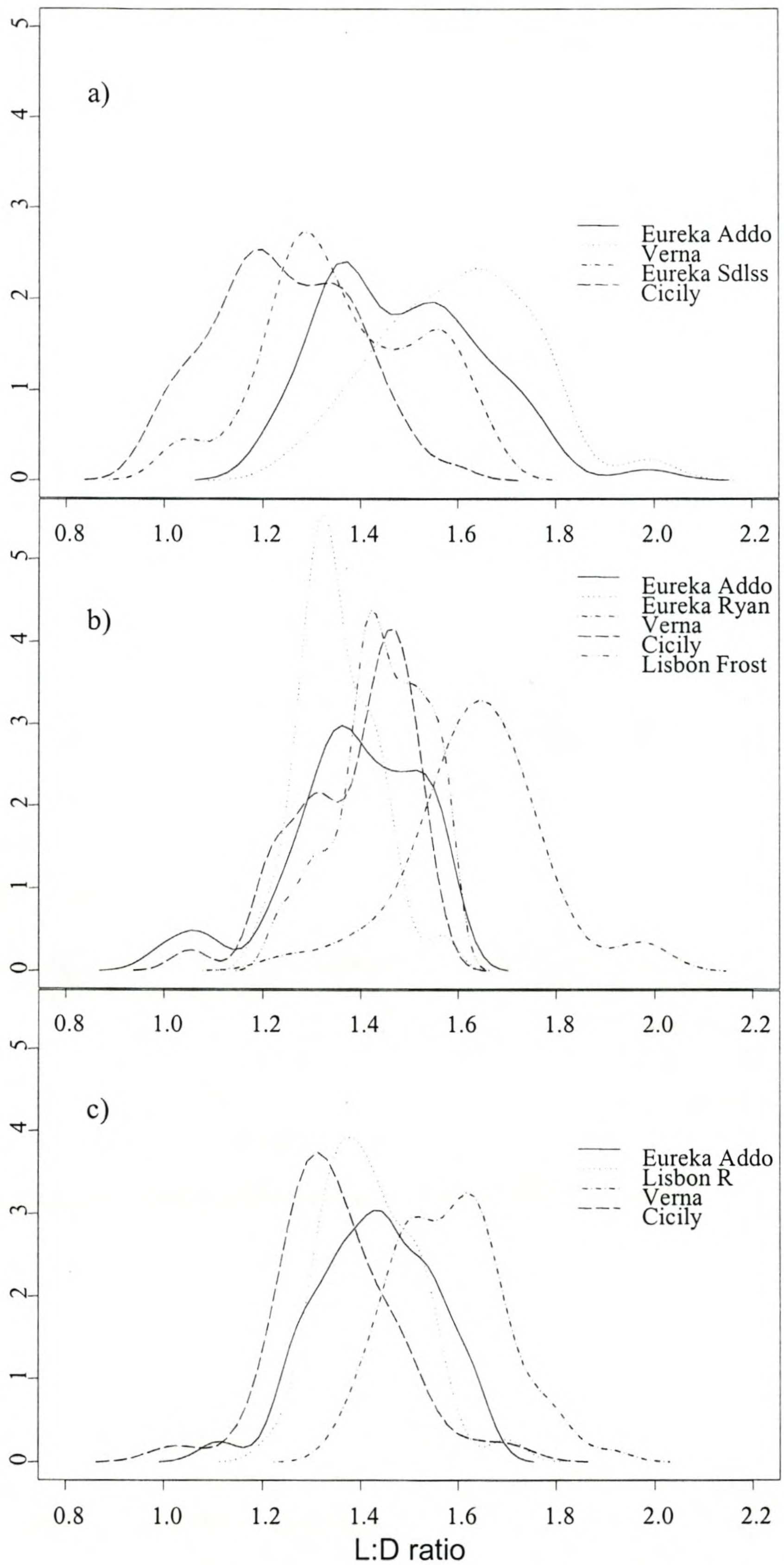

Figure 9. Density plot showing L:D ratio of different scions budded on 'Carrizo' citrange from Addo, 2001 cropping season. a) First pick b) Second pick c) Third pick. (Lisbon R = 'Lisbon Rosenberger', Eureka Sdlss = 'Eureka seedless')

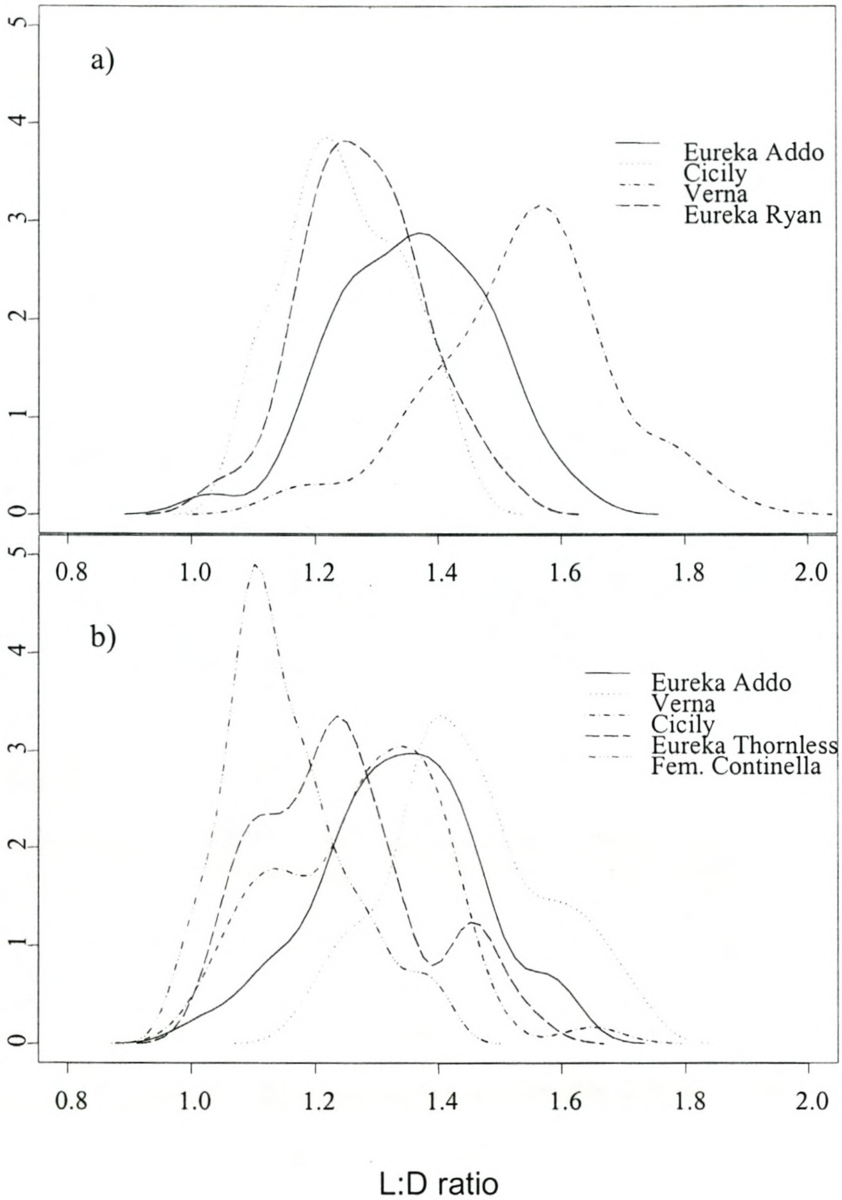

Figure 10. Density plot showing L:D ratio of different scions budded on 'Volckameriana' lemon rootstock from Citrusdal, 2000 cropping season. a) First pick b) Second pick. (Fem. Continella = 'Feminello Continella')

Paper IV: Manipulation of 'Eureka' lemon fruit shape by means of chemical manipulation.

Abstract

Gibberellins and cytokinins have previously been used to affect fruit shape of apples by elongation of the calyx lobes of the fruit. Certain market segments pay premium prices for lemon fruit with a larger length:diameter (L:D) ratio. No means of manipulating lemon fruit shape has been reported to date. In our trial, 'Eureka' lemons were treated with gibberellins (GA_{4+7}, GA_3), cytokinins (6-benzyladenine), combinations thereof, as well as 2,4-DP (dichlorophenoxypropionic acid), also known as Corasil E®. Growth regulators were sprayed at different concentrations and at different times. Split applications of Promalin® (GA_{4+7}, BA) were compared to single applications. Promalin® sprayed 6 and 8 weeks after full-bloom increased L:D ratio in the first season, but this was not consistent in the second season. Accel® (GA_{4+7}, BA), Provide® (GA_{4+7}), Progibb® (GA_3) and Corasil E® did not alter fruit shape. Corasil E® had a thinning effect that resulted in increased fruit size. Provide® seemed to increase fruit size without reducing fruit set. Promalin® and Corasil E® reduced fruit set.

Introduction

The production of premium quality fruit, satisfying the demands of discerning markets, is becoming increasingly important. Japan is a market with specific preferences for elongated lemons, paying premium prices for elongated fruit. More slices can be cut from an elongated lemon. Fruit shape is expressed as the length to diameter (L:D) ratio. Lemons with an L:D ratio of 1.25 and higher are exported to Japan.

No growth regulator has been evaluated on citrus fruit to improve fruit shape. A larger percentage of fruit would be exportable to Japan if a growth regulator could be economically used to elongate lemons. Combinations of GA (gibberellins) and BA (6-benzyladeninepurine) have been used to elongate fruit shape of 'Delicious' type apples. Unrath (1974) applied GA_{4+7} and BA to 'Starkrimson Delicious' apples. In initial tests, GA_{4+7} and BA (50 to 200 mg/l) increased fruit length, fruit weight and L:D ratio, but it did not alter fruit diameter. Williams and Stahly (1969) used Promalin® (GA_{4+7} and 6-BA) to elongate 'Delicious' apples. They discovered that application of cytokinins and GA alone and in combination to 'Delicious' apples just after full-bloom affected fruit shape by increasing the (L:D) ratio. This was also confirmed by other researchers (McLaughlin and Green, 1984; Burak and Büyükyilmaz, 1997). Stembridge and Morrel (1969) found that BA was the most effective in altering fruit L:D ratio when compared to GA_{4+7}, but a combination of the two plant growth regulators (PGR's) was the most effective in altering fruit shape.

From Paper I, it was evident that the presence and number of seeds are correlated with fruit shape. Seeds produce gibberellins (Dennis, 1976),and as a result, gibberellin containing chemicals were used (amongst others) in this study in an attempt to alter lemon fruit shape.

It is important to evaluate other effects growth regulators might have on fruit, such as thinning or malformation. Curry and Williams (1983), Stembridge and Morrell (1972), Unrath (1974), McLaughlin and Greene (1984), and Burak and Büyükyilmaz (1997) found that GA_{4+7} and BA at high doses, alone or in combination reduced fruit set.

Unrath (1974) found that air blast applications of GA_{4+7} + BA were as effective as hand-gun applications even when the amount of spray mixture was substantially reduced. Unrath (1974) also found that split applications were significantly less effective than a single application at the same concentration. Thus single applications were preferable to split applications.

Other growth regulators that might promote fruit elongation include auxins. Westwood and Blaney (1963) stated that cell elongation is mediated by auxin, and proposed that the factors affecting fruit shape do so by regulating the auxin available to them. Auxins promote cell elongation, via loosening of the cell walls and making them more susceptible to turgor-derived extension (Shoseyov and Dekel-Reichenbach, 1993). Late fruit growth and final fruit size of 'Satsuma' mandarin were increased by the application of the synthetic auxin 2,4,5-trichlorophenoxyacetic-acid. The auxin had a specific effect on the enlargement of the juice vesicles (Guardiola et al., 1993).

In this communication, the effect of GA and BA (either singly or in combination) and auxin on lemon fruit shape are reported on. The effect on fruit set was evaluated and different concentrations and spray dates were compared.

Materials and Methods

Three spray trials (Trials 1 to 3) were conducted in the 1999/2000 season, and a further three spray trials (Trials 4 to 6) in the following season of 2000/2001. Trials were done in the Western Cape, South Africa (34°S 19°E, 146 m.a.s.l.; Mediterranean-type climate). Eight-year-old 'Eureka' lemon trees budded to rough lemon rootstock were used for all trials. The same orchard was used in both seasons. In the case of Trial 1, Promalin® was applied as a full-cover spray until run-off. In the case of Trials 2 to 6, growth regulators were applied by a hand-held spray gun, spraying smaller branch units, until run-off. In all Promalin® trials, Agral (alkyl polyglycol ether), a wetting agent, was applied at 15ml/100l. In the case of Corasil E® sprays, Orchex mineral oil was used as a wetting agent. Smaller branch units, approximately 0.5 to 1.0 m long, were randomly selected. All branch units were properly tagged at a height of 0.5 to 1 m above ground level. Details on the time and concentration of growth regulator application are summarised in Table 1. Control trees or control branch units used in all trials were not sprayed. Prior to application of growth regulators, the number of fruit was counted on a tagged branch unit, and every 2 weeks thereafter until the end of the physiological fruit drop, to determine the percentage fruit set and to evaluate thinning effects of growth regulators applied. At harvest, length (L) and diameter (D) measurements were taken in all six trials, using a hand-held calliper, and L:D ratios were calculated. Fruit juice percentage was calculated using the same method in all six trials. In the case of Trial 1, 12 fruit per tree were used to determine juice percentage. In the case of Trials 2 and 3, five replicates were grouped together and Trials 4 to 6, two replicates were grouped together. Six fruit per group were used to determine juice percentage. Fruit with approximately the same diameter was selected for determining juice percentage. Juice percentage was determined as follows: juice % = (total fruit mass – pulp mass) / (total fruit mass) x 100 using the procedure described by Gilfillan (1990). Juice was extracted from fruit using a rotary juice extractor.

All trials were laid out as a randomised complete block design. Trials 1, 4, 5, 6 had 10 single-tree replicates. Trials 2 and 3 had 25 and 20 single-tree replicates, respectively. To prevent missing values as a result of all fruit abscising on a tagged branch, as in the 1999 season, five smaller branches per tree 0.5 to 1.0 m above ground, were tagged to serve as one replicate. This method was used for Trials 4, 5 and 6. For data analysis in Trial 1, the mean of the 50 fruit picked per tree were used as a single value. In the case of Trials 2 to 6, the mean of fruit per branch (or group of branches) picked was used as a single value. The General Linear Means (GLM) procedure of the Statistical Analysis System (SAS) was used to analyse the data (SAS Institute Inc., 1990). Single degree of freedom orthogonal polynomial contrast could not be fitted due to missing values in some trials.

Results and discussion

Effect of GA_{4+7} + BA

Split applications of Promalin® did not differ significantly from single applications (Table 2). In the first season, full-cover Promalin® sprays at 5, 10 and 20 mg/l sprayed at both full-bloom and 2 weeks after full bloom (AFB), reduced percentage fruit set without altering fruit shape or fruit size. Juice percentage negatively correlates with rind thickness, therefore fruit with a lower juice percentage have thicker rinds (Embleton and Jones, 1966). All treatments except the 10 mg/l split application significantly reduced juice percentage and thus probably increased rind thickness. Fruit sprayed with Promalin® at 100 and 200 mg/l 2 weeks AFB and 200 mg/l at FB, increased L:D ratio slightly as a result of increased length, but this increase was not significant when compared to control treatments (Table 3). All Promalin® treatments had the lowest percentage fruit set. Promalin® at 100 and 200 mg/l sprayed at FB thinned more than treatments sprayed 2 weeks AFB (Table 3). Juice percentage was not significantly affected by Promalin® treatments. Accel® sprays at 100 and 200 mg/l sprayed at both FB and 2 weeks AFB had no effect on fruit shape or size. Accel® sprays at 100 and 200 mg/l sprayed at FB had a slighty smaller percentage fruit set, while sprays 2 weeks AFB did not thin fruit in any way (Table 3). None of the Accel® sprays had an effect on juice percentage. Promalin® differ from Accel® only in having a higher gibberellin content.

Later Promalin® treatments (6 and 8 weeks AFB) of 25, 50 and 100 mg/l increased L:D ratio of fruit by increasing fruit length without increasing fruit diameter (Table 4). Increase in L:D ratios was statistically significant but, commercially, differences seem too small to be meaningful. The only treatment resulting in a larger increase in L:D ratio was Promalin® at 100 mg/l sprayed at 6 weeks AFB (Table 4). This treatment was however also the treatment with the lowest percentage fruit set. Fruit set was not significantly reduced by any of these later Promalin® treatments. Juice percentage was not affected, and thus rind thickness was probably also not affected.

In Trial 5, no Promalin® spray increased L:D ratio (Table 5) The only Promalin® treatment significantly reducing fruit set, was at 3 weeks BFB at 100 mg/l. Juice percentage was not consistently affected by any treatment.

Effect of GA_{4+7}

Provide® treatments at 7 weeks AFB significantly increased fruit length (Table 6). The increase was however accompanied by a significant increase in diameter, resulting in larger fruit without altering fruit shape significantly. This was also true for Provide® sprayed 9 weeks AFB at 100 mg/l. Provide® treatments did not reduce fruit set or juice percentage. As juice percentage was not affected, rind thickness was also unaffected.

Effect of GA_3

ProGibb® sprayed 9 weeks AFB at 200 mg/l resulted in larger fruit increasing the length as well as the diameter, but not altering fruit shape (Table 6). No other ProGibb® spray affected fruit size or shape significantly. ProGibb® did not reduce fruit set. Juice percentage of treated fruit did not differ significantly when compared to the control treatment.

Effect of dichlorophenoxypropionic acid

A significant increase in fruit size was recorded for Corasil E® sprays at both 100 and 200 mg/l sprayed at 4 as well as 8 weeks AFB (Table 7). The increase in diameter is however not accompanied by an increase in fruit length and thus no increase in L:D ratio occurred. Corasil E® sprays 4 weeks AFB at both 100 and 200 mg/l resulted in a decreased percentage fruit set. Sprays at 8 weeks AFB at 100 and 200 mg/l also decreased percentage fruit set, but not significantly. None of the Corasil E® sprays had an effect on juice percentage.

Conclusion

Different types of growth regulators tested over two consecutive seasons did not seem to successfully alter fruit shape. Promalin® sprayed 6 and 8 weeks AFB in the 1999/2000 season, resulted in elongated lemons, but these results could not be repeated for Promalin® sprays at 6 and 9 weeks AFB in the 2000/2001 season. While the L:D ratio increase achieved by later Promalin® sprays in the 1999/2000 season is statistically significant, it does not seem to be commercially significant. Corasil E®, as was the case for early Promalin® sprays, had a thinning effect. Provide® increased fruit size without thinning, while Corasil E® increased fruit size, but as a result of thinning. Accel® and ProGibb® had no effect on fruit shape or fruit set.

From Paper I, it seemed that gibberellins produced by the seeds might play a significant part in determining final fruit shape. Ovules are formed at flower differentiation. This was the reason for Promalin® being applied earlier in the 2000/2001 season by spraying as early as 3 weeks before full-bloom. The sprays were however unsuccessful. There might be a number of reasons for this, i.e. poor absorption of the Promalin®. GA_3 was also not used in early sprays. It is suggested that further research is done on the use of gibberellin containing sprays at different times.

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Table 1. Details of time and type of chemical spayed on 'Eureka' lemon trees at different concentrations. (Prom = Promalin®, Cor = Corasil E®, Prov = Provide®, ProG = ProGibb®)

	Chemical / Concentration					
Time	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trail 6**
	Control	Control	Control	Control	Control	Control
	Control	Control	Control	-	-	-
3 wks BFB[z]	Prom 25 mg/l	-	-	Prom 25 mg/l	-	-
3 wks BFB	Prom 50 mg/l	-	-	Prom 50 mg/l	-	-
3 wks BFB	Prom 100 mg/l	-	-	Prom 100 mg/l	-	-
FB[Y]	Prom 5 mg/l	Prom 100 mg/l	-	Prom 25 mg/l	-	-
FB	Prom 10 mg/l	Prom 200 mg/l	-	Prom 50 mg/l	-	-
FB	Prom 20 mg/l	Accel 100 mg/l	-	Prom 100 mg/l	-	-
FB	-	Accel 200 mg/l	-	-	-	-
2 wks AFB[X]	Prom 5 mg/l	Prom 100 mg/l	-	-	-	-
2 wks AFB	Prom 10 mg/l	Prom 200 mg/l	-	-	-	-
2 wks AFB	Prom 20 mg/l	Accel 100 mg/l	-	-	-	-
2 wks AFB	-	Accel 200 mg/l	-	-	-	-
FB + 2 wks AFB	Prom 10 mg/l	-	-	-	-	-
FB + 2 wks AFB	Prom 20 mg/l	-	-	-	-	-

3 wks AFB	-	-	-	Prom 25 mg/l	-	-
3 wks AFB	-	-	-	Prom 50 mg/l	-	-
3 wks AFB	-	-	-	Prom 100 mg/l	-	-
4 wks AFB	-	-	-	-	-	Cor 100 mg/l
4 wks AFB	-	-	-	-	-	Cor 200 mg/l
6 wks AFB	-	-	Prom 25 mg/l	Prom 25 mg/l	-	-
6 wks AFB	-	-	Prom 50 mg/l	Prom 50 mg/l	-	-
6 wks AFB	-	-	Prom 100 mg/l	Prom 100 mg/l	-	-
7 wks AFB	-	-	-	-	Prov 100 mg/l	-
7 wks AFB	-	-	-	-	Prov 200 mg/l	-
7 wks AFB	-	-	-	-	ProG 100 mg/l	-
7 wks AFB	-	-	-	-	ProG 200 mg/l	-
8 wks AFB	-	-	Prom 25 mg/l-	-	-	Cor 100 mg/l
8 wks AFB	-	-	Prom 50 mg/l	-	-	Cor 200 mg/l
8 wks AFB	-	-	Prom 100 mg/l	-	-	-
9 wks AFB	-	-	-	Prom 25 mg/l	Prov 100 mg/l	-
9 wks AFB	-	-	-	Prom 50 mg/l	Prov 200 mg/l	-
9 wks AFB	-	-	-	Prom 100 mg/l	ProG 100 mg/l	-
9 wks AFB	-	-	-	-	ProG 200 mg/l	-

Z = before full bloom Y = full bloom X=after full bloom

Table 2. Length (L), diameter (D), L:D ratio, fruit set percentage and juice percentage of 'Eureka' lemons following full-cover Promalin® sprays. (Trial 1; 1999/2000 season). FB = full-bloom, AFB = after full-bloom

Treatment timing		**Concentration**		**L**	**D**	**L:D**	**% Set**	**% Juice**
Control				77.88 ab	57.87 ab	1.35 bc	12.66 bc	38.75 a
Control				77.68 b	56.23 b	1.38 ab	27.88 ab	35.93 b
Promalin®	FB	5 mg/l		78.99 ab	57.06 ab	1.39 a	6.64 c	33.70 b
Promalin®	FB	10 mg/l		77.00 b	57.44 ab	1.34 c	12.48 c	34.39 b
Promalin®	FB	20 mg/l		78.81 ab	58.35 ab	1.35 bc	9.06 c	33.67 b
Promalin®	2 wks AFB	5 mg/l		78.45 ab	57.55 ab	1.36 abc	18.04 bc	34.78 b
Promalin®	2 wks AFB	10 mg/l		80.48 a	57.90 ab	1.39 a	14.22 bc	35.40 b
Promalin®	2 wks AFB	20 mg/l		79.03 ab	57.72 ab	1.37 abc	16.70 bc	34.87 b
Promalin®	FB + 2 wks AFB	10 mg/l		78.84 ab	58.55 a	1.35 bc	33.53 a	36.06 ab
Promalin®	FB + 2 wks AFB	20 mg/l		79.19 ab	58.06 ab	1.36 abc	11.99 c	35.18 b
Significance level			**df**					
Treatment			**9**	0.4173	0.6789	0.0335	0.0277	0.0244
*Control vs. Promalin®			1	0.1889	0.4088	0.5012	0.2512	0.0005
FB vs. 2 wks AFB			1	0.1758	0.8430	0.1178	0.1219	0.1756
Single application vs. Double application			1	0.7730	0.2691	0.2320	0.0297	0.1513
LSD (P=0.05)				2.64	1.97	0.03	15.37	2.72

* Single degree orthogonal polynomial contrasts

Table 3. Length (L), diameter (D), L:D ratio, fruit set and juice percentage of 'Eureka' lemon trees sprayed with Accel® and Promalin® with a hand-held spray-gun. (Trial 2; 1999/2000 season). FB = full-bloom, AFB = after full-bloom

Treatment	Time	Concentration	L	D	L:D	% Set	% Juice
Control			74.85 b	53.68 b	1.39 ab	17.77 abcd	35.88 bc
Control			76.11 ab	55.89 ab	1.37 b	23.98 ab	37.48 ab
Promalin®	FB	100 mg/l	76.29 ab	55.64 ab	1.37 b	13.28 d	37.06 ab
Promalin®	FB	200 mg/l	80.13 a	56.10 ab	1.43 a	11.69 d	32.66 c
Accel®	FB	100 mg/l	75.60 b	56.11 ab	1.35 b	19.52 abcd	34.88 bc
Accel®	FB	200 mg/l	78.98 ab	56.58 a	1.39 ab	15.26 cd	36.72 ab
Promalin®	2 wks AFB	100 mg/l	77.67 ab	55.78 ab	1.40 ab	16.53 bcd	33.92 bc
Promalin®	2 wks AFB	200 mg/l	78.87 ab	55.23 ab	1.43 a	16.38 bcd	35.98 bc
Accel®	2 wks AFB	100 mg/l	75.86 ab	55.54 ab	1.37 b	24.87 a	40.30 a
Accel®	2 wks AFB	200 mg/l	76.20 ab	55.72 ab	1.37 b	22.92 abc	35.06 bc
Significance level			0.3325	0.6935	0.0441	0.0098	0.0191
LSD (P=0.05)			4.41	2.45	0.051	7.96	3.73

Table 4. Length (L), diameter (D), L:D ratio, fruit set and juice percentage of 'Eureka' lemon trees, sprayed with Promalin® with a hand-held spray-gun. (Trial 3; 1999/2000 season). FB = full-bloom, AFB = after full-bloom

Treatment	**Time**	**Concentration**	**L**	**D**	**L:D**	**% Set**	**% Juice**
Control			76.11 d	54.12 b	1.40 bc	42.39 ab	33.58 ab
Control			78.24 cd	57.05 a	1.37 c	45.61 a	37.61 a
Promalin®	6 wks AFB	25 mg/l	81.66 abc	56.53 a	1.44 ab	36.61 ab	31.62 bc
Promalin®	6 wks AFB	50 mg/l	82.26 ab	57.72 a	1.43 abc	41.81 ab	37.53 a
Promalin®	6 wks AFB	100 mg/l	84.44 a	56.91 a	1.49 a	30.27 b	28.16 c
Promalin®	8 wks AFB	25 mg/l	80.10 bc	56.13 ab	1.43 bc	47.93 a	34.05 ab
Promalin®	8 wks AFB	50 mg/l	81.87 ab	56.45 a	1.45 ab	44.48 ab	35.41 ab
Promalin®	8 wks AFB	100 mg/l	82.49 ab	57.72 a	1.43 abc	41.17 ab	36.50 a
Significance level			0.0004	0.0281	0.0146	0.3782	0.0051
LSD (P=0.05)			3.57	2.05	0.06	15.00	4.65

Table 5. Length (L), diameter (D), L:D ratio, fruit set and juice percentage of 'Eureka' lemon trees sprayed with Promalin® (single application), with a hand-held spray-gun. (Trial 4; 2000/2001 season). BFB = before full-bloom, FB = full-bloom, AFB = after full-bloom

Treatment	Time	Concentration	L	D	L:D	% Set	% Juice
Control			72.77 abcd	56.31 bc	1.29 a	12.47 abc	32.90 bcd
Promalin®	3 wks BFB	25 mg/l	75.32 ab	59.80 ab	1.26 a	11.95 abc	31.75 cd
Promalin®	3 wks BFB	50 mg/l	69.44 cde	55.78 bc	1.25 a	12.10 abc	35.01 abcd
Promalin®	3 wks BFB	100 mg/l	67.81 ef	53.05 cd	1.28 a	7.03 d	36.26 ab
Promalin®	FB	25 mg/l	71.59 bcde	56.31 bc	1.27 a	11.29 abc	33.71 abcd
Promalin®	FB	50 mg/l	64.43 f	51.11 d	1.26 a	13.77 ab	35.26 abcd
Promalin®	FB	100 mg/l	70.59 cde	56.23 bc	1.26 a	10.52 bcd	35.13 abcd
Promalin®	3 wks AFB	25 mg/l	71.59 bcde	56.39 bc	1.27 a	11.91 abc	31.11 d
Promalin®	3 wks AFB	50 mg/l	68.91 def	54.61 cd	1.27 a	13.92 ab	34.88 abcd
Promalin®	3 wks AFB	100 mg/l	76.79 a	60.63 a	1.28 a	12.83 abc	32.56 bcd
Promalin®	6 wks AFB	25 mg/l	73.11 abcd	56.04 bc	1.31 a	14.30 a	34.52 abcd
Promalin®	6 wks AFB	50 mg/l	73.84 abc	56.87 abc	1.30 a	13.96 ab	35.95 abc
Promalin®	6 wks AFB	100 mg/l	70.80 bcde	54.98 cd	1.29 a	11.15 abc	33.15 bcd
Promalin®	9 wks AFB	25 mg/l	71.81 bcde	56.18 bc	1.28 a	10.31 bcd	37.80 a
Promalin®	9 wks AFB	50 mg/l	69.74 cde	55.88 bc	1.25 a	9.50 cd	34.35 abcd
Promalin®	9 wks AFB	100 mg/l	71.75 bcde	56.87 abc	1.26 a	11.31 abc	33.20 bcd
Significance level		**df**					
Treatment		15	0.0001	0.0058	0.8689	0.0168	0.2029
*Promalin® vs. Control		1	0.3449	0.8635	0.3596	0.5875	0.3676
3 wks BFB vs. 9 wks AFB		1	0.8554	0.9361	0.9257	0.9910	0.5275
25 mg/l vs. 100 mg/l		1	0.2758	0.5203	0.6965	0.1014	0.7674
LSD (P=0.05)			4.59	4.07	0.061	3.71	4.25

*Single degree orthogonal polynomial contrasts

Table 6. Length (L), diameter (D), L:D ratio, fruit set and juice percentage of 'Eureka' lemon trees , sprayed with Provide® and ProGibb® with a hand-held spray-gun. (Trial 5; 2000/2001 season). AFB = after full-bloom

Treatment	Time	Concentration	df	L	D	Ratio	% Set	% Juice
Control				68.71 c	53.39 d	1.29 a	62.04 abc	33.77 ab
Provide®	7 wks AFB	100 mg/l		73.67 ab	56.96 a	1.29 a	69.17 ab	34.95 ab
Provide®	7 wks AFB	200 mg/l		73.79 ab	56.71 ab	1.30 a	61.24 bc	36.03 ab
ProGibb®	7 wks AFB	100 mg/l		70.45 abc	54.69 bcd	1.29 a	57.96 c	30.58 b
ProGibb®	7 wks AFB	200 mg/l		70.21 abc	54.63 bcd	1.29 a	72.11 a	31.31 ab
Provide®	9 wks AFB	100 mg/l		72.85 ab	56.66 ab	1.29 a	70.16 ab	36.42 a
Provide®	9 wks AFB	200 mg/l		72.48 abc	55.36 abcd	1.31 a	67.72 abc	33.11 ab
ProGibb®	9 wks AFB	100 mg/l		70.05 bc	54.34 cd	1.29 a	64.35 abc	37.10 a
ProGibb®	9 wks AFB	200 mg/l		74.22 a	56.11 abc	1.32 a	68.52 abc	36.41 a
Significance level			**df**					
Treatment			8	0.0749	0.0217	0.9341	0.1555	0.2458
*Control vs. ProGibb®			1	0.1253	0.0866	0.6525	0.3885	0.5495
Control vs. Provide®			1	0.0072	0.0011	0.6375	0.2410	0.9705
ProGibb® vs. Provide®			1	0.0590	0.0110	0.9736	0.6204	0.3762
ProGibb® 7 wks AFB vs. 9 wks AFB			1	0.2184	0.4826	0.3622	0.7144	0.7220
Provide® 7 wks AFB vs. 9 wks AFB			1	0.4648	0.3072	0.9813	0.3297	0.0070
ProGibb® 100 mg/l vs. 200 mg/l			1	0.5585	0.1800	0.2869	0.0187	0.5845
Provide® 100 mg/l vs. 200 mg/l			1	0.4404	0.9313	0.3372	0.1774	0.9937
LSD (P=0.05)				4.09	2.26	0.06	10.73	5.80

* Single degree orthogonal polynomial contrasts

Table 7. Length (L), diameter (D), L:D ratio, fruit set and juice percentage of 'Eureka' lemon trees sprayed with Corasil E®, with a hand-held spray-gun (Trial 6; 2000/2001 season). AFB = after full-bloom

Treatment	**Time**	**Concentration**	**L**	**D**	**L:D**	**% Set**	**% Juice**
Control			67.15 b	52.78 b	1.27 a	23.61 a	37.26 a
Corasil E®	4 wks AFB	100 mg/l	72.99 a	57.99 a	1.26 a	8.99 c	36.53 a
Corasil E®	4 wks AFB	200 mg/l	71.36 ab	57.71 a	1.24 a	13.99 bc	39.80 a
Corasil E®	8 wks AFB	100 mg/l	70.66 ab	55.76 a	1.27 a	19.64 ab	39.76 a
Corasil E®	8 wks AFB	200 mg/l	71.11 ab	56.80 a	1.25 a	19.00 ab	35.21 a
Significance level		**df**	0.2013	0.0040	0.9378	0.0003	0.2672
Treatment		4					
*Control vs. Corasil E®		1	0.0278	0.0004	0.5837	0.0016	0.7680
4 wks AFB vs. 8 wks AFB		1	0.4560	0.1171	0.6827	0.0008	0.6983
Corasil E® 100 mg/l vs. 200 mg/l		1	0.7340	0.7019	0.5820	0.3160	0.7092
LSD (P=0.05)			4.90	2.80	0.08	6.15	5.06

* Single degree orthogonal polynomial contrasts

GENERAL CONCLUSIONS

Lemon fruit shape is partly determined during early fruit development when the seeds are developed (Paper I). The presence and number of seeds played a significant part in fruit shape. Seeds are producers of gibberellins, which results in increased rind thickness at both stylar- and stem-ends, as well as in the middle, of fruit. The other factor influencing fruit shape was the number of segments. The number of segments is determined during flower differentiation. Both factors indicated that final fruit shape is already determined during flower initiation and early fruit development.

The effect of winter temperatures on fruit shape (summer temperatures having no effect) also corroborates with the fact that fruit shape is determined early. It is known that some cold-requiring plants have higher gibberellin levels at lower temperatures. Vaalharts had significantly lower minimum winter temperatures and also had more elongated fruit (Paper II).

Rootstocks did not influence lemon fruit shape (Paper III). As a result, the hypothesis that different rootstocks may supply scions differently with endogenous growth hormones could not be proved.

There were larger variations in L:D ratio between scions than between rootstocks. In the case of certain scions, two peaks were clear in the density plots, pointing to the fact that the particular scion had round as well as elongated fruit. For further research it would be interesting to determine the number of seeds and segments as well as rind thickness for the two groups evident within the same scion. This would give an indication whether factors such as the seed count was responsible for the variation or whether the variation within the scion is due to genotype. If seed count plays a major role in fruit shape of different scions, the inconsistent fruit shape of some scions can be explained by the varying conditions favourable for self- or cross-pollination.

From Paper I it is clear that early PGR application should be used to manipulate fruit shape by means of chemical sprays. The importance of seeds in fruit shape, points to gibberellins as the endogenous hormone being responsible for variation in fruit shape. Comparing Promalin® (GA_{4+7} + BA) (with a higher GA content) and Accel® (GA_{4+7} + BA), it is clear that Promalin® was more effective. In citrus, it is not known which gibberellin is produced by the seeds. GA_3 was only sprayed at a later stage, and early sprays should be investigated. Promalin® sprayed at 3 weeks BFB failed in altering fruit shape, but the trial was done for one season only, and it might be worthwhile repeating it.

Appendix: Paper II

Specific picking dates

Addo	**2000**	Pick 1	12 May
		Pick 2	5 July
	2001	Pick 1	24 April
		Pick 2	4 July
		Pick 3	22 August
Citrusdal	**2000**	Pick 1	10 May
		Pick 2	28 June
	2001	Pick 1	18 April
		Pick 2	18 June
Nelspruit	**2000**	Pick 1	17 April
		Pick 2	19 May
Stelllenbosch	**2000**	Pick 1	16 May
		Pick 2	11 July
	2001	Pick 1	23 May
		Pick 2	29 June
Uitenhage	**2000**	Pick 1	10 May
		Pick 2	28 August
	2001	Pick 1	25 April
Vaalharts	**2000**	Pick 1	18 April
	2001	Pick 1	10 April
		Pick 2	10 July

Anova table for lengths measured from 'Eureka' lemon in 2000 cropping season for six different production areas in South Africa.

	Degrees of freedom	Sum of Squares	Mean squares	F value	Pr(F)
	10	184887.5	18488.75	256.1244	0
Total	**4781**	**345124.2**	**72.19**		

Anova table for diameters measured from 'Eureka' lemon in 2000 cropping season for six different production areas in South Africa.

	Degrees of freedom	Sum of Squares	Mean squares	F value	Pr(F)
	10	26353.8	2635.382	89.36453	0
Total	**4781**	**140992.9**	**29.490**		

Anova table for L:D ratios calculated from 'Eureka' lemon in 2000 cropping season.

	Degrees of freedom	Sum of Squares	Mean squares	F value	Pr(F)
	10	22.57605	2.257605	199.0886	0
Total	**4781**	**54.21511**	**0.011340**		

Anova table for lengths measured from 'Eureka' lemon in 2001 cropping season for five different production areas in South Africa.

	Degrees of freedom	Sum of Squares	Mean squares	F value	Pr(F)
	9	369324.8	41036.09	492.206	0
Total	**5334**	**444705.0**	**83.37**		

Anova table for diameters measured from 'Eureka' lemon in 2001 cropping season for five different production areas in South Africa.

	Degrees of freedom	Sum of Squares	Mean squares	F value	Pr(F)
	9	93500.3	10388.93	319.7081	0
	5334	**173328.5**	**32.5**		

Anova table for L:D ratios calculated from 'Eureka' lemon in 2001 cropping season for five different production areas in South Africa.

	Degrees of freedom	Sum of Squares	Mean squares	F value	Pr(F)
	9	16.45243	1.828048	128.6163	0
Total	**5334**	**75.81317**	**0.014213**		

99 % Simulataneous confidence intervals for specified linear combinations, by the Scheffe method. Intervals excluding 0 are flagged by '****'. Intervals excluding zero: Hypothesis that the difference between the respective population mean is zero, is the rejected at a 1% significance level. Fruit shape of six areas were compared using 'Eureka' lemons fruit for both 2000 and 2001 cropping season.

	Estimate	Std.Error	Lower Bound	Upper Bound
2000 Cropping season				
Length				
ADDO:1-ADDO:2	3.2100	0.678	-0.0526	6.480
ADDO:1-CITRUS:1	12.1000	0.655	8.9500	15.300 ****
ADDO:1-CITRUS:2	4.7900	0.665	1.5800	8.000 ****
ADDO:1-NELS:1	6.7100	0.555	4.0300	9.390 ****
ADDO:1-NELS:2	7.4300	0.566	4.7000	10.200 ****
ADDO:1-STELL:1	6.6000	0.612	3.6500	9.550 ****
ADDO:1-STELL:2	10.3000	0.680	6.9800	13.500 ****
ADDO:1-UITEN:1	7.3600	0.685	4.0600	10.700 ****
ADDO:1-UITEN:2	10.9000	0.685	7.6100	14.200 ****
ADDO:1-VAAL:1	-14.2000	0.660	-17.4000	-11.000 ****
ADDO:2-CITRUS:1	8.8900	0.655	5.7300	12.100 ****
ADDO:2-CITRUS:2	1.5800	0.666	-1.6300	4.790
ADDO:2-NELS:1	3.5000	0.556	0.8170	6.180 ****
ADDO:2-NELS:2	4.2100	0.566	1.4800	6.940 ****
ADDO:2-STELL:1	3.3900	0.613	0.4330	6.340 ****
ADDO:2-STELL:2	7.0400	0.680	3.7600	10.300 ****
ADDO:2-UITEN:1	4.1500	0.686	0.8400	7.450 ****
ADDO:2-UITEN:2	7.7000	0.686	4.4000	11.000 ****
ADDO:2-VAAL:1	-17.4000	0.660	-20.6000	-14.200 ****
CITRUS:1-CITRUS:2	-7.3200	0.643	-10.4000	-4.220 ****

CITRUS:1-NELS:1	-5.4000	0.528	-7.9400	-2.850 ****
CITRUS:1-NELS:2	-4.6800	0.539	-7.2800	-2.080 ****
CITRUS:1-STELL:1	-5.5000	0.588	-8.3400	-2.670 ****
CITRUS:1-STELL:2	-1.8500	0.657	-5.0200	1.320
CITRUS:1-UITEN:1	-4.7400	0.663	-7.9400	-1.550 ****
CITRUS:1-UITEN:2	-1.1900	0.663	-4.3900	2.010
CITRUS:1-VAAL:1	-26.3000	0.637	-29.4000	-23.300 ****
CITRUS:2-NELS:1	1.9200	0.541	-0.6870	4.530
CITRUS:2-NELS:2	2.6400	0.552	-0.0240	5.300
CITRUS:2-STELL:1	1.8100	0.600	-1.0800	4.700
CITRUS:2-STELL:2	5.4600	0.668	2.2400	8.680 ****
CITRUS:2-UITEN:1	2.5700	0.674	-0.6780	5.820
CITRUS:2-UITEN:2	6.1300	0.674	2.8800	9.380 ****
CITRUS:2-VAAL:1	-19.0000	0.648	-22.1000	-15.900 ****
NELS:1-NELS:2	0.7160	0.412	-1.2700	2.700
NELS:1-STELL:1	-0.1090	0.474	-2.3900	2.180
NELS:1-STELL:2	3.5400	0.558	0.8500	6.230 ****
NELS:1-UITEN:1	0.6510	0.565	-2.0800	3.380
NELS:1-UITEN:2	4.2100	0.565	1.4800	6.930 ****
NELS:1-VAAL:1	-20.9000	0.534	-23.5000	-18.400 ****
NELS:2-STELL:1	-0.8250	0.487	-3.1700	1.520
NELS:2-STELL:2	2.8300	0.569	0.0827	5.570 ****
NELS:2-UITEN:1 -	0.0652	0.576	-2.8400	2.710
NELS:2-UITEN:2	3.4900	0.576	0.7140	6.270 ****
NELS:2-VAAL:1 -	21.6000	0.545	-24.3000	-19.000 ****
STELL:1-STELL:2	3.6500	0.615	0.6840	6.620 ****
STELL:1-UITEN:1	0.7590	0.622	-2.2400	3.760
STELL:1-UITEN:2	4.3200	0.622	1.3200	7.310 ****
STELL:1-VAAL:1	-20.8000	0.593	-23.7000	-18.000 ****
STELL:2-UITEN:1	-2.8900	0.688	-6.2100	0.426
STELL:2-UITEN:2	0.6640	0.688	-2.6500	3.980

STELL:2-VAAL:1	-24.5000	0.663	-27.7000	-21.300 ****
UITEN:1-UITEN:2	3.5600	0.694	0.2110	6.900 ****
UITEN:1-VAAL:1	-21.6000	0.668	-24.8000	-18.400 ****
UITEN:2-VAAL:1	-25.1000	0.668	28.4000	-21.900 ****
Diameter				
ADDO:1-ADDO:2	1.550	0.433	-0.537	3.640
ADDO:1-CITRUS:1	7.540	0.418	5.520	9.550 ****
ADDO:1-CITRUS:2	1.120	0.425	-0.932	3.170
ADDO:1-NELS:1	4.120	0.355	2.410	5.830 ****
ADDO:1-NELS:2	3.680	0.362	1.940	5.430 ****
ADDO:1-STELL:1	5.610	0.391	3.720	7.490 ****
ADDO:1-STELL:2	4.620	0.434	2.520	6.710 ****
ADDO:1-UITEN:1	6.090	0.438	3.980	8.200 ****
ADDO:1-UITEN:2	7.350	0.438	5.240	9.460 ****
ADDO:1-VAAL:1	-0.148	0.422	-2.180	1.880
ADDO:2-CITRUS:1	5.990	0.419	3.970	8.000 ****
ADDO:2-CITRUS:2	-0.433	0.426	-2.490	1.620
ADDO:2-NELS:1	2.570	0.355	0.859	4.280 ****
ADDO:2-NELS:2	2.130	0.362	0.387	3.880 ****
ADDO:2-STELL:1	4.050	0.392	2.170	5.940 ****
ADDO:2-STELL:2	3.070	0.435	0.972	5.160 ****
ADDO:2-UITEN:1	4.540	0.438	2.430	6.650 ****
ADDO:2-UITEN:2	5.800	0.438	3.690	7.920 ****
ADDO:2-VAAL:1	-1.700	0.422	-3.730	0.335
CITRUS:1-CITRUS:2	-6.420	0.411	-8.400	-4.440 ****
CITRUS:1-NELS:1	-3.410	0.337	-5.040	-1.790 ****
CITRUS:1-NELS:2	-3.850	0.344	-5.510	-2.190 ****
CITRUS:1-STELL:1	-1.930	0.376	-3.740	-0.119 ****
CITRUS:1-STELL:2	-2.920	0.420	-4.940	-0.891 ****
CITRUS:1-UITEN:1	-1.440	0.424	-3.490	0.600

CITRUS:1-UITEN:2	-0.184	0.424	-2.230	1.860
CITRUS:1-VAAL:1	-7.680	0.407	-9.650	-5.720 ****
CITRUS:2-NELS:1	3.000	0.346	1.340	4.670 ****
CITRUS:2-NELS:2	2.570	0.353	0.866	4.270 ****
CITRUS:2-STELL:1	4.490	0.383	2.640	6.340 ****
CITRUS:2-STELL:2	3.500	0.427	1.440	5.560 ****
CITRUS:2-UITEN:1	4.970	0.431	2.900	7.050 ****
CITRUS:2-UITEN:2	6.230	0.431	4.160	8.310 ****
CITRUS:2-VAAL:1	-1.270	0.414	-3.260	0.730
NELS:1-NELS:2	-0.439	0.263	-1.710	0.831
NELS:1-STELL:1	1.480	0.303	0.022	2.940 ****
NELS:1-STELL:2	0.496	0.357	-1.220	2.220
NELS:1-UITEN:1	1.970	0.361	0.227	3.710 ****
NELS:1-UITEN:2	3.230	0.361	1.490	4.970 ****
NELS:1-VAAL:1	-4.270	0.341	-5.920	-2.630 ****
NELS:2-STELL:1	1.920	0.311	0.423	3.420 ****
NELS:2-STELL:2	0.935	0.364	-0.818	2.690
NELS:2-UITEN:1	2.410	0.368	0.633	4.180 ****
NELS:2-UITEN:2	3.670	0.368	1.890	5.440 ****
NELS:2-VAAL:1	-3.830	0.348	-5.510	-2.150 ****
STELL:1-STELL:2	-0.987	0.393	-2.880	0.910
STELL:1-UITEN:1	0.486	0.397	-1.430	2.400
STELL:1-UITEN:2	1.750	0.397	-0.169	3.660
STELL:1-VAAL:1	-5.750	0.379	-7.580	-3.930 ****
STELL:2-UITEN:1	1.470	0.440	-0.648	3.590
STELL:2-UITEN:2	2.730	0.440	0.613	4.850 ****
STELL:2-VAAL:1	-4.770	0.424	-6.810	-2.730 ****
UITEN:1-UITEN:2	1.260	0.443	-0.877	3.400
UITEN:1-VAAL:1	-6.240	0.427	-8.300	-4.180 ****
UITEN:2-VAAL:1	-7.500	0.427	-9.560	-5.440 ****

Ratio

ADDO:1-ADDO:2	0.017300	0.00849	-0.023600	0.05830
ADDO:1-CITRUS:1	0.038800	0.00821	-0.000769	0.07840
ADDO:1-CITRUS:2	0.055700	0.00834	0.015500	0.09590 ****
ADDO:1-NELS:1	0.021600	0.00696	-0.012000	0.05510
ADDO:1-NELS:2	0.043500	0.00709	0.009320	0.07770 ****
ADDO:1-STELL:1	-0.016600	0.00768	-0.053600	0.02040
ADDO:1-STELL:2	0.068400	0.00852	0.027300	0.10900 ****
ADDO:1-UITEN:1	-0.015700	0.00859	-0.057100	0.02570
ADDO:1-UITEN:2	0.019700	0.00859	-0.021700	0.06110
ADDO:1-VAAL:1	-0.223000	0.00827	-0.263000	-0.18300 ****
ADDO:2-CITRUS:1	0.021400	0.00821	-0.018100	0.06100
ADDO:2-CITRUS:2	0.038400	0.00835	-0.001870	0.07860
ADDO:2-NELS:1	0.004210	0.00697	-0.029400	0.03780
ADDO:2-NELS:2	0.026200	0.00710	-0.008070	0.06040
ADDO:2-STELL:1	-0.034000	0.00768	-0.071000	0.00309
ADDO:2-STELL:2	0.051000	0.00853	0.009910	0.09210 ****
ADDO:2-UITEN:1	-0.033100	0.00860	-0.074500	0.00839
ADDO:2-UITEN:2	0.002340	0.00860	-0.039100	0.04380
ADDO:2-VAAL:1	-0.240000	0.00828	-0.280000	-0.20000 ****
CITRUS:1-CITRUS:2	0.016900	0.00805	-0.021900	0.05580
CITRUS:1-NELS:1	-0.017200	0.00661	-0.049100	0.01460
CITRUS:1-NELS:2	0.004720	0.00675	-0.027800	0.03730
CITRUS:1-STELL:1	-0.055400	0.00736	0.090900	-0.01990 ****
CITRUS:1-STELL:2	0.029600	0.00824	-0.010200	0.06930
CITRUS:1-UITEN:1	-0.054500	0.00831	-0.094600	-0.01440 ****
CITRUS:1-UITEN:2	-0.019100	0.00831	-0.059200	0.02100
CITRUS:1-VAAL:1	-0.261000	0.00798	-0.300000	-0.22300 ****
CITRUS:2-NELS:1	-0.034200	0.00678	-0.066900	-0.00148 ****
CITRUS:2-NELS:2	-0.012200	0.00692	-0.045600	0.02110
CITRUS:2-STELL:1	-0.072300	0.00751	-0.109000	-0.03610 ****

CITRUS:2-STELL:2	0.012600	0.00837	-0.027700	0.05300
CITRUS:2-UITEN:1	-0.071400	0.00845	-0.112000	-0.03070 ****
CITRUS:2-UITEN:2	-0.036000	0.00845	-0.076800	0.00469
CITRUS:2-VAAL:1	-0.278000	0.00812	-0.318000	-0.23900 ****
NELS:1-NELS:2	0.022000	0.00517	-0.002950	0.04690
NELS:1-STELL:1	-0.038200	0.00594	-0.066800	-0.00951 ****
NELS:1-STELL:2	0.046800	0.00700	0.013100	0.08060 ****
NELS:1-UITEN:1	-0.037300	0.00709	-0.071400	-0.00310 ****
NELS:1-UITEN:2	-0.001860	0.00709	-0.036000	0.03230
NELS:1-VAAL:1	-0.244000	0.00669	-0.277000	-0.21200 ****
NELS:2-STELL:1	-0.060100	0.00610	-0.089500	-0.03070 ****
NELS:2-STELL:2	0.024900	0.00713	-0.009530	0.05920
NELS:2-UITEN:1	-0.059200	0.00722	-0.094000	-0.02440 ****
NELS:2-UITEN:2	-0.023800	0.00722	-0.058600	0.01100
NELS:2-VAAL:1	-0.266000	0.00683	-0.299000	-0.23300 ****
STELL:1-STELL:2	0.085000	0.00771	0.047800	0.12200 ****
STELL:1-UITEN:1	0.000892	0.00779	-0.036700	0.03850
STELL:1-UITEN:2	0.036300	0.00779	-0.001270	0.07390
STELL:1-VAAL:1	-0.206000	0.00744	-0.242000	-0.17000 ****
STELL:2-UITEN:1	-0.084100	0.00862	-0.126000	-0.04250 ****
STELL:2-UITEN:2	-0.048700	0.00862	-0.090300	-0.00709 ****
STELL:2-VAAL:1	-0.291000	0.00831	-0.331000	-0.25100 ****
UITEN:1-UITEN:2	0.035400	0.00869	-0.006520	0.07730
UITEN:1-VAAL:1	-0.207000	0.00838	-0.247000	-0.16700 ****
UITEN:2-VAAL:1	-0.242000	0.00838	-0.283000	-0.20200 ****

2001 Cropping season

Length

ADDO:1-ADDO:2	-4.360	0.500	-6.69	-2.030 ****
ADDO:1-ADDO:3	-5.600	0.502	-7.94	-3.260 ****

ADDO:1-CITRUS:1	13.100	0.629	10.10	16.000 ****
ADDO:1-CITRUS:2	9.770	0.620	6.89	12.700 ****
ADDO:1-STELL:1	6.230	0.628	3.31	9.160 ****
ADDO:1-STELL:2	4.350	0.629	1.42	7.280 ****
ADDO:1-UITEN:1	1.730	0.498	-0.59	4.050
ADDO:1-VAAL:1	-13.800	0.455	-15.90	-11.700 ****
ADDO:1-VAAL:2	-13.400	0.506	-15.70	-11.000 ****
ADDO:2-ADDO:3	-1.240	0.517	-3.65	1.170
ADDO:2-CITRUS:1	17.400	0.641	14.40	20.400 ****
ADDO:2-CITRUS:2	14.100	0.631	11.20	17.100 ****
ADDO:2-STELL:1	10.600	0.640	7.61	13.600 ****
ADDO:2-STELL:2	8.710	0.641	5.73	11.700 ****
ADDO:2-UITEN:1	6.090	0.512	3.70	8.470 ****
ADDO:2-VAAL:1	-9.430	0.471	-11.60	-7.230 ****
ADDO:2-VAAL:2	-9.030	0.521	-11.50	-6.600 ****
ADDO:3-CITRUS:1	18.700	0.642	15.70	21.600 ****
ADDO:3-CITRUS:2	15.400	0.633	12.40	18.300 ****
ADDO:3-STELL:1	11.800	0.641	8.84	14.800 ****
ADDO:3-STELL:2	9.950	0.642	6.96	12.900 ****
ADDO:3-UITEN:1	7.330	0.515	4.93	9.720 ****
ADDO:3-VAAL:1	-8.190	0.473	-10.40	-5.980 ****
ADDO:3-VAAL:2	-7.790	0.523	-10.20	-5.350 ****
CITRUS:1-CITRUS:2	-3.280	0.738	-6.72	0.152
CITRUS:1-STELL:1	-6.830	0.745	-10.30	-3.360 ****
CITRUS:1-STELL:2	-8.710	0.746	-12.20	-5.230 ****
CITRUS:1-UITEN:1	-11.300	0.639	14.30	-8.350 ****
CITRUS:1-VAAL:1	-26.800	0.606	29.70	-24.000 ****
CITRUS:1-VAAL:2	-26.400	0.646	-29.50	-23.400 ****
CITRUS:2-STELL:1	-3.540	0.737	-6.98	-0.110 ****
CITRUS:2-STELL:2	-5.420	0.738	-8.86	-1.980 ****
CITRUS:2-UITEN:1	-8.050	0.630	-11.00	-5.110 ****

CITRUS:2-VAAL:1	-23.600	0.597	-26.30	-20.800 ****
CITRUS:2-VAAL:2	-23.200	0.637	-26.10	-20.200 ****
STELL:1-STELL:2	-1.880	0.745	-5.35	1.590
STELL:1-UITEN:1	-4.500	0.638	-7.48	-1.530 ****
STELL:1-VAAL:1	-20.000	0.605	-22.80	-17.200 ****
STELL:1-VAAL:2	-19.600	0.645	-22.60	-16.600 ****
STELL:2-UITEN:1	-2.620	0.639	-5.60	0.352
STELL:2-VAAL:1	-18.100	0.606	-21.00	-15.300 ****
STELL:2-VAAL:2	-17.700	0.646	-20.70	-14.700 ****
UITEN:1-VAAL:1	-15.500	0.469	-17.70	-13.300 ****
UITEN:1-VAAL:2	-15.100	0.519	-17.50	-12.700 ****
VAAL:1-VAAL:2	0.399	0.478	-1.83	2.630
Diameter				
ADDO:1-ADDO:2	-4.520	0.312	-5.9700	-3.0600 ****
ADDO:1-ADDO:3	-6.110	0.313	-7.5700	-4.6500 ****
ADDO:1-CITRUS:1	4.930	0.393	3.1000	6.7600 ****
ADDO:1-CITRUS:2	0.576	0.387	-1.2300	2.3800
ADDO:1-STELL:1	1.740	0.392	-0.0885	3.5600
ADDO:1-STELL:2	0.394	0.393	-1.4300	2.2200
ADDO:1-UITEN:1	-2.280	0.311	-3.7200	-0.8290 ****
ADDO:1-VAAL:1	-8.110	0.284	-9.4400	-6.7900 ****
ADDO:1-VAAL:2	-9.250	0.316	-10.7000	-7.7800 ****
ADDO:2-ADDO:3	-1.600	0.322	-3.1000	-0.0933 ****
ADDO:2-CITRUS:1	9.450	0.400	7.5900	11.3000 ****
ADDO:2-CITRUS:2	5.090	0.394	3.2600	6.9300 ****
ADDO:2-STELL:1	6.250	0.399	4.3900	8.1100 ****
ADDO:2-STELL:2	4.910	0.400	3.0500	6.7700 ****
ADDO:2-UITEN:1	2.240	0.320	0.7500	3.7300 ****
ADDO:2-VAAL:1	-3.600	0.294	-4.9700	-2.2300 ****
ADDO:2-VAAL:2 -	4.740	0.325	-6.2500	-3.2200 ****
ADDO:3-CITRUS:1	11.000	0.401	9.1800	12.9000 ****

ADDO:3-CITRUS:2	6.690	0.395	4.8500	8.5300 ****
ADDO:3-STELL:1	7.850	0.400	5.9800	9.7200 ****
ADDO:3-STELL:2	6.510	0.401	4.6400	8.3700 ****
ADDO:3-UITEN:1	3.840	0.321	2.3400	5.3300 ****
ADDO:3-VAAL:1	-2.000	0.296	-3.3800	-0.6230 ****
ADDO:3-VAAL:2	-3.140	0.326	-4.6600	-1.6200 ****
CITRUS:1-CITRUS:2	-4.360	0.461	-6.5000	-2.2100 ****
CITRUS:1-STELL:1	-3.190	0.465	-5.3600	-1.0300 ****
CITRUS:1-STELL:2	-4.540	0.465	-6.7100	-2.3700 ****
CITRUS:1-UITEN:1	-7.210	0.399	-9.0700	-5.3500 ****
CITRUS:1-VAAL:1	-13.000	0.378	-14.8000	-11.3000 ****
CITRUS:1-VAAL:2	-14.200	0.403	-16.1000	-12.3000 ****
CITRUS:2-STELL:1	1.160	0.460	-0.9810	3.3100
CITRUS:2-STELL:2	-0.182	0.461	-2.3300	1.9600
CITRUS:2-UITEN:1	-2.850	0.393	-4.6800	-1.0200 ****
CITRUS:2-VAAL:1	-8.690	0.373	-10.4000	-6.9500 ****
CITRUS:2-VAAL:2	-9.830	0.397	-11.7000	-7.9800 ****
STELL:1-STELL:2	-1.340	0.465	-3.5100	0.8220
STELL:1-UITEN:1	-4.010	0.398	-5.8700	-2.1600 ****
STELL:1-VAAL:1	-9.850	0.378	-11.6000	-8.0900 ****
STELL:1-VAAL:2	-11.000	0.403	-12.9000	-9.1200 ****
STELL:2-UITEN:1	-2.670	0.399	-4.5300	-0.8120 ****
STELL:2-VAAL:1	-8.510	0.378	-10.3000	-6.7400 ****
STELL:2-VAAL:2	-9.650	0.403	-11.5000	7.7700 ****
UITEN:1-VAAL:1	-5.840	0.293	-7.2000	-4.4700 ****
UITEN:1-VAAL:2	-6.980	0.324	-8.4900	-5.4700 ****
VAAL:1-VAAL:2	-1.140	0.298	-2.5300	0.2490

Ratio

ADDO:1-ADDO:2	4.360	0.500	-6.69	-2.030 ****
ADDO:1-ADDO:3	-5.600	0.502	-7.94	-3.260 ****
ADDO:1-CITRUS:1	13.100	0.629	10.10	16.000 ****
ADDO:1-CITRUS:2	9.770	0.620	6.89	12.700 ****
ADDO:1-STELL:1	6.230	0.628	3.31	9.160 ****
ADDO:1-STELL:2	4.350	0.629	1.42	7.280 ****
ADDO:1-UITEN:1	1.730	0.498	-0.59	4.050
ADDO:1-VAAL:1	-13.800	0.455	-15.90	-11.700 ****
ADDO:1-VAAL:2	-13.400	0.506	-15.70	-11.000 ****
ADDO:2-ADDO:3	-1.240	0.517	-3.65	1.170
ADDO:2-CITRUS:1	17.400	0.641	14.40	20.400 ****
ADDO:2-CITRUS:2	14.100	0.631	11.20	17.100 ****
ADDO:2-STELL:1	10.600	0.640	7.61	13.600 ****
ADDO:2-STELL:2	8.710	0.641	5.73	11.700 ****
ADDO:2-UITEN:1	6.090	0.512	3.70	8.470 ****
ADDO:2-VAAL:1	-9.430	0.471	-11.60	-7.230 ****
ADDO:2-VAAL:2	-9.030	0.521	-11.50	-6.600 ****
ADDO:3-CITRUS:1	18.700	0.642	15.70	21.600 ****
ADDO:3-CITRUS:2	15.400	0.633	12.40	18.300 ****
ADDO:3-STELL:1	11.800	0.641	8.84	14.800 ****
ADDO:3-STELL:2	9.950	0.642	6.96	12.900 ****
ADDO:3-UITEN:1	7.330	0.515	4.93	9.720 ****
ADDO:3-VAAL:1	-8.190	0.473	-10.40	-5.980 ****
ADDO:3-VAAL:2	-7.790	0.523	-10.20	-5.350 ****
CITRUS:1-CITRUS:2	-3.280	0.738	-6.72	0.152
CITRUS:1-STELL:1	-6.830	0.745	-10.30	-3.360 ****
CITRUS:1-STELL:2	-8.710	0.746	-12.20	-5.230 ****
CITRUS:1-UITEN:1	-11.300	0.639	-14.30	-8.350 ****
CITRUS:1-VAAL:1	-26.800	0.606	-29.70	-24.000 ****
CITRUS:1-VAAL:2	-26.400	0.646	-29.50	-23.400 ****

CITRUS:2-STELL:1	-3.540	0.737	-6.98	-0.110 ****
CITRUS:2-STELL:2	-5.420	0.738	-8.86	-1.980 ****
CITRUS:2-UITEN:1	-8.050	0.630	-11.00	-5.110 ****
CITRUS:2-VAAL:1	-23.600	0.597	-26.30	-20.800 ****
CITRUS:2-VAAL:2	-23.200	0.637	-26.10	-20.200 ****
STELL:1-STELL:2	-1.880	0.745	-5.35	1.590
STELL:1-UITEN:1	-4.500	0.638	-7.48	-1.530 ****
STELL:1-VAAL:1	20.000	0.605	-22.80	-17.200 ****
STELL:1-VAAL:2	-19.600	0.645	-22.60	-16.600 ****
STELL:2-UITEN:1	-2.620	0.639	-5.60	0.352
STELL:2-VAAL:1	-18.100	0.606	-21.00	-15.300 ****
STELL:2-VAAL:2	-17.700	0.646	-20.70	-14.700 ****
UITEN:1-VAAL:1 -	15.500	0.469	-17.70	-13.300 ****
UITEN:1-VAAL:2 -	15.100	0.519	-17.50	-12.700 ****
VAAL:1-VAAL:2	0.399	0.478	-1.83	2.630

Median and variance values of the length (L), diameter (D) and L:D ratio measured on 'Eureka' lemon fruit from six different areas in the 2000 cropping season.

Pick	Area	Length	Diameter	L:D Ratio
Median				
1	**Addo**	83.34	62.40	1.34
1	**Citrusdal**	71.46	55.63	1.30
1	**Nelspruit**	76.78	58.67	1.31
1	**Stellenbosch**	76.88	57.17	1.35
1	**Uitenhage**	75.75	57.00	1.33
1	**Vaalharts**	98.00	63.00	1.55
2	**Addo**	80.20	61.06	1.31
2	**Citrusdal**	78.79	61.63	1.28
2	**Nelspruit**	75.75	58.79	1.29
2	**Stellenbosch**	73.52	57.67	1.26
2	**Uitenhage**	73.00	55.00	1.31
Variance				
1	**Addo**	89.29	32.93	0.01
1	**Vaalharts**	77.11	27.02	0.01
1	**Citrusdal**	69.09	23.29	0.01
1	**Nelspruit**	51.65	21.87	0.01
1	**Stellenbosch**	77.62	27.13	0.02
1	**Uitenhage**	92.15	42.60	0.02
2	**Addo**	84.28	37.39	0.01
2	**Citrusdal**	116.02	37.34	0.01

2	**Nelspruit**	50.25	23.22	0.01
2	**Stellenbosch**	65.55	38.74	0.01
2	**Uitenhage**	88.94	40.26	0.01

Median and variance values of the length (L), diameter (D) and L:D ratio measured on 'Eureka' lemon fruit from five different areas in the 2001 cropping season.

Pick	Area	Length	Diameter	L:D Ratio
Median				
1	**Addo**	77.80	55.10	1.40
1	**Citrusdal**	64.15	50.40	1.28
1	**Stellenbosch**	70.98	54.01	1.32
1	**Uitenhage**	76.50	57.90	1.32
1	**Vaalharts**	91.10	63.30	1.44
2	**Addo**	81.60	60.00	1.36
2	**Citrusdal**	67.40	55.00	1.23
2	**Stellenbosch**	73.57	55.30	1.35
2	**Vaalharts**	91.20	64.30	1.40
3	**Addo**	83.00	62.00	1.35
Variance				
1	**Addo**	76.65	38.38	0.02
1	**Citrusdal**	32.04	13.66	0.01
1	**Stellenbosch**	83.67	31.90	0.02
1	**Uitenhage**	74.41	42.02	0.02
1	**Vaalharts**	78.16	25.66	0.01
2	**Addo**	78.18	33.57	0.02
2	**Citrusdal**	44.75	14.74	0.01
2	**Stellenbosch**	62.75	26.34	0.01

2	**Vaalharts**	149.83	40.83	0.01
3	**Addo**	103.20	38.35	0.01

Median and variance values of the length (L), diameter (D) and L:D ratio measured on 'Eureka' lemon fruit on rough lemon rootstock from six different areas in the 2000 cropping season.

Pick	Area	Length	Diameter	L:D Ratio
Median				
1	**Addo**	83.75	64.42	1.33
1	**Citrusdal**	70.84	55.63	1.29
1	**Nelspruit**	78.89	59.83	1.33
1	**Stellenbosch**	76.88	57.17	1.35
1	**Uitenhage**	72.00	54.50	1.31
1	**Vaalharts**	98.00	62.00	1.57
2	**Addo**	77.59	60.15	1.31
2	**Citrusdal**	81.04	62.83	1.28
2	**Nelspruit**	79.99	62.39	1.28
2	**Stellenbosch**	73.52	57.67	1.26
2	**Uitenhage**	70.00	53.50	1.31
Variance				
1	**Addo**	96.94	40.92	0.01
1	**Citrusdal**	69.02	21.10	0.01
1	**Nelspruit**	53.42	19.70	0.01
1	**Stellenbosch**	77.62	27.13	0.02

1	**Uitenhage**	53.39	50.23	0.02
1	**Vaalharts**	72.71	23.37	0.01
2	**Addo**	78.53	28.68	0.01
2	**Citrusdal**	94.79	24.94	0.01
2	**Nelspruit**	67.61	22.86	0.01
2	**Stellenbosch**	65.55	38.74	0.01
2	**Uitenhage**	73.85	34.38	0.02

Median and variance values of the length (L), diameter (D) and L:D ratio measured on 'Eureka' lemon fruit on rough lemon rootstock from four different areas in the 2001 cropping season.

Pick	Area	Length	Diameter	L:D Ratio
Median				
1	**Addo**	78.50	55.75	1.43
1	**Stellenbosch**	70.98	54.01	1.32
1	**Uitenhage**	73.20	57.80	1.28
1	**Vaalharts**	92.65	64.10	1.44
2	**Addo**	82.20	60.50	1.36
2	**Stellenbosch**	73.57	55.30	1.35
2	**Vaalharts**	95.80	67.00	1.42
3	**Addo**	82.60	61.00	1.35
Variance				
1	**Addo**	81.64	36.47	0.02
1	**Stellenbosch**	83.67	31.89	0.02
1	**Uitenhage**	68.72	36.11	0.02
1	**Uitenhage**	68.72	36.11	0.02
1	**Vaalharts**	64.35	26.05	0.01
2	**Addo**	82.05	39.83	0.01

2	**Stellenbosch**	62.75	26.34	0.01
2	**Vaalharts**	110.69	33.40	0.01
3	**Addo**	97.32	33.19	0.01

Appendix: Paper III

Median and variance values of 'Eureka' lemon fruit on four different rootstocks from Addo in the Eastern Cape region of South Africa.

Pick	Rootstock	Length	Diameter	L:D Ratio
Median				
1	**Carrizo citrange**	75.30	54.60	1.39
1	**Rosehaugh Empress**	75.60	53.60	1.37
1	**Rough lemon**	78.50	55.75	1.43
1	**Volckameriana**	80.00	57.30	1.40
2	**Carrizo citrange**	82.70	59.75	1.40
2	**Rosehaugh Empress**	80.00	59.90	1.33
2	**Rough lemon**	82.20	60.50	1.36
2	**Volckameriana**	82.35	59.85	1.36
3	**Carrizo citrange**	81.90	61.25	1.34
3	**Rosehaugh Empress**	81.30	60.85	1.36
3	**Rough lemon**	82.60	61.00	1.35
3	**Volckameriana**	85.85	63.80	1.34
Variance				
1	**Carrizo citrange**	77.24	41.93	0.02
1	**Rosehaugh Empress**	67.87	36.20	0.01
1	**Rough lemon**	81.64	36.47	0.02
1	**Volckameriana**	64.99	35.01	0.02
2	**Carrizo citrange**	90.44	37.61	0.03
2	**Rosehaugh Empress**	65.79	26.09	0.02
2	**Rough lemon**	82.05	39.83	0.01
2	**Volckameriana**	72.72	33.11	0.01
3	**Carrizo citrange**	113.63	40.54	0.01
3	**Rosehaugh Empress**	95.77	38.40	0.01

3	**Rough lemon**	97.32	33.19	0.01
3	**Volckameriana**	100.93	35.57	0.01

Median and variance values of 'Lisbon' lemon fruit on nine different rootstocks from Nelspruit in the Mpumalanga region of South Africa.

Pick	Rootstock	Length	Diameter	L:D Ratio
Median				
1	**C-35**	80.93	62.77	1.29
1	**Carrizo citrange**	81.01	61.74	1.31
1	**Flying dragon**	82.78	62.58	1.31
1	**Minneola**	77.10	61.57	1.24
	Trifoliate			
1	**Rough lemon**	81.57	61.61	1.31
1	**Swingle citrumelo**	82.64	60.68	1.35
1	**Sour orange**	83.64	62.59	1.33
1	**Terra Bella citrange**	80.03	60.96	1.30
1	**X639**	82.46	61.88	1.32
2	**C-35**	80.15	62.40	1.28
2	**Carrizo citrange**	79.35	63.31	1.27
2	**Flying dragon**	81.86	64.25	1.27
2	**Minneola**	82.78	64.47	1.29
	Trifoliate			
2	**Flying dragon**	88.92	71.02	1.27
2	**Swingle citrumelo**	83.19	63.08	1.31
2	**Sour orange**	79.42	61.75	1.29
2	**Terra Bella citrange**	77.87	60.93	1.27
2	**X639**	86.22	67.05	1.28
	C-35			
Variance				
1	**C-35**	43.46	26.69	0.01
1	**Carrizo citrange**	93.48	30.88	0.01

1	**Flying dragon**	50.02	26.10	0.01
1	**Minneola**	38.44	23.12	0.01
	Trifoliate			
1	**Rough lemon**	56.82	17.51	0.01
1	**Swingle citrumelo**	63.41	23.08	0.01
1	**Sour orange**	57.33	24.08	0.01
1	**Terra Bella citrange**	49.77	28.76	0.01
1	**X639**	65.24	26.34	0.01
2	**C-35**	47.09	17.10	0.01
2	**Carrizo citrange**	66.93	27.75	0.01
2	**Flying dragon**	65.27	29.07	0.01
2	**Minneola**	61.87	28.68	0.01
	Trifoliate			
2	**Rough lemon**	82.39	19.88	0.01
2	**Swingle citrumelo**	87.88	33.11	0.01
2	**Sour orange**	56.54	21.62	0.01
2	**Terra Bella citrange**	36.02	20.81	0.01
2	**X639**	65.46	26.06	0.01

Median and variance values of 'Eureka' lemon fruit on four different rootstocks from Citrusdal in the Western Cape region of South Africa.

Pick	Rootstock	Length	Diameter	L:D Ratio
Median				
1	**Carrizo citrange**	74.05	57.32	1.31
1	**Citremon**	63.44	50.62	1.24
1	**Rosehaugh Empress**	72.96	54.27	1.34
1	**Rough lemon**	70.84	55.63	1.29
1	**Volckameriana**	72.58	58.31	1.26
2	**Carrizo citrange**	81.09	62.68	1.27
2	**Citremon**	77.62	61.25	1.28
2	**Rosehaugh Empress**	76.57	58.86	1.33
2	**Rough lemon**	81.04	62.83	1.28
2	**Volckameriana**	76.66	62.01	1.24
Variance				
1	**Carrizo citrange**	72.43	17.80	0.01
1	**Citremon**	63.80	19.73	0.02
1	**Rosehaugh Empress**	38.81	14.11	0.01
1	**Rough lemon**	69.02	21.10	0.01
1	**Volckameriana**	53.87	23.31	0.01
2	**Carrizo citrange**	127.51	58.65	0.01
2	**Citremon**	143.33	36.23	0.02
2	**Rosehaugh Empress**	92.53	30.70	0.01
2	**Rough lemon**	94.79	24.94	0.01
2	**Volckameriana**	111.18	29.90	0.01

Median and variance values of the length (L), diameter (D) and L:D ratio measurements of fruit from different lemon selections on 'Carrizo' citrange rootstock from Addo in the Eastern Cape region of South Africa.

Pick	Selection	Length	Diameter	L:D Ratio
Median				
1	**Cicily**	68.90	56.30	1.23
1	**Eureka seedless**	84.85	62.30	1.35
1	**Eureka**	75.30	54.60	1.39
1	**Eureka Addo**	81.80	55.90	1.48
1	**Eureka Cook`s**	71.95	53.40	1.37
1	**Eureka Frost**	75.75	56.00	1.40
1	**Eureka Ryan**	67.90	51.20	1.35
1	**Eureka Thornless**	75.70	54.55	1.36
1	**Eureka UCLA**	76.50	63.10	1.24
1	**Fino**	78.45	55.65	1.44
1	**Genoa**	74.60	53.60	1.34
1	**Israel Eureka Seedless**	81.30	58.10	1.40
1	**Lisbon**	73.60	55.30	1.36
1	**Lisbon Frost**	71.50	51.25	1.39
1	**Lisbon Prior**	68.80	48.70	1.41
1	**Lisbon Yen-Ben**	61.15	44.75	1.36
1	**Lisbon Rosenberger**	75.55	54.60	1.38
1	**Lisbon Thornless**	73.20	58.90	1.25
1	**Verna**	76.50	46.95	1.60
1	**Villafranca**	75.10	60.00	1.24
2	**Cicily**	82.15	60.35	1.42
2	**Eureka**	82.70	59.75	1.40
2	**Eureka Addo**	81.70	58.25	1.39

2	**Eureka Cook`s**	84.45	58.05	1.40
2	**Eureka Frost**	80.10	56.15	1.39
2	**Eureka Ryan**	76.80	57.20	1.34
2	**Eureka Thornless**	84.95	58.40	1.44
2	**Eureka UCLA**	83.50	63.70	1.33
2	**Fino**	87.25	63.00	1.41
2	**Genoa**	80.00	55.85	1.39
2	**Lisbon**	81.30	60.11	1.38
2	**Lisbon Yen-Ben**	68.00	49.40	1.35
2	**Lisbon Frost**	79.05	54.50	1.44
2	**Lisbon Prior**	79.20	57.35	1.37
2	**Lisbon Rosenberger**	84.60	60.35	1.41
2	**Lisbon Thornless**	81.55	58.80	1.41
2	**Verna**	86.60	52.30	1.64
3	**Cicily**	82.75	62.40	1.34
3	**Eureka**	81.90	61.25	1.34
3	**Eureka Addo**	81.70	57.40	1.44
3	**Eureka Cook`s**	81.55	59.40	1.37
3	**Eureka Frost**	87.35	63.00	1.38
3	**Eureka Ryan**	78.80	57.05	1.33
3	**Eureka Thornless**	82.30	60.75	1.35
3	**Eureka UCLA**	91.0	69.30	1.36
3	**Fino**	94.95	66.10	1.43
3	**Genoa**	80.60	59.60	1.35
3	**Lisbon**	81.55	58.05	1.41
3	**Lisbon Frost**	84.70	60.20	1.42
3	**Lisbon Prior**	81.00	58.20	1.37
3	**Lisbon Rosenberger**	90.00	65.00	1.41
3	**Lisbon Thornless**	87.60	62.85	1.39
3	**Verna**	89.70	56.40	1.58

Variance

1	**Cicily**	34.26	31.15	0.02
1	**Eureka seedless**	122.36	61.22	0.26
1	**Eureka**	77.24	41.93	0.019
1	**Eureka Addo**	99.93	38.64	0.03
1	**Eureka Cook's**	49.63	30.06	0.01
1	**Eureka Frost**	71.11	29.98	0.02
1	**Eureka Ryan**	34.97	24.12	0.02
1	**Eureka Thornless**	51.92	29.84	0.01
1	**Eureka UCLA**	86.89	46.60	0.02
1	**Fino**	54.89	19.97	0.02
1	**Genoa**	54.81	44.04	0.02
1	**Israel Eureka Seedless**	68.52	32.83	0.02
1	**Lisbon**	76.80	36.93	0.02
1	**Lisbon Yen-Ben**	47.45	33.62	0.01
1	**Lisbon Frost**	37.72	35.37	0.03
1	**Lisbon Prior**	29.90	13.75	0.01
1	**Lisbon Rosenberger**	65.92	16.89	0.02
1	**Lisbon Thornless**	48.09	45.40	0.03
1	**Verna**	51.81	23.15	0.03
1	**Villafranca**	45.21	18.70	0.01
2	**Cicily**	43.89	23.07	0.13
2	**Eureka**	90.44	37.61	0.027
2	**Eureka Addo**	75.58	69.93	0.02
2	**Eureka Cook's**	48.76	34.95	0.01
2	**Eureka Frost**	64.91	17.89	0.01
2	**Eureka Ryan**	33.29	19.38	0.01
2	**Eureka Thornless**	75.38	34.88	0.01
2	**Eureka UCLA**	78.43	42.02	0.01

2	**Fino**	79.74	25.18	0.01
2	**Genoa**	59.88	20.56	0.03
2	**Lisbon**	67.65	37.55	0.02
2	**Lisbon Yen-Ben**	31.82	19.00	0.01
2	**Lisbon Frost**	67.18	32.48	0.01
2	**Lisbon Prior**	44.44	16.28	0.01
2	**Lisbon Rosenberger**	64.66	21.91	0.01
2	**Lisbon Thornless**	55.15	24.65	0.02
2	**Verna**	88.80	31.10	0.02
3	**Cicily**	93.70	20.27	0.14
3	**Eureka**	113.63	40.54	0.01
3	**Eureka Addo**	98.09	34.36	0.01
3	**Eureka Cook's**	86.90	29.78	0.01
3	**Eureka Frost**	68.43	24.73	0.01
3	**Eureka Ryan**	52.52	26.11	0.01
3	**Eureka Thornless**	133.03	45.67	0.01
3	**Eureka UCLA**	80.75	19.72	0.01
3	**Fino**	120.25	35.93	0.01
3	**Genoa**	107.85	20.99	0.02
3	**Lisbon**	59.64	28.70	0.01
3	**Lisbon Frost**	99.88	34.80	0.01
3	**Lisbon Prior**	31.80	18.01	0.01
3	**Lisbon Rosenberger**	67.95	20.74	0.01
3	**Lisbon Thornless**	110.10	30.10	0.01
3	**Verna**	85.70	17.11	0.01

Median and variance values of the length (L), diameter (D) and L:D ratio measurements of fruit from different lemon selections on 'Volckameriana' lemon rootstock from Citrusdal in the Western Cape region of South Africa.

Pick	Selection	Length	Diameter	L:D Ratio
Median				
1	**Cicily**	72.43	57.26	1.24
1	**Eureka**	72.58	58.31	1.26
1	**Eureka Addo**	67.17	49.22	1.37
1	**Eureka Cook's**	71.41	55.77	1.29
1	**Eureka Frost**	71.29	53.04	1.33
1	**Eureka Ryan**	66.65	51.47	1.28
1	**Eureka Thornless**	67.23	51.83	1.30
1	**Eureka UCLA**	72.96	56.08	1.29
1	**Fino**	72.77	56.87	1.27
1	**Genoa**	79.76	57.52	1.39
1	**Lisbon**	71.61	56.00	1.28
1	**Lisbon Frost**	73.74	55.36	1.31
1	**Lisbon Prior**	75.13	57.14	1.30
1	**Lisbon Thornless**	65.46	53.48	1.24
1	**Verna**	86.63	57.28	1.55
2	**Cicily**	83.31	64.35	1.28
2	**Eureka**	76.66	62.01	1.24
2	**Eureka Addo**	79.23	59.94	1.34
2	**Eureka Cook's**	80.83	63.42	1.32
2	**Eureka Frost**	75.50	60.80	1.25
2	**Eureka Frost**	67.58	53.63	1.26
2	**Eureka Frost**	74.10	58.64	1.23
2	**Eureka UCLA**	80.92	64.81	1.25
2	**Feminello Continella**	67.54	59.78	1.13

2	**Fino**	784.96	63.69	1.29
2	**Lisbon**	76.82	59.85	1.29
2	**Lisbon Frost**	84.01	64.97	1.32
2	**Lisbon Prior**	82.66	63.58	1.29
2	**Verna**	83.03	58.81	1.43
Variance				
1	**Cicily**	61.81	23.77	0.01
1	**Eureka**	53.87	23.31	0.01
1	**Eureka Addo**	61.08	23.81	0.02
1	**Eureka Cook's**	48.66	17.49	0.01
1	**Eureka Frost**	69.71	20.51	0.01
1	**Eureka Ryan**	51.77	21.18	0.01
1	**Eureka Thornless**	58.39	23.44	0.01
1	**Eureka UCLA**	74.06	31.28	0.01
1	**Fino**	45.08	11.97	0.01
1	**Genoa**	89.11	24.25	0.01
1	**Lisbon**	49.93	16.09	0.01
1	**Lisbon Frost**	65.03	24.25	0.01
1	**Lisbon Prior**	99.20	47.14	0.01
1	**Lisbon Thornless**	90.67	22.46	0.01
1	**Verna**	98.78	18.89	0.02
2	**Cicily**	136.54	69.53	0.02
2	**Eureka**	111.18	29.90	0.01
2	**Eureka Addo**	114.45	41.67	0.02
2	**Eureka Cook's**	194.71	116.00	0.01
2	**Eureka Frost**	101.05	38.27	0.01
2	**Eureka Ryan**	93.51	41.91	0.01
2	**Eureka Thornless**	144.32	35.79	0.02
2	**Eureka UCLA**	84.14	33.66	0.01
2	**Feminello Continella**	50.86	15.15	0.01

2	**Fino**	74.57	19.07	0.01
2	**Lisbon**	83.71	27.52	0.01
2	**Lisbon Frost**	67.26	20.94	0.01
2	**Lisbon Prior**	103.48	48.89	0.01
2	**Verna**	181.57	50.23	0.02