Witloof chicory (*Cichorium intybus* L. var. *foliosum*) - evaluation of new forcing techniques.

By

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Declaration

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

Abstract

South Africa is one of the worlds leading producers of chicory (*Cichorium intybus* L.). Most of the chicory produced is used locally for the production of instant coffee. Witloof chicory, or Belgian endive, however, is a vegetable crop grown from the root of *Cichorium intybus* L. var. *foliosum*. This is done by placing the mature taproot in a controlled, dark environment after vernalization and supplying it with water and nutrients by means of hydroponics. Witloof chicory is new to the South African market and is only produced on a limited scale. Nonetheless, seeing that chicory is successfully grown on a large scale for the coffee industry it seemed reasonable to investigate the cultivation of this essentially unknown vegetable locally.

The focus of this study was on the evaluation of new witloof production techniques during the second stage of witloof (chicon) cultivation, also called 'forcing'. To this end, locally grown witloof chicory roots were used in all trials. In order to establish the effects of several irrigation methods on lateral root formation and chicon quality, witloof chicory roots were forced using the conventional means of hydroponic irrigation as well as ebb-and-flood and aeroponic irrigation. Lateral root formation was significantly increased when either ebb-and-flood or aeroponic irrigation was applied compared to that obtained with the conventional method. This increase in lateral root formation was, however, to the detriment of chicon quality (QI), possibly as a result of competition for limited carbohydrate reserves.

In an attempt to optimize the aeroponic irrigation method, roots were forced in non-vertical positions. Placing roots horizontally during forcing resulted in a significantly lower marketable chicon yield than where roots were placed vertically. The loss in yield was probably brought about by an increased fallout percentage rather than by a decrease in chicon production.

Considering the pivotal role that sucrose plays in the development of the chicory head, sucrose was applied exogenously to the root before and/or during forcing. Dry matter chicon yield was

negatively effected by exogenously applied sucrose. This could have been due to an increased incidence of fungal or bacterial infections or causative of roots absorbing less water resulting in the inability of the plant to utilize the applied sucrose during chicon development.

Fungal and bacterial infections are known to have a detrimental effect on witloof chicory production. An environmentally friendly product for disease control, 'Desogerme SP®', was used to contain or reduce infection. Irrigation of roots with 'Desogerme SP®' containing nutrient solution increased chicon yield by 31%.

From this study it became clear that some new production techniques applied had the potential of improving lateral root formation or quality during growth. However, the conventional way of irrigation remains the most effective compared to the other techniques applied, but could possibly be improved to some extent by incorporating 'Desogerme SP®' either as a pretreatment or in the nutrient solution.

A breakthrough was made with the development of the quality index (QI). The ongoing limitation of statistically analyzing quality data of chicons sorted according to quality-classes was overcome by making use of this tool. Despite the fact that the index was developed specifically for use on witloof, it is has the potential of being applied to quality data of a wide variety of crops.

Uitreksel

Suid Afrika is een van die wêreld se grootste produsente van sigorei (*Cichorium intybus* L.). Die meeste plaaslik geproduseerde sigorei word vir die produksie van kitskoffie benut. Witloof-sigorei, of Belgiese "endive", is egter 'n groentegewas wat vanaf die wortel van *Cichorium intybus* L. var. *foliosum* gekweek word. Dit word gedoen deur die volwasse penwortel na vernalisasie in 'n gekontroleerde, donker omgewing te plaas en met 'n hidrokultuurstelsel van water en voedingselemente te voorsien. Witloof is nuut op die Suid Afrikanse mark en word net op beperkte skaal geproduseer. Aangesien sigorei suksesvol op groot skaal vir die koffie-industrie geproduseer word, blyk dit logies om die moontlikhede te ondersoek om hierdie relatief onbekende groente plaaslik te kweek.

Die fokus van hierdie studie was gerig op die evaluasie van nuwe produksietegnieke gedurende die tweede fase van witloofproduksie, wat ook as forsering bekend is. Plaaslik gekweekte witloof sigoreiwortels is vir alle eksperimente gebruik. Die invloed van 'n verskeidenheid besproeiingsmetodes is op sywortelproduksie en witloof krop-kwaliteit ondersoek. Witloof-wortels is geforseer deur van 'n konvensionele hidrokultuur-stelsel gebruik te maak wat met 'n ebb-en-vloed en 'n lugsproei sisteem vergelyk is. Sywortel-produksie was betekenisvol hoër waar ebb-en-vloed of lugsproei sisteme toegepas is. Hierdie verbetering in sywortel-ontwikkeling was egter tot nadeel van krop-kwaliteit, vermoedelik as gevolg van die allokasie van koolhidrate na sywortels, eerder as na die groeipunt.

In 'n poging om die lugsproei besproeiingsmetode te verbeter en om swamsiektes te verminder, is wortels in nie-vertikale posisies geforseer. Wortels wat gedurende forsering horisontaal ingetafel was, het 'n betekenisvol laer opbrengs van bemarkbare kroppe getoon as wortels wat vertikaal geplaas was. Die verlies aan opbrengs kon toegeskryf word aan 'n verhoging van afval, aangesien geen betekenisvolle afname in vars krop-gewig gevind is nie.

Aangesien sukrose 'n belangrike rol in die ontwikkeling van die witloofkrop speel, is sukrose voor en tydens forsering aan die wortels toegedien. Droë materiaal krop-opbrengs is negatief deur die toediening van sukrose beïnvloed. Dit kon moontlik as gevolg van 'n verhoogde voorkoms van swam- of bakteriese infeksies gewees het of 'n aanduiding wees dat behandelde wortels minder water geabsorbeer het en die toegediende sukrose nie kon gebruik gedurende krop-ontwikkeling nie.

Swam- en bakteriese infeksies is bekend vir hul negatiewe uitwerking op witloofproduksie. 'n Omgewingsvriendelike middel, 'Desogerme SP®' is gebruik om siektes te beheer of te verminder. Wortels wat met 'n 'Desogerme SP®' bevattende voedingsoplossing besproei is, het 'n 31% verhoging in krop-opbrengs getoon.

Uit data wat gedurende hierdie studie ingesamel is, blyk dit duidelik dat sommige van die nuwe produksietegnieke wel die potensiaal het om sekere planteienskappe te verbeter. In geheel gesien bly die konvensionele metode van besproeiing die mees effektiewe, wanneer dit vergelyk word met die ander wat getoets is. Die konvensionele metode kan moontlik verbeter word as 'Desogerme SP®' as 'n vooraf-behandeling of as deel van die voedingsoplossing geïnkorporeer word.

'n Deurbraak is met die ontwikkeling van 'n kwaliteitsindeks (QI) gemaak. Ernstige beperkings word met statistiese ontledings van kwaliteitsdata ervaar waar kroppe volgens kwaliteitsklasse gesorteer word. Hierdie probleme is met behulp van die QI oorkom. Ongeag die feit dat die indeks spesifiek vir gebruik by witloof ontwikkel is, het dit die potensiaal om toepassing te vind by 'n wye reeks landboukundige produkte.

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CHAPTER 1

Chicory (*Cichorium intybus* L.) – an overview

Chicory (Cichorium *intybus* L.) – an overview

1 The origin of witloof chicory

Witloof chicory (*Cichorium intybus* L. var. *foliosum*), also known as Belgian endive, is a vegetable crop related to endive (*Cichorium endivia* L.) and dandelion (*Taraxacum officinale*) (Burt, 1999). It is derived through selection from coffee chicory (*Cichorium intybus* L. *sativum*), which in turn originates from wild chicory (*Cichorium intybus* L. var. *intybus*) (Demeulemeester, 2001). The place chicory holds in the biological system is as follows:

Division		SPERMATOPHYTES (seed producing plants)
	Subdivision:	Angiospermae (covered seeds)
	Class:	Mmagnolopsida / Dicotyledonae
	Sub-class:	Asteridae / Sympetalae
	Family:	Asteraceae (flowering plants or composites)
	Sub-family:	Lactucoideae (all ligulate herbs with a milky latex)
Genus		*Cichorium*
	Species:	*Cichorium intybus* L.
	Variety:	*foliosum* : witloof-chicory
		sativum : chicory for coffee production

Wild chicory originated in the Mediterranean area and was eaten as a salad vegetable by the early Egyptians, Greeks and Romans. Its green leaves have a fresh, but slightly bitter taste. The root, too, was often used for medicinal purposes and sometimes as a potion. In this way chicory coffee first appeared around the year 1775. Chicory has now spread over Western, Central and Southern Europe, Northern Africa and the temperate regions of Asia (Demeulemeester, 1995).

Witloof (white leaf) chicory is a type of vegetable that grows from the root of *Cichorium intybus* L. *foliosum* and thrives in the dark, producing etiolated leaves. The final edible product consists of tightly packed yellowish/white leaves that form a characteristic tapered head. Its discovery was quite by chance around the year 1850 in Belgium, but it was not until 1873 that it made its first appearance as a vegetable at an exhibition. Auctions of witloof chicory were held in 1913, but it was not until 1930 that the product really caught on and it gained in popularity in the years after 1945. Today it is produced on a large scale in Belgium, France and the Netherlands.

2 Chicory in South Africa

2.1 Coffee chicory

Chicory (*Cichorium intybus* L. var. *sativum*) is a well-known crop in the districts of Alexandria, Albany and Bathurst in the Eastern Cape region of South Africa. In the late 80's and early 90's South Africa became, next to France and Belgium, the world's largest producer of chicory and also the second largest consumer (Luckman, 1987). Annually 6 000 to 7 000 ha of chicory is planted (Anonymous, 2000), yielding approximately 50 000 tons of fresh root weight per year (Anonymous, 1998). The country's total annual production of between 14 000 and 16 000 tons of dried chicory root is consumed locally in the coffee industry. Chicory is used as a coffee substitute or is blended with true coffee in order to give it more body and colour. It is free from caffeine and substantially cheaper than real coffee. Processing of chicory into roasted ground chicory is achieved by cutting the fleshy root into small pieces and roasting them, a process during which the saps are caramelized (Leroux, 1987). Approximately 85% of all coffee consumed in South Africa contains chicory with the content varying between 25 and 75% (Luckman, 1987).

2.2 Fructooligosaccharides

The taproot of *Cichorium intybus* L. is distinctive in that it contains inulin as its main reserve of carbohydrate. Inulin is a long chain fructan composed of 35 to 40 fructose units with a terminal glucose unit. It is readily hydrolyzed into its component monosaccharides by enzymatic action and is subsequently a rich source of fructose sugar. Besides the fact that fructose is a sugar acceptable for use by diabetics and that a general increase in demand is experienced by the health conscious first-world consumers, it has many food applications (Fuchs, 1991; Spiegel, *et al.*, 1994; Sommers, 1999), and perhaps surprisingly, also non-food applications (Fuchs, 1991). In recent years the focus in South African chicory production has shifted to the development of technology for the extraction of fructooligosaccharides (inulin) from the chicory roots, rather than the production of coffee. The premium prices paid for fructose on world markets, together with a weak local currency, make chicory the ideal export product, capable of generating foreign currency and substantially increasing the net income of its producers.

2.3 Witloof chicory

Witloof chicory (*Cichorium intybus* L. var. *foliosum*) is one of the most consumed winter vegetables in Belgium, the Netherlands and France and is exported all over the world (Sarrazyn, 1990a). Witloof is a very versatile product and can easily be prepared as a cooked vegetable or eaten raw as a salad. While retaining the refreshing taste, the pronounced bitter taste of the white leaves is nowadays eliminated to a large extent by careful selection and breeding. The vegetable contains only 67 kJ per 100 g of chicory while its nutritional value is as set out below:

Water:	94 g
Albumen:	1 g
Fat:	0.1 g
Carbohydrates:	3 g
Sodium:	5 mg
Potassium:	200 mg
Calcium:	20 mg
Phosphorus:	20 mg
Ascorbic acid (Vitamin C):	5 mg

Cultivation of witloof chicory (*Cichorium intybus* L. var. *foliosum*) has recently spread from its native production areas of Belgium, the Netherlands and France to the United States of America (Corey, Marchant & Whitney, 1990), Australia (Burt, 1999) and South Africa (Coetsee, 1996). Despite the fact that South Africa has become one of the largest producers of chicory (*Cichorium intybus* L. var. *sativum*) in the world, witloof chicory as a vegetable remains an unknown product to the local market. Seeing that chicory production for coffee on a large scale was so successful, it was a logical next step to start experimenting with witloof cultivation. Over the past decade several attempts have been made to produce and market this crop locally, both by individual producers and by institutions (Coetsee, 1996). Currently only three commercial producers of this crop remain, two of them in the Gauteng province which was until recently not associated with this crop. The main reasons for the slow progress are to be found in a lack of knowledge and proper facilities, both essential factors in successful witloof (chicon) cultivation.

3 The production cycle of witloof chicory

3.1 Morphology and the natural growth cycle

Cichorium intybus L. is a perennial herb and completes its growth cycle in two stages: During the first year a fleshy taproot is formed in which carbohydrates are accumulated in the form of inulin.

The second year is marked by the appearance and development of the "above-ground" reproductive part at the expense of the accumulated energy stored up in the taproot during the previous year.

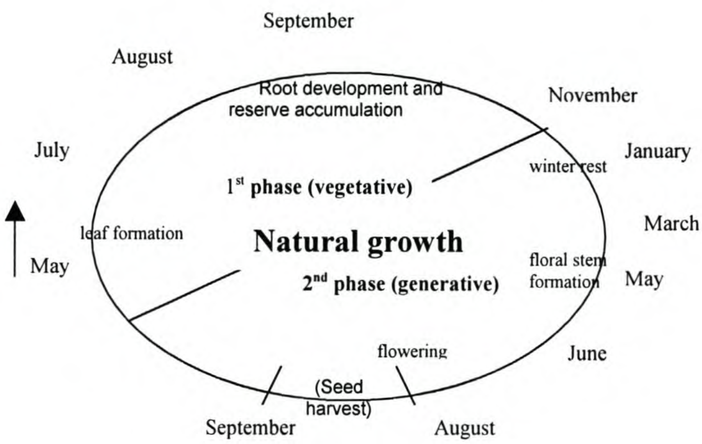

Figure 1 Natural growth cycle of *Cichorium intybus* L. in the northern hemisphere

Seeing that *Cichorium intybus* L. is indigenous to the Mediterranean region, the schematic growth cycle depicted in Figure 1 would be true only for the northern hemisphere. The plant remains in a vegetative state until it is vernalized during the cold and short day period at the end of the first growing season. As soon as the daylength reaches 13 hours or more in early May (spring) of the following year, the main vegetative bud forms a leafed, generative axis that is evenly branched over its entire length during June / July. This flowering stem may reach a length of 1.5 to 2 meters and produces a large number of blue or white bisexual flowers, 3 to 4 cm in diameter. Flowering commences in July and can last till late in the season. Chicory is generally considered an allogamous plant and relies on insects, especially bees, for the pollination of its flowers.

3.2 Witloof cultivation

3.2.1 Production of roots (first stage)

As a crop *Cichorium intybus* L. is a biennial plant. Commercial witloof (chicon) cultivation consists of two major steps, the field growth stage and the subsequent forcing of the roots using hydroponic culture in a dark environment. During the first stage seed is sown into prepared seedbeds on the open field and allowed to germinate (Croon, 1993a, Croon, 1993b). During spring and summer the plant produces a rosette of green leaves and a fleshy taproot, as would be the case in the natural growth cycle. After about 160 days the dry matter of the root has reached about 20% of the fresh root weight. This, together with other factors described by De Proft, *et al.*, (1993) determines the optimal time of root harvest. At harvest the natural growth cycle is interrupted (Figure 2). The roots are stripped of their green leaves, treated against fungal infection and placed into special cold storage facilities where they are artificially vernalized over a period of two weeks to eight months, depending on the cultivar. During the vernalization / storage period the conversion of inulin into usable sugars continues, the optimum being attained when the fructose and sucrose contents reach 30 - 60 µmol/g and 30 - 100 µmol/g fresh root weight, respectively.

According to Vandendriessche & Geypens (1993) and Sarrazyn (1990b) the field growth stage is of pivotal importance to the entire witloof production process since high quality chicons can only be grown from high-quality roots. Any unfavourable factor during the field growth period is bound to have a negative impact during the second stage of production and ultimately the final product.

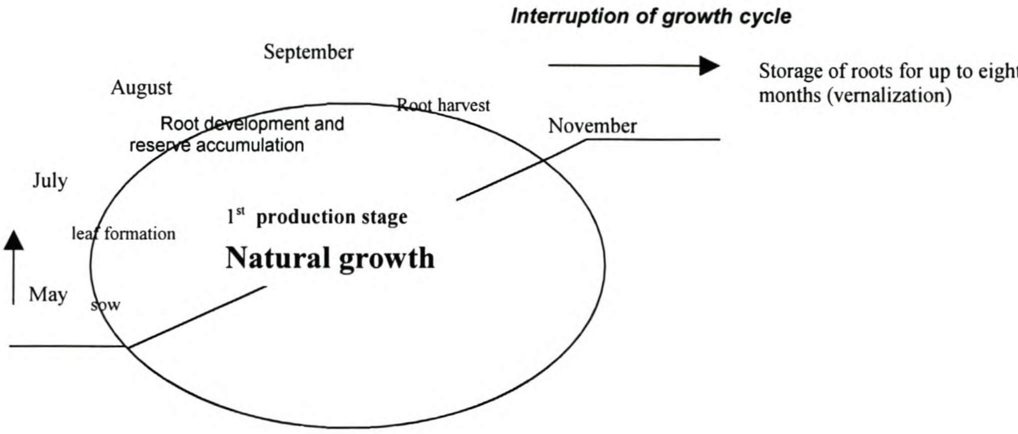

Figure 2 Interruption of the natural growth cycle for witloof (chicon) cultivation

3.2.2 Forcing (second stage)

The second stage in the production of witloof commences only after vernalization and involves the placement of the harvested roots into a hydroponic production unit under high relative humidity and in the dark for 21 – 23 days. The roots are set up in an upright position in trays and are constantly supplied with a nutrient solution (Deckers, 1991) by means of a gravity driven cascade system.

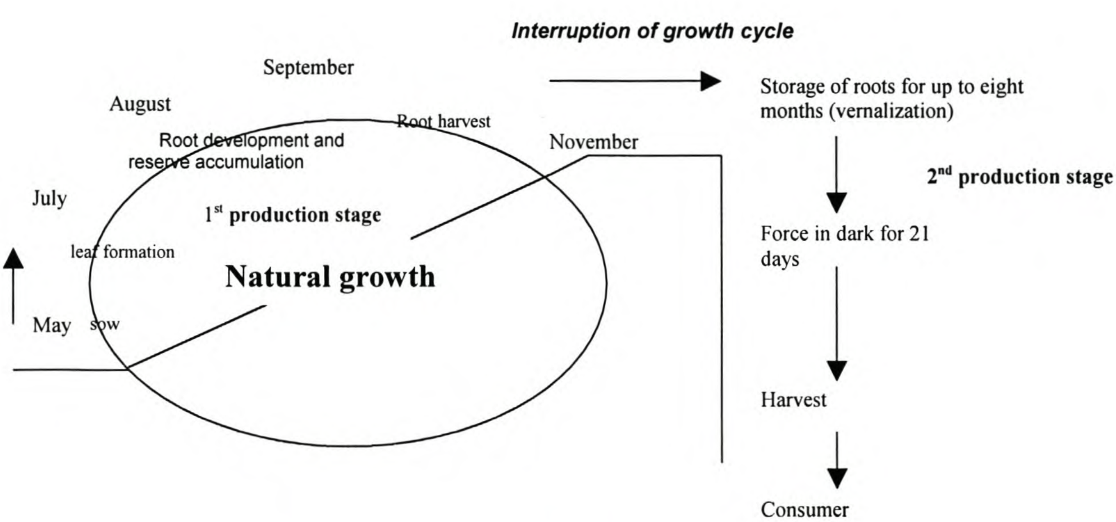

Figure 3 The complete production process of witloof chicory

The controlled environment required for successful forcing is created in a growth chamber as described by Kruistum (1997). Roots forced early in the season require a **water temperature** of 19°C and an **air temperature** of 17°C. These values decrease gradually as the season progresses, respectively to 11.5°C and 10 °C. The **relative humidity** throughout the forcing period must be maintained at 85 – 95%, with variation of not more that 5%. The **pH-value** of the nutrient solution should be about 6.5 while the electric conductivity (**EC**) strived for is 2 mS cm^{-1}. Seeing that each of these factors or a combination thereof may influence the quality of the final product (Bogaerts, *et al.*,1993), it is obvious that the cultivation of witloof is by no means a simple matter.

When roots are placed into a warm dark environment after vernalization, their apical meristems are induced to sprout. Since this is an artificial way of stimulating renewed vegetative growth, it is referred to as "forcing". The carbohydrates required for the formation of the new floral stem (pith) and fleshy leaves covering it, is obtained from inulin reserves in the taproot. Inulin is hydrolyzed and becomes available for chicon development in the form of sucrose and fructose. Water is the main transport medium for sucrose from the root to the apical growth point. On average ± 170 g of water is required for the production of 100 g witloof. At first water absorption is slow since the absorptive area is limited due to a lack of lateral roots. As lateral roots develop the emerging growth point also gradually increases in size. Chicon development occurs first through apical lengthening and then by transverse growth, the latter giving it volume and its distinct form. The growth period in the dark room is about 21 days after which the witloof head (chicon) is removed by hand, the outer leaves removed, if it is found necessary, and sorted into quality and size classes (Sarrazyn, 1991a). The final product is then generally packed in 5 kg boxes and covered with a dark blue wax paper to prevent moisture loss and light from entering, turning the white leaves green. Storage at 12°C for a period of seven to eight days is not a problem, provided that the chicons are shielded from light. Lowering the temperature will prolong the shelf life by as much as a week. The type of packaging and the cultivar also have a significant influence on these results (De Putter, 1998; Tomassen, 1997).

4 Witloof chicory in South Africa

4.1 Witloof availability

Witloof chicory is a vegetable crop that is virtually unknown to the local market. The marketing of this product thus far has been a futile effort and there are a number of very basic reasons for this:

Firstly, the supply of the crop is sporadic and inconsistent. Large food stores and restaurants, especially those offering high quality and exotic foods and cater for the affluent population, require a constant supply of produce on an ongoing basis, throughout the year. This is of particular importance with new products as the potential client needs to be exposed to the product continuously until the first purchase and then must be able to buy it at any time thereafter. A large food chain discontinued the marketing of witloof chicory because of such inconsistency.

The second reason for the unsuccessful marketing of the crop is the fact that the vegetable is sensitive to the impact of light. Chicons need to be protected from direct light as light stimulates chlorophyll-formation and turns the etiolated leaves green. Once this has occurred, witloof looses its identity and attains a bad image in the eyes of the consumer. A balance needs to be found as the product is not visible in a non-transparent package but rapidly decreases in quality if it is exposed to light for a long period. Customarily, witloof is displayed in special 500g presentation trays covered with transparent foil. One producer developed a large "display box" into which a large number of these trays could be placed. The lid of the "display box" could be opened and would always fall back into its closed position. Since the consumer still had to lift the lid to expose the fresh product, the shop managers permanently removed the lid. The total batch turned green, the product was not purchased which in turn upset the store manager and witloof was not ordered again. The alternative is to display only as many presentation trays as would be sold on any specific day and to top them up if the need arises – as is done in Europe.

Thirdly, there are serious quality problems concerning witloof in South Africa. There is no strict standardization of the crop and chicons that would be sold as Class II in Europe are considered top-of-the-range locally while even a European Class III would still be "acceptable" for marketing to the producer.

4.2 Witloof cultivation

Seeing that there are currently only three producers of witloof chicory in the country, it is understandable that witloof is not readily available. Producers, in general, are reluctant to start producing a product that is not proven to be worth their while. For potential producers of chicory there are the other options of producing for the coffee industry or the extraction of fructooligosaccharides. The capital layout for high output witloof cultivation facilities is very high and so is the risk of whether the product will be purchased. These factors are to the disadvantage of witloof production but some producers keep on trying by making use of very basic facilities that enable them to produce only small quantities of witloof at a time. Only one of the producers, a large institution, is in actual fact in the traditional chicory producing area, the Eastern Cape, while the other two are individuals in the Gauteng Province.

4.3 Root production

Even though the chicory industry is well established in South Africa, it is unclear whether witloof chicory can be cultivated as successfully as in Europe since the crop is relatively sensitive to soil type, nutrient availability and climate (Vandendriessche & Geypens, 1993). The Eastern Cape has a very mild climate with rain throughout the year and temperatures ranging between 25°C during summer and 9°C during winter. Coffee chicory is grown here throughout the year. In the light of this, it may also be possible to produce witloof root material throughout the year, which would make long-term cold storage obsolete and create the possibility of year-round witloof cultivation. The major problem faced by chicory producers in the Eastern Cape is the fungi *Cercospora* (Coetsee, 1995) and infection by the chicory yellow blotch virus.

The Gauteng Province, on the other hand, is a summer rainfall area with cold, dry winters. The climate is ideal as the roots remain in the soil until the cold winter sets in and are then harvested and placed directly into the forcing chamber, without an additional artificial vernalization period required. The main problem here is the high possibility of hail during the summer that may destroy the entire crop. The growing season is longer than in Europe and there is no need to harvest the roots early as the soil does not freeze and/or become muddy and impede the harvesting process. In theory the witloof production process would be similar to that in Europe, only with the advantage that roots may be stored and vernalized in the soil.

Much of the work that is done mechanically in Europe is done by hand in South Africa. Of particular interest for the cultivation of witloof is harvesting of the roots. For the coffee industry roots are harvested by hand and left lying in the hot sun until they are collected. This may not affect the coffee quality but has a detrimental effect on witloof cultivation. Roots that got sun burnt produce less lateral roots during the hydroponic production phase (Sarrazyn, 1991b) with the result that chicon development and quality may be reduced. Harvesting roots for witloof production will have to be much more controlled and done with a sense of care.

Last but not least, crop production in South Africa has in many cases been hampered by theft. Chicory farmers, however, make mention that this is not a problem as the roots are extremely bitter and unpleasant to eat.

5 Conclusion

The production of witloof chicory is a challenging yet very interesting industry to start up in South Africa, where chicory production is successful and already established. Whether the local market is ready for this new vegetable is not certain but with the devaluation of the local currency it may even be possible to create a new product for export – once quality chicons are produced.

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CHAPTER 2

Lateral root production of witloof chicory (*Cichorium intybus* L.) in response to ebb-and-flood nutrient supply in hydroponics

Lateral root production of witloof chicory (*Cichorium intybus* L.) in response to ebb-and-flood nutrient supply in hydroponics

Abstract

Witloof chicory is currently grown on a large scale by making use of gravity driven hydroponic cascade systems. The simplicity thereof makes them very user-friendly, a possible drawback being that the taproot is only submerged in the nutrient solution to a depth of about 30 mm. Lateral roots are believed to be responsible for most nutrient and water absorption and it was found that most of them emerge below the water line, leaving the greater part of the taproot without any lateral roots. For this reason it was hypothesised that it could be beneficial to raise the nutrient solution level and by doing so, stimulate more root primordia to grow into fully functional absorptive lateral roots. In order to achieve this without creating an anoxic environment, use was made of the ebb-and-flood technique by introducing a simple component into the already existing cascade system. The results not only showed an increase in lateral roots formed along the root axes but also a significant increase in total lateral root production for one of the two cultivars tested.

Keywords: chicory, ebb-and-flood, hydroponics, lateral roots, witloof

1 Introduction

Traditional methods of forcing witloof chicory involved the placing of roots in a bed of soil followed by covering them with a layer of topsoil and/or horse manure (Zhi Yi Tan & Corey, 1990). Not only did this result in a favourable increased forcing temperature but also supplied newly formed lateral roots with a medium to extract nutrients and water from. A similar method is still being used on a small scale today for superiour quality, organically grown witloof (Croon, 1997). The majority of modern witloof producers, however, make use of a variety of hydroponic systems, the most commonly used being the simple yet effective cascade system. Here roots are placed into basins that are stacked one above the other and a continuous stream of a gravity driven nutrient solution supplies the roots with necessary nutrients (Anonymous, 1997). The basal part of the root is constantly kept submerged in the solution to a depth of about 30 mm and it is from this submerged root-zone that the majority of lateral roots originate.

The chicory root is a fully developed respiring organism with all physiological and energy requirements met for chicon production. No sunlight energy is required given the accumulated carbohydrates in the taproot. The only requirement for the mobilization of these sugars is an adequate temperature after vernalization and a large supply of water (Sarrazyn, 1991). Additional nutrients added to the water were found to increase chicon quality and yield.

Zhang & Hasenstein (1999) cite that lateral roots increase the absorptive surface of the plant. Protruding from lateral roots are root hairs, which are believed to be involved in extraction of nutrients (Nye, 1966; Itoh & Barber, 1983; Clarkson, 1991) and uptake of water (Cailloux, 1972), from the growing medium. When the chicory root is set up for forcing, there are usually only a few lateral roots present as most are lost during harvesting or cold storage. According to Sarrazyn (1991), water absorption increases gradually for the first week of forcing and then increases exponentially over the following week. This is understandable since lateral root production starts slowly, with the formation of lateral root primordia, followed by the growth and only then the emergence of visible lateral roots from the main axis (Biddington & Dearman, 1982/83). As laterals appear, absorption will increase, soon followed by chicon growth.

The authors postulate that one possible reason for the mentioned superiour quality of soil grown witloof, may be traced to the fact that the entire taproot axis is exposed to and in contact with the nutrient containing substrate, allowing for increased absorption. For this reason beneficial effects were expected if the number of lateral roots was artificially increased.

Much information, albeit inconclusive, is available from research conducted on the effect of hormones on lateral root formation. Available evidence shows that auxins can promote the development of lateral root primordia under certain conditions (Torrey, 1950; Böttger, 1974). Consumers are, however, weary of hormone treated produce and it was therefore decided to try and achieve increased lateral root formation by stimulating the chicory root by natural means. From the paper by Torrey (1956), it becomes clear that the array of physiological and biochemical processes involved in lateral root formation is immense and far from fully understood.

Meins (1986) defines "competence" in plants as a state of reactivity of cells to respond to specific stimuli. Considering that the majority of lateral roots develop below the 30 mm waterline, it was suggested that the nutrient solution could possibly contain a stimulus (chemical, physical or temperature) supporting lateral root initiation. This theory can easily be tested by raising the nutrient solution level along the axis of the taproot during forcing. No literature covering such topic *per se* was found. Considering, however, that waterlogged soils under field conditions pose the problem of limiting O_2 supply to the root systems of most plants, it must be expected that roots submerged in large volumes of water (hydroponics) might experience similar restrictions (Crawford, 1992). One way of achieving a balance between increased water level and sufficient aeration is by making use of an ebb-and-flood irrigation technique. The aim of this study was to verify whether such a treatment would indeed promote total lateral root formation when compared to the conventional irrigation method.

2 Materials and methods

The two witloof chicory cultivars that were used in this trial, 'Tabor' and 'Focus', were grown in the traditional chicory producing area of South Africa, the Eastern Cape. They were harvested after a growing season of 160 days and placed into cold storage at –1 °C for 5 weeks. Before placement for forcing, the leaves were trimmed to 30 mm above the taproot shoulders and the root tip removed to reduce the root to 180 mm length. All roots had a diameter of between 30 and 40 mm.

In a totally randomized block design each cultivar was exposed to three different ebb-and-flood irrigation treatments and a control, the latter representing the conventional way of forcing witloof roots. Ten roots with a total average weight of 1350 ± 50 g, formed an experimental unit and were placed into a cylindrical container (150 mm diameter and 160 mm height), which allowed nutrient solution to pass freely through large openings at the bottom and along the sides. Four such containers were placed into a basin, which was supplied with a nutrient solution as proposed by Deckers (1991). Two experimental units for each cultivar were placed into a basin for each of the irrigation treatments, repeated twice in two blocks.

For the control, the nutrient solution was continuously supplied to the basin at a speed of 500 ml min^{-1} and the water level maintained constant, at ± 30 mm. For the ebb-and-flood irrigation treatments a principle described by Combrink & Harms (2000) was used. The outlet was modified by introducing a simple regulatory device, as shown in Figure 1.

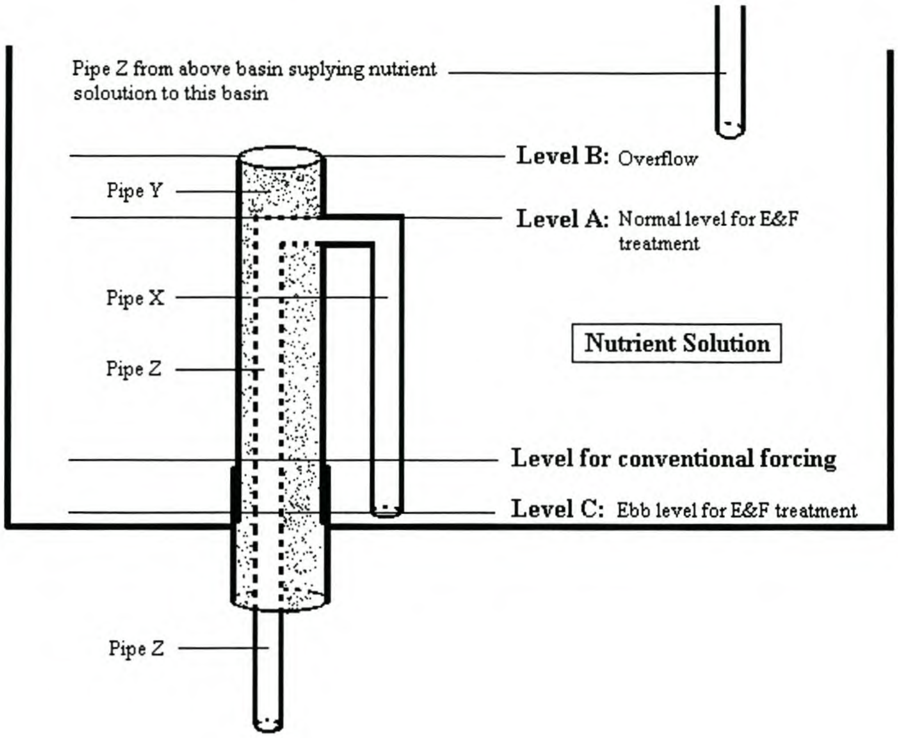

Figure 1 Device for controlled ebb-and-flood (E&F) irrigation. Nutrient solution is supplied from the above basin, as in any cascade system, and allowed to rise to Level A. Once this level is reached, a siphon action commences and slowly drains the basin to Level C. Draining occurs through pipe X-Z. Pipe Z is within pipe Y while the latter acts as an overflow leading any excess solution to the lower basin, should the nutrient solution exceed Level B.

During this trial the distance from the base of the basin to level A was 60 mm for ebb-and-flood treatment A and 100 mm for treatments B and C. These distances represented the level to which the nutrient solution level was allowed to rise at intervals as set out in Table 1. In this way roots were submerged in the nutrient solution for approximately 20 minutes and allowed to drain the rest of the time between cycles.

Water- and ambient temperatures were controlled at 16°C and 14°C respectively. The pH was maintained at 6.5 and the EC adjusted daily to a reading of 2 mS cm^{-1}. The relative humidity in the growth chamber was maintained at 92%.

Table 1 Irrigation Treatments

Irrigation treatments	Nutrient solution level	Time between cycles
Control	30 mm	Constant flow
Ebb-and-flood A	60 mm	45 minutes
Ebb-and-flood B	100 mm	45 minutes
Ebb-and-flood C	100 mm	90 minutes

Seeing that root size (diameter) and weight varied to some extent, the average percentage dry material (DM) of the fresh root was recorded and used to homogenize the experimental units. The average DM was 22.9 percent and 23.5 percent for Tabor and Focus respectively. Before forcing, the fresh weight of each experimental unit (10 roots) was noted and the dry weight calculated. At the time of harvest, 25 days after the roots were placed into the growth chamber, the lateral roots that formed on the taproot were removed by scraping them off with a sharp blade held perpendicularly to the taproot. They were then dried at 80°C for 24 hours and weighed. Dry lateral root weight was compared to the dry taproot weight and expressed as a percentage. The resulting LRI (lateral root index) value was used to compare lateral root development for the two cultivars and irrigation treatments.

$$LRI = [DM \text{ of lateral roots (g)} / DM \text{ of taproot (g)}] \times 100$$

The statistical analysis was done with SAS and Student's LSD ($P = 0.05$) used to compare treatment means.

3 Results and discussion

Despite the fact that no data was collected quantifying the actual lateral root producing area along the root axis during this trial, it was clear that lateral roots were more abundant higher up along the root axes of roots subjected to greater irrigation depths than was the case with the control. Figure 2 shows typical lateral root formation zones for the four irrigation treatments applied during this trial with the lateral roots indicating clearly the level to which the solution level was raised along the root axis. Lateral root formation along the root axis, as a function of the irrigation level, was found to support the idea of plant competence as suggested by Meins (1986), where contact of the nutrient solution with the tap root surface could act as a stimulus promoting lateral root formation in the case of chicory roots.

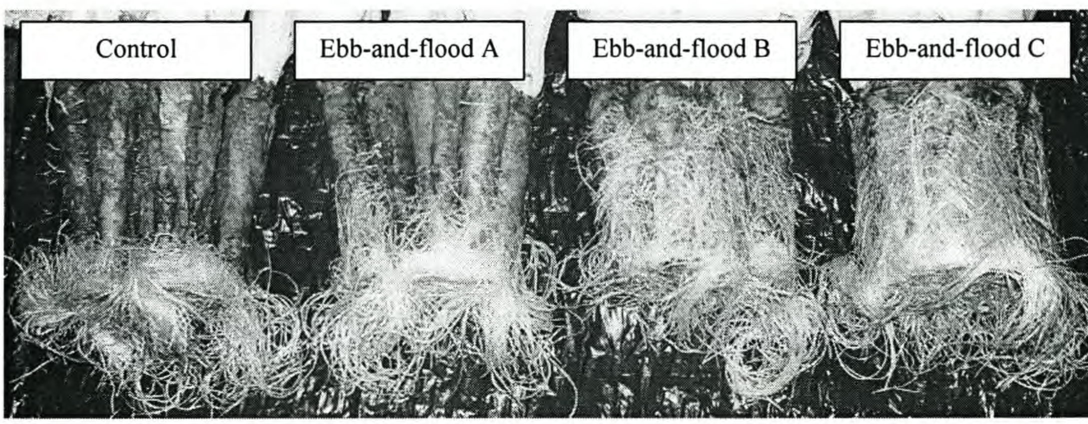

Figure 2 Typical lateral root development along the root axes in response to ebb-and-flood irrigation treatments. Flood depth was 60 mm for treatment A while it was 100 mm for treatments B and C. Intervals between cycles were 45 minutes for treatments A and B and 90 minutes for treatment C. The control was continuously supplied with nutrient solution to a depth of 30 mm.

The hypothesis was that an increased taproot surface area exposed to a nutrient solution would increase the total lateral root production. Seeing, however, that lateral root production represents a substantial investment in plant biomass (Torrey, 1976), it may be that the number of lateral roots along the axis did increase while the total DM production, as measured by LRI, did not. If this was found to be true, it would be highly unlikely that the absorptive root area increased. Statistical analysis of the recorded LRI data showed an interaction between cultivars and irrigation treatments at SL = 0.0345.

From Figure 3 it is evident that both cultivars, Focus and Tabor, showed identical lateral root formations at a constant nutrient solution level. As expected, a positive trend for LRI resulted when ebb-and-flood treatments were applied. However, this increased LRI was only significant when Focus was used and where the distance between the flood- and ebb levels were 100 mm. The relatively poor performance of Focus at the 60 mm ebb-and-flood treatment was thought to be as a result of the fact that one of the four experimental units for this treatment was slightly infected by *Sclerotinia sclerotiorum*. In Chapter 6 Desogerme SP® was used as disease control but no effect on lateral root formation was found.

LSD = 0.404

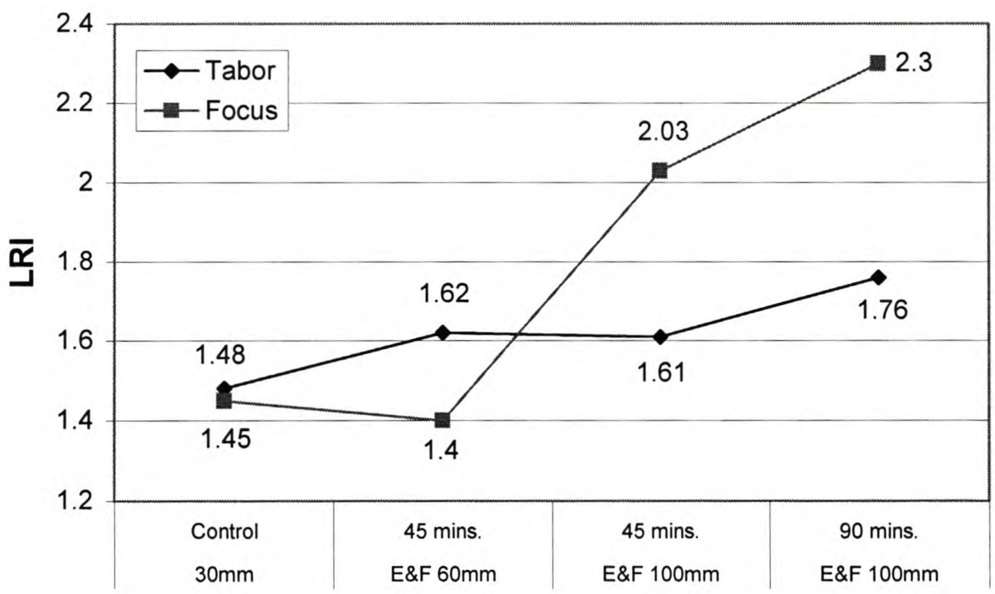

Figure 3 Lateral Root Index (LRI) affected by an interaction between two cultivars and four ebb-and-flood (E&F) irrigation treatments.

It can be concluded that formation of lateral roots can be stimulated by exposing a greater root surface area to contact with the nutrient solution. Although the response was only significant when Focus was used, the LRI also tended to increase when Tabor was exposed to the 100 mm (90 min) ebb-and-flood treatment. This, together with results presented in Chapter 3, supports the findings made by Crawford (1992) who reported that proper root aeration is of cardinal importance for respiration during root development.

However, it is difficult to predict why the positive reaction of Tabor was less prominent than with Focus when greater root surfaces were wetted and sufficient time allowed for aeration. Focus and Tabor are classified as early and late types respectively, Anonymous (1995). Late types typically require a longer vernalization period than do early ones in order to convert complex carbohydrates into simple sugars to be used during lateral root formation and chicon growth (Fitters *et al*., 1991). Seeing that both cultivars were cold-stored for five weeks, this could be a possible reason for the deviating growth response of the two cultivars. Clearly cultivar differences must be expected but as yet no anatomical, physiological or genetic study has been undertaken.

4 Conclusion

In this study, the authors have shown that lateral root formation, and therefore the absorptive root area, can be enhanced significantly using the chicory cultivar 'Focus'. These results were obtained by using an ebb-and-flood system through which the nutrient solution level was raised during the forcing process of witloof chicory. The effect hereof on chicon yield and quality requires investigation and will be the topic of chapter 3.

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CHAPTER 3

Witloof chicory (*Cichorium intybus* L.) quality and lateral root production affected by irrigation systems during forcing

Witloof chicory (*Cichorium intybus* L.) quality and lateral root production affected by irrigation systems during forcing

Abstract

Witloof chicory roots were irrigated conventionally, aeroponically or by means of ebb-and-flood irrigation during forcing. Where nutrient solution was supplied by means of an aeroponic technique a significantly lower chicon quality was achived than where irrigation was applied at a constant level of nutrient solution to a depth of 100 mm or by means of an ebb-and-flood treatment to the same depth. It was found that enhanced lateral root development occurred to the detriment of chicon quality, possibly because of the diversion of energy to developing roots, rather than to chicon development. There was no significant difference in total chicon leaf weight when irrigation treatments were compared. Furthermore, a quality index was developed for the better evaluation of chicon quality in this trial. Use hereof simplified statistical procedures as well as the interpretation of data.

Keywords: aeroponics, chicory, ebb-and-flood, quality, witloof

1 Introduction

Witloof chicory is a valuable vegetable crop, produced mainly in France, Belgium and the Netherlands (Sarrazyn, 1990b). The quality standards of these countries are extremely high and strict norms govern the grading process (Muyldermans, Lambrechts & Steenberghen, 1993; Organization for Economic Co-operation and Development, 1994). Data of most trials done on the quality aspect of witloof is presented in table form and focuses wholly on the yield of class 1, totally ignoring the effect of the less sought-after classes on the total yield (Brakeboer, 1997). Accordingly, adequate statistical analysis is absent resulting in the scarcity of publications on witloof chicory in scientific journals. This is understandable seeing that witloof is graded into classes, making the analysis of collected data more complex because of its ordinal nature. It would, however, be of advantage if such data could be converted into parametric data allowing it to be analyzed using an analysis of variance (ANOVA).

The ebb-and-flood technique is not new and previous trials seem to have given good results (Sarrazyn 1990a; Sarrazyn, 1991a), yet no scientific publication on this topic was found. Crawford (1992) makes mention of the importance of adequate root aeration in general, while Sarrazyn (1991b) showed how sufficient root aeration improves chicon production favourably during forcing. Aeroponics seems to give very good results but the capital investment may not be justified (Sarrazyn, 1991b). Seeing that the root will be totally out of the nutrient solution at times during ebb-and-flood irrigation, it is believed that there should not be a significant difference between these two irrigation systems. To establish whether this is the case, both treatments were included in this trial.

The possibility of growing witloof chicory using an ebb-and-flood technique was studies previously (Chapter 2). The focus was entirely on lateral root formation as it was hypothesized and demonstrated that an ebb-and-flood technique may increase lateral root formation. Whether this would have any effect on chicon growth is unclear since, as Kramer (1983) points out, the capacity of roots to absorb water and minerals does not increase in direct proportion to the increase in length or area of roots. The reason given is that while new roots are being added, older roots are maturing and becoming less permeable. The principal aim of this study, however, was to find a relationship between lateral root formation and chicon quality and yield.

2 Definition of quality index (QI)

Witloof chicory is graded into four classes according to EU standards, namely Extra, 1, 2 and 3. The market value is dependent on these classes, being highest for class Extra and lowest for class 3. However, not all chicons are actually marketable and, especially in the EU, a penalty is payable for excess organic waste. To accommodate this factor a class 4, which is not part of the EU grading system, was added for our evaluation system. Representing the pricing of chicons in the different classes, a value (V) was allocated to each class as follows: Extra = 10, class 1 = 8, class 2 = 5 and class 3 = 3. A negative value of –1 was given to class 4 to account for the additional cost of waste removal. After each chicon is graded, these values can be used to calculate the QI of any batch size, according to the following equation:

$$QI = [((n_E \times V_E) + (n_1 \times V_1) + (n_2 \times V_2) + (n_3 \times V_3) + (n_4 \times V_4)) / N] - P$$

In each case n_i represents the number of chicons in the class i (Extra, 1, 2, 3, 4) while V_i represents the value associated with each of the classes as explained above. N is the total number of chicons harvested and P the correction factor for physiological disorders noted on the whole batch.

$$P = n_P \times w$$

For the calculation of P, n_P represents the number of chicons in any batch with disorders such as brown core, red discolouration, point noir, hollow pith and more, as described by Reerink (1994), while w controls the weight that these disorders are to carry during any experiment, e.g. 0.2 being 20%.

The obtained QI-value will fall somewhere on a "QI-scale" and indicate the average quality for any number of chicons taking the EU grading system as basis. The calculated value will never be greater than 10 but is open-ended to the negative side. In this way a single value describing the average chicon quality, based on market value for any batch size is obtained, making statistical analysis using an analysis of variance possible.

3 Material and methods

'Focus' was used as the only cultivar during this trial. Roots were grown in the traditional chicory producing area of South Africa, the Eastern Cape. They were harvested after a growing season of 160 days and placed into cold storage for 9 weeks. Before placement for forcing, the leaves were trimmed to 30 mm above the taproot shoulders and the root tips removed to reduce the total root length to 180 mm. All roots had a diameter of between 30 and 40 mm and fifty experimental units, with an average weight of 720 g ± 30 g, were prepared by tying five roots together in each case. Ten units were then used for each of the five irrigation treatments which supplied the nutrient solution, as described by Deckers (1991).

Irrigation treatments were as follows: For a control the nutrient solution was supplied at a constant rate of 500 ml min^{-1} to maintain a depth of 30 mm. The second treatment was similar, the only difference being that the roots were continually submerged to a depth of 100 mm, thereby possibly simulating an oxygen-poor environment for the roots. As a third treatment, an ebb-and-flood technique as described in Chapter 2 was used to allow the nutrient level to rise 100 mm along the root axes at time intervals of 90 minutes between cycles. In addition, two aeroponic treatments were included. For these, roots were set up on a grid situated 100 mm above the base of the basin forming sufficient space for nutrient solution to be sprayed in between the roots from below by two static flat spreaders. These were supplied by Dan Sprinklers, Kibutz Dan, 12245 Israel, but the nozzles were removed. The two treatments differed in that the first sprayed for 15 seconds every 30 minutes while the second sprayed 15 seconds at 90 minute intervals.

The roots were placed in the growth chamber for 27 days. Water and ambient temperatures were controlled at 16°C and 14°C respectively. The pH was maintained at 6.5 and the EC adjusted daily to a reading of 2 mS cm^{-1}. The relative humidity in the growth chamber was maintained at 92%.

At harvest the lateral root index (LRI) was calculated with the dry matter (DM) of fresh roots being 23.5%. LRI is defined as the DM of lateral roots expressed as a percentage of the DM of the taproot (Chapter 2). All chicons were graded according to EU standards (Muyldermans, *et al.*, 1993). The number of chicons showing any degree of physiological deficiencies as described by Reerink (1994) was noted for the calculation of the QI. In addition, total yield was measured and recorded as "gram witloof per 100 gram fresh root mass". The data was analyzed using SAS (1990) and Student's LSD (P = 0.05) was used to compare treatment means.

4 Results and discussion

The QI-column of Table 1 shows the QI-values representing the treatment means for the five irrigation methods analyzed statistically using an ANOVA. When comparing the irrigation treatments on the basis of quality (QI), it is clear that there was a statistically significant difference between treatments 2 and 4 as well as between treatments 3 and 4. It is evident that roots irrigated to a depth of 100 mm (constant level or ebb-and-flood) produced chicons of significantly higher quality than where irrigation was by means of aeroponics at a 30 minute spraying cycle.

Table 1 Treatment means for quality index (QI), lateral root index (LRI) and total leaf yield (chicon and fall-out) in gram per 100 gram fresh root weight

Irrigation treatment	**QI**	**LRI** (%)	**Total leaf yield** (g / 100 g)
1) Constant flow at 30 mm	6.88 ab	2.61 b	47.07 a
2) Constant flow at 100 mm	7.90 a	1.95 c	51.62 a
3) Ebb-and-flood to 100 mm	7.84 a	2.74 ab	58.82 a
4) Aeroponics at 30 min. cycle	5.95 b	3.17 a	65.01 a
5) Aeroponics at 90 min. cycle	6.91 ab	3.05 ab	59.61 a
LSD (5%)	**1.848**	**0.712**	**NS**
CV	18.00	20.41	42.49

Means with the same letter are not significantly different

NS = no significant differences

The LRI column of Table 1 displays the lateral root formation for the five irrigation treatments. Irrigation by means of aeroponics produced the highest LRI but there was no significant difference between aeroponics and an ebb-and-flood treatment. Of interest is the fact that irrigation treatment 2 produced a significantly lower LRI than the rest, possibly as a result of limited oxygen supply. However, it is the same treatment that produced among the highest quality chicons. When these readings, LRI and QI, are compared using Pearson's Correlation Coefficient, a negative value of $r = -0.212$ is obtained, indicating that chicon quality diminishes as lateral root production increases. However, this trend must be interpreted with caution since the R^2 value was relatively low (0.045) for the 50 pairs compared (Figure 1). Torrey (1976) explains that lateral roots are formed at a substantial investment in plant biomass. This could serve as an explanation for the deteriorating chicon quality where roots produce many laterals, since the energy is diverted to the root instead of the chicon. It must be noted that witloof chicory leaves cannot photosynthesize as they are grown in a dark chamber. All the energy required for chicon growth has to originate from the taproot, which serves as a storage organ. The limited available energy may not be sufficient to produce more lateral roots and at the same time high quality chicons.

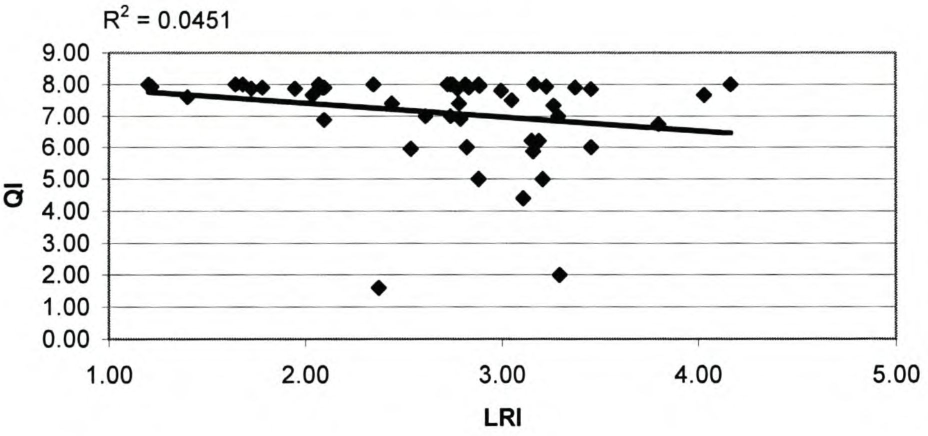

Figure 1 Association between lateral root index (LRI) and chicon quality index (QI).

No statistically meaningful difference was found for any of the five irrigation treatments regarding total leaf yield (Table 1). However, comparing total leaf yield with lateral root formation, produced a positive correlation coefficient of 0.184, indicating that a rise in LRI may result in an increase in leaf yield, although the chicon quality decreased. From Figure 2 it is apparent that this can only be said with 3.4% certainty for the 50 pairs compared. Since there are factors, other than lateral root formation detrimentally affecting chicon quality (Bogaerts, *et al.*, 1993), further investigation in this field needs to be done.

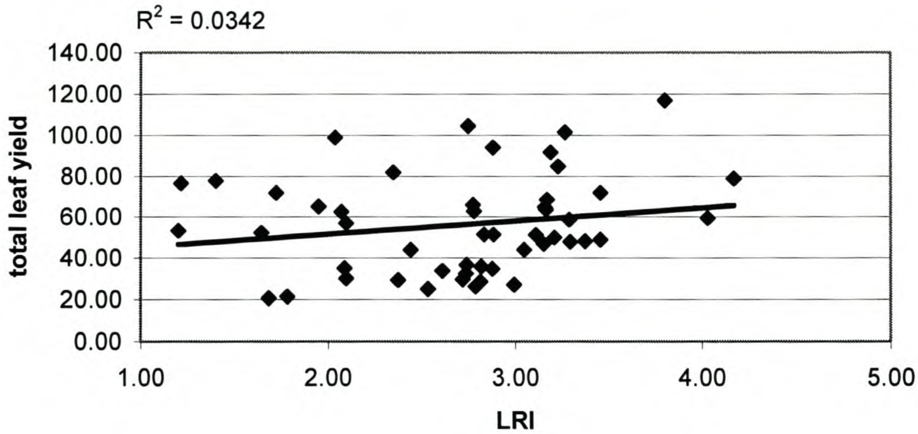

Figure 2 Association between lateral root index (LRI) and total yield (g per 100g fresh root weight) of witloof chicory.

5 Conclusion

From the trial it was evident that roots irrigated with nutrient solution by means of an aeroponic technique produced significantly lower chicon quality but better lateral root development than where roots were conventionally supplied with nutrient solution to a depth of 100 mm or by means of an ebb-and-flood treatment. Lateral root formation had a detrimental effect on chicon quality, probably because of the diversion of energy to developing roots, rather than to chicon development.

The use of an index to evaluate chicon quality proved to be extremely useful since it improved the accuracy of the statistical procedures and simplified the interpretation of data.

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CHAPTER 4

The effect of geotropism on the quality of witloof chicory (*Cichorium intybus* L.)

The effect of geotropism on the quality of witloof chicory (*Cichorium intybus* L.)

Abstract

In order to establish the effect of geotropism on chicon quality and yield, witloof chicory roots were forced at three angles. It was shown that roots forced in a horizontal position, produced a significantly lower marketable chicon yield than roots forced in a vertical position or at an angle of 45°. This reduced yield was brought about by an increased fall-out percentage where chicons were grown from roots placed at an angle.

Keywords: chicons, chicory, ebb-and-flood, geotropism, hydroponics

1 Introduction

The production of witloof chicory has evolved into a highly specialized and competitive industry since its beginnings some 150 years ago. Production techniques have developed from growing this vegetable crop in soil beds, to production using high-tech hydroponic systems (Sarrazyn, 1991). The major issue today is producing high quality chicons (Reerink, 1993; Muyldermans, Lambrechts & Steenberghen, 1993) while there is a continuous search for new forcing techniques.

In the Eastern Cape of South Africa, roots that were buried during the previous harvest are often lifted when preparing the soil for a new crop. In many instances perfectly formed, high quality chicons have formed, even on roots buried horizontally. In such cases the chicon develops in a vertical direction, resulting in an acute angle between the axis of the root and that of the chicon, in some cases up to 90°. The negative geotropic nature of most shoots was summarized by Wilkins (1984). The authors investigated the effect of geotropism on the growth and quality of chicons when roots were placed in a horizontal position during forcing. The problem of irrigating these horizontally placed roots was overcome by making use of an aeroponic system.

2 Materials and methods

Chicory roots of the cultivar 'Focus' and of diameter 30 to 40 mm were used. The roots were grown for 160 days and stored at 1°C for nine weeks. They were trimmed to 180 mm in length and 28 experimental units, consisting of 15 roots, each were prepared. These were placed on a dome-shaped frame covered with mesh wire (Figure 1). Seven experimental units were placed horizontally at the bottom, seven units half way up at an approximate angle of 45° and seven were placed vertically at the top. Irrigation was applied by a single static spreader, placed in the center of the basin below the roots. The roots were sprayed with a nutrient solution for 15 minutes in 30 minute cycles. The nutrient solution used was as advised by Deckers (1991). A control also consisting of seven experimental units was included as a fourth treatment. Here roots were forced according to conventional methods, constantly being supplied with nutrient solution via a separate pump to a depth of 30 mm (Kruistum, 1997). After 24 days, the chicons were harvested and the total marketable yield (sum of classes Extra, 1 and 2), was recorded as g per 100 g fresh root weight (Figure 2). The fall-out was weighed and expressed as percentage leaf weight of total leaf weight harvested (Figure 2).

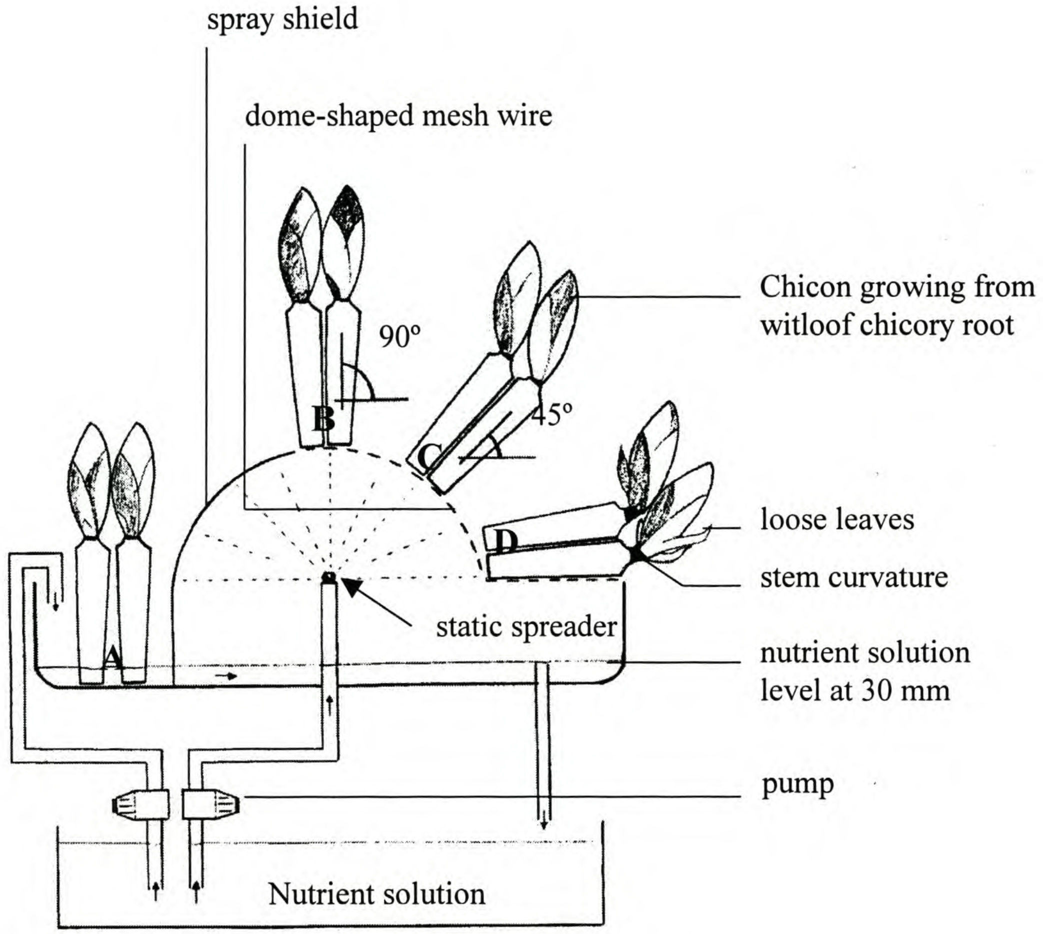

Figure 1 Technique used for evaluating the effects of geotropism and irrigation method on chicon yield for roots placed at different angles. A = roots placed vertically and forced conventionally at a nutrient solution level of 30 mm. Treatments B, C and D were irrigated by means of aeroponics. B = roots forced vertically, C = at an angle of 45° and D = horizontal root placement.

3 Results and discussion

There was a highly significant difference (SL = 0.001) in chicon yield when irrigation treatments were compared. Using Student's LSD to compare treatment means, no statistically significant difference was found when roots were placed in a vertical position and irrigated by either the conventional way or by means of aeroponics. These results are in line with those found in chapter 3. Of importance to this discussion is the fact that marketable chicon yield (g chicons per 100g fresh root weight) decreased significantly as the angle of inclination during forcing decreased from vertical (90°) to horizontal (0°) (Figure 2). There was no statistical difference between vertical (90°) root placement and placement at a 45° angle even though there was a noticeable decrease in yield for the latter. This trend was accentuated by the highly significant decrease in marketable chicon yield for roots that were forced while lying in a horizontal position.

Hangarter (1997) states that gravitropism plays an important role in determining whole-plant form in addition to the vertical positioning of the main axis of the stem and root. When chicons were harvested from horizontally placed roots, it was obvious that the outermost leaves were loosely packed and stood away from the chicon. Such leaves need to be removed for marketing purposes and by doing so chicon mass as well as -dimension are lost. Furthermore, for roots placed horizontally, a prominent stem curvature (Figure 1) was present, in which case even more leaves had to be removed in order for the final product to be presentable (Reerink, 1993). The calculated mean fall-out of aeroponically grown roots was 13.6% for roots placed vertically, 22.8% for roots placed at a 45° angle and 39.8% when roots were lying horizontally (Figure 2). All these differences were highly significant at P = 0.05 with the fall-out increasing significantly as the angle of placement decreased (LSD = 5.41). The control had a mean fall-out of 19.8%, which was significantly higher than vertically placed roots irrigated aeroponically but statistically similar to that of roots placed at an angle of 45°.

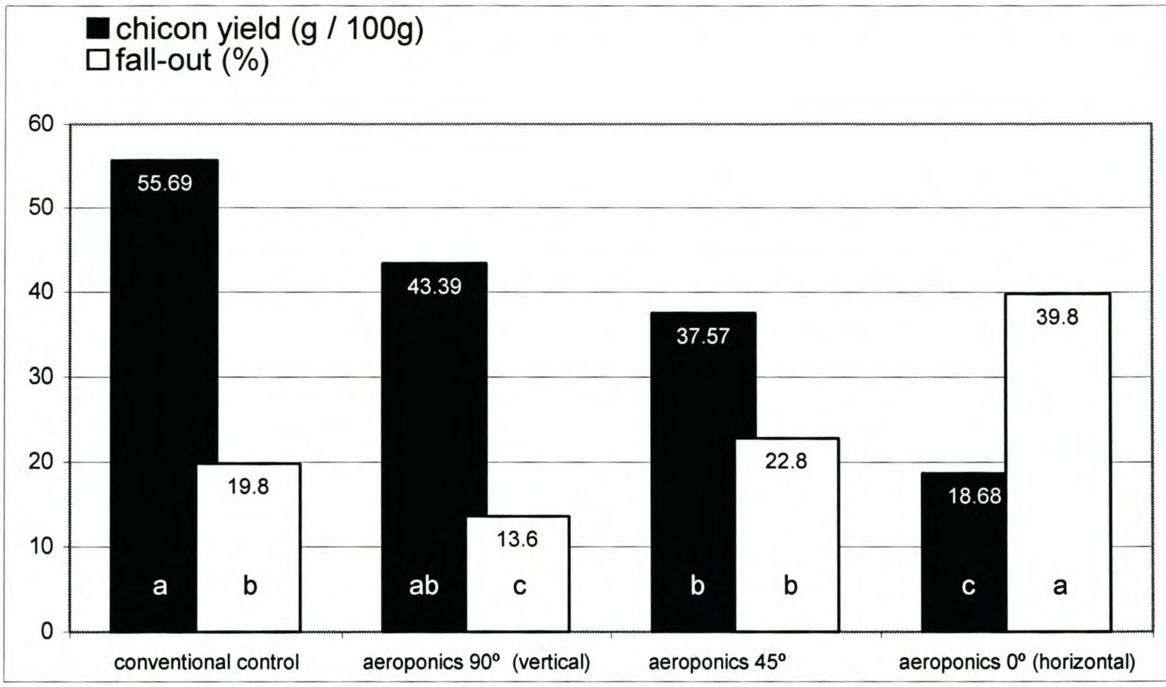

Figure 2 Marketable chicon yield per 100g fresh root weight and fall out percentage affected by irrigation method and inclination. Yield means with the same letter are not significantly different.

To summarize: It was shown that chicon yield and quality was affected by the negative gravitropic nature of apical meristems. The result of forcing roots horizontally was a sharp increase in fall-out percentage, which ultimately had a detrimental effect on yield. Furthermore, there was no significant difference in yield between roots forced conventionally and by means of aeroponics. However, the fall out was significantly reduced when aeroponics was used as irrigation technique.

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CHAPTER 5

Exogenous application of sucrose to witloof chicory (*Cichorium intybus* L.) roots during forcing and its effect on chicon yield

Exogenous application of sucrose to witloof chicory (*Cichorium intybus* L.) roots during forcing and its effect on chicon yield

Abstract

Sucrose is the predominant mobile source of energy available to the apical growth point for chicon development. Sucrose was added exogenously to the chicory root before and/or during forcing and the effects on the dry matter content and the yield of marketable chicons were tested. The dry matter (DM) yield of chicons was affected negatively when sucrose was added to the nutrient solution and irrigation was applied aeroponically. The same trend was noticed when roots were pretreated with a 5% sucrose solution before being forced by means of aeroponics. Marketable chicon yield was also detrimentally affected when sucrose was added to the nutrient solution while a sucrose pretreatment had no effect. Apart from a possible associated osmotic effect restricting the uptake of water, sucrose could have increased the risk of bacterial or fungal infection that consequently reduced the marketable yield. A root pretreatment with 'Desogerme SP®' (50.0 g L^{-1} N-Alkyl Dimethyl Benzyl Ammonium Chlorures + 20.0 g L^{-1} Poly Hydrochloryde) together with conventional irrigation had a positive effect on DM yield as well as chicon yield.

Keywords: chicory, Desogerme SP ®, dry matter, irrigation, witloof

1 Introduction

The first year of witloof chicory's natural growth cycle is marked by vegetative growth and the accumulation of carbohydrates in a taproot. Carbohydrates are stored in the form of β-(2-1) linked fructans called inulin (Meier & Reid, 1982). As vegetative growth progresses and the root reaches physiological ripeness, these complex sugars consisting of 35 to 40 fructose units and a single glucose molecule on one end (Sarrazyn, 1991) are hydrolyzed into simple sugars, predominantly fructose (Van den Ende, *et al.*, 1996). For chicon production (bud formation in a dark room) the root is harvested after the first growing season, in a state of transition, where the plant is in physiological rest (Demeulemeester & De Proft, 1993; Gianquinto, 1997; Van den Acker). A cold period is required for root vernalization. During cold storage and the subsequent forcing of chicory roots, depolymerization of large fructans and the accumulation of fructose are accelerated 10-fold (Ernst, Chatterton & Harrison, 1995; Rutherford & Phillips, 1975; Rutherford & Weston, 1968). Fructose, however, is not considered a mobile sugar in chicory and is converted to sucrose (De Proft, *et al.*, 1993). Sucrose moves freely from the cytoplasm into the transport tissue of the root and onwards to the growth point where it is used as an energy source for the formation of the flowering stem during the generative growth phase or the chicon during forcing (Sarrazyn, 1991). The dynamics of inulin synthesis and breakdown during chicory root development, storage and forcing have been described by Rutherford & Weston, (1968) and Van den Ende & Van Laere, (1996). According to Demeulemeester (1995), an analysis of sugar content during the generative re-growth of chicory plants showed the important role of sucrose in the flowering process. Friend, Bodson & Bernier (1984) and Tanimoto & Harada (1981) respectively reported on the flower-promoting effect of sucrose on flowering in *Brassica campestris* L. cv Ceres and *Torenia fournieri* Lind. From the work of Friend, Bodson & Bernier (1984) and Ishioka, Tanimoto & Harada (1991) it is apparent that young plants are able to absorb carbohydrates when these are supplied exogenously. Hadara (1966) also showed that floral-bud formation was promoted in organ segments of *Cichorium* when they were cultured on a medium containing a high sucrose concentration. The inulin content of a fully developed chicory root is as high as 20% of the fresh root weight or 80% of root dry weight (Van den Ende, *et al.*, 1996). The question arose, whether additional sucrose supplied prior to or during forcing, would be beneficial for chicon development. The high root inulin content may affect the osmotic gradient and it is unclear whether sucrose would actually be absorbed by the physiologically mature chicory root.

This paper reports on the effects of sucrose on chicon yield and quality when added exogenously to the chicory root before forcing as well as when it is included in the nutrient solution during forcing. Seeing that commercial forcing of chicory does not take place in sterile conditions, bacteria and/or fungi may colonize a sucrose-enriched nutrient solution or roots that are submerged in a sucrose solution. 'Desogerme SP Vegetals' (SPS International, P.O.Box 991, Witkoppen, 2068, Republic of South Africa) was included as a treatment to control bacterial and fungal infection (active ingredients: 50.0 g L^{-1} N-Alkyl Dimethyl Benzyl Ammonium Chlorures + 20.0 g L^{-1} Poly Hydrochloryde), and the effect thereof on yield was recorded. In previous studies (Chapter 3) the effects of three irrigation treatments; conventional, ebb-and-flood and aeroponics on chicon quality and yield were examined. These treatments were once more included for further evaluation.

2 Materials and methods

Chicory seed of the witloof cultivar 'Focus' was sown in sandy loam soil in the traditional chicory producing area of South Africa, the Eastern Cape on 13 June 2000. The roots were harvested by hand on 21 January 2001 and stored at 1°C for nine weeks. Only roots with a diameter of 30 to 40 mm were used. The roots were trimmed to 180 mm in length prior to forcing and 54 experimental units consisting of 10 roots each were prepared (total average weight of 10 roots was 1320 ± 60 g).

Three factors were factorially arranged (2x3x3) in this trial and replicated three times using a complete block design. Two levels of sucrose in the nutrient solution (SS) were included: In the first case sucrose was absent while the nutrient solution was modified to contain 5% sucrose after 14 days of forcing in the other. For the three pre-forcing treatments (PS) roots were either soaked in pure water (control), in water with 10 ml L^{-1} 'Desogerme SP®' or in a 5% sucrose solution with 10 ml L^{-1} 'Desogerme SP®', all for a period of 30 mins. The three irrigation methods (IM) were as follows: For the conventional way of irrigation (control) the nutrient solution (Deckers, 1991) was continuously supplied to the root-containing basin at a flow rate of 500 ml min^{-1} and the water level maintained constant, at ± 30 mm. The ebb-and-flood irrigation treatment was similar to that described by Combrink & Harms (2000) with the depth to which the solution could rise set at 100 mm. The basin was filled every 45 mins and allowed to drain completely between cycles. Aeroponic irrigation was applied by means of a single static spreader placed in the basin below the roots. The roots were sprayed with a nutrient solution for 15 minutes in 30 min cycles. In all cases 10 ml L^{-1} 'Desogerme SP®' were added to the nutrient solution during forcing.

The chicons were grown for 20 days at water- and ambient temperatures set at 16°C and 14°C respectively. The pH was maintained at 6.5 for the first two weeks but fluctuated between 6.8 and 8.1 during the last week of forcing. The EC was adjusted daily to a reading of 2 mS cm^{-1} and the relative humidity in the growth chamber was maintained at 91%. At harvest the total marketable chicon yield was recorded as mass per 100 g fresh root weight. Furthermore the dry matter (DM) of the chicons was determined by placing chicons halved longitudinally into a ventilated oven at 85°C for 24 hours. The DM chicon yield per 100 g fresh root weight was then calculated. The data were statistically analyzed using SAS (1990) and Student's LSD was utilized to compare treatment means. Due to the limited number of replications used, the variation resulting from the three-factor-interaction was added to "Error". Only the two-factor-interactions were used.

3 Results and discussion

3.1 Dry matter (DM) chicon yield / 100g fresh root weight

As flows from the analysis of variance (Table 1), all three factors were involved in two significant interactions; SS x IM ($P = 0.0053$) and PS x IM ($P < 0.0028$). The SS x IM interaction, shown in Figure 1, indicates that there was no significant difference between the irrigation treatments when no sucrose was present in the nutrient solution. When sucrose was added to the nutrient solution

Table 1 ANOVA table for dry matter (DM) yield and marketable chicon yield

Source	DF	P (DM yield / 100 g roots)	P (Chicon Yield / 100 g roots)
Repetition	2	0.8734	0.8351
Sucrose solution = (SS)	1	0.2324	0.0001
Pre-forcing soak = (PS)	2	0.4188	0.8531
(SS) x (PS)	2	0.5613	0.9393
Irrigation method = (IM)	2	0.2385	0.2448
(SS) x (IM)	2	0.0053	0.1051
(PS) x (IM)	4	0.0028	0.0468
Error	38		
Total	53		
CV		31.19	27.96

the conventional way of irrigation produced a significantly higher DM yield than both the ebb-and-flood and aeroponic irrigation systems. A possible reason for this may be that nutrient absorbing lateral roots were continually in contact with the sucrose-rich nutrient solution when irrigated the conventional way. Roots may have had more time to absorb and use the sucrose for dry matter production while inherent interruptions in the cases of ebb-and-flood and aeroponic treatments might have prevented this. This would, however, not account for the significant difference in DM yield when aeroponic irrigation was applied in the presence or absence of sucrose. A possible explanation for the reduction in DM yield in the presence of sucrose with the aeroponic system could possibly be found by studying the formation and spread of spores and bacteria that cause infection. The sucrose-rich nutrient solution is an ideal breeding place for bacteria and with aeroponics a greater root surface area, and even the bases of chicons, were wetted and exposed to infection. This would, on the other hand, also partly be the case with ebb-and-flood irrigation. No significant difference was found with the addition of sucrose, using the ebb-and-flood system. In all cases 'Desogerme SP®' was part of the sucrose solution as a preventative measure against disease but may have lost its effectiveness when used in conjunction with the aeroponic irrigation system. In Chapter 6 no such decrease in effectiveness was shown but it must also betaken into account that the build-up of spores in a sucrose-rich environment may have been so immense that the chemical was unable to control it at the applied concentration. Further investigation on this topic is required.

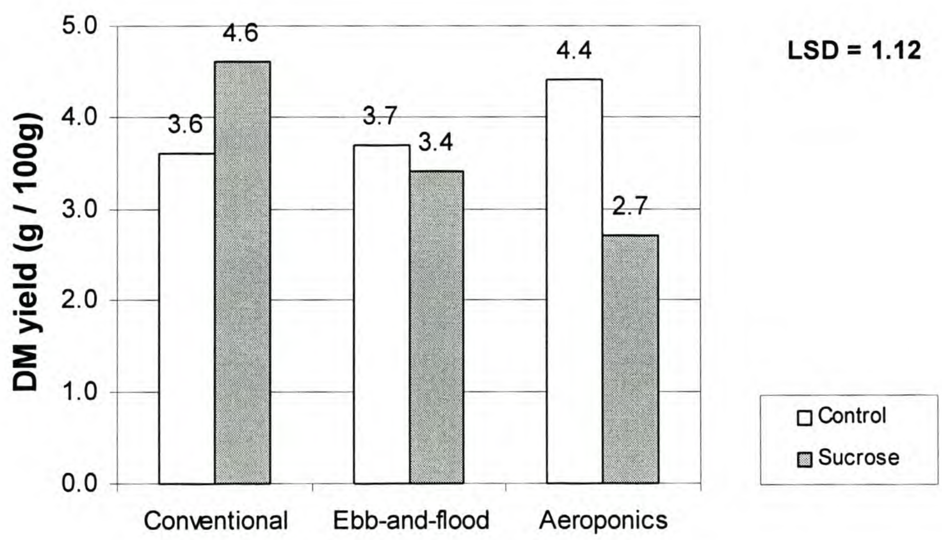

Figure 1 The interaction between a sucrose-rich nutrient solution and three irrigation methods on dry matter (DM) yield of chicons (g DM / 100 g fresh root weight) during forcing of witloof chicory roots.

From Figure 2 (PS x IM) it is evident that roots soaked in 'Desogerm SP®' and forced using the conventional method had a positive effect on DM yield when compared to the untreated control. However, 'Desogerme SP®'-root-soaking had no positive effect on DM yield when ebb-and-flood irrigation and aeroponic irrigation systems were used. In fact DM yield was significantly reduced where roots were pre-treated with 'Desogerme SP®' and irrigation was applied by way of aeroponics. It is possible that 'Desogerm SP®' was washed off by both, ebb-and-flood and aeroponic irrigation since the greater part of the root is wetted by the nutrient solution. Excessive exposure to fungal or bacterial infection may result in decay of lateral roots and a diminished nutrient absorption (Van Melckebeke, 1993). Figure 2 also shows that DM yield was not significantly improved by soaking roots in a 5% sucrose solution for 30 mins, especially where the aeroponic system was used. The time allowed for absorption may have been too short or, alternatively, the high carbohydrate content of the root relative to the sucrose solution could have impeded osmotic uptake.

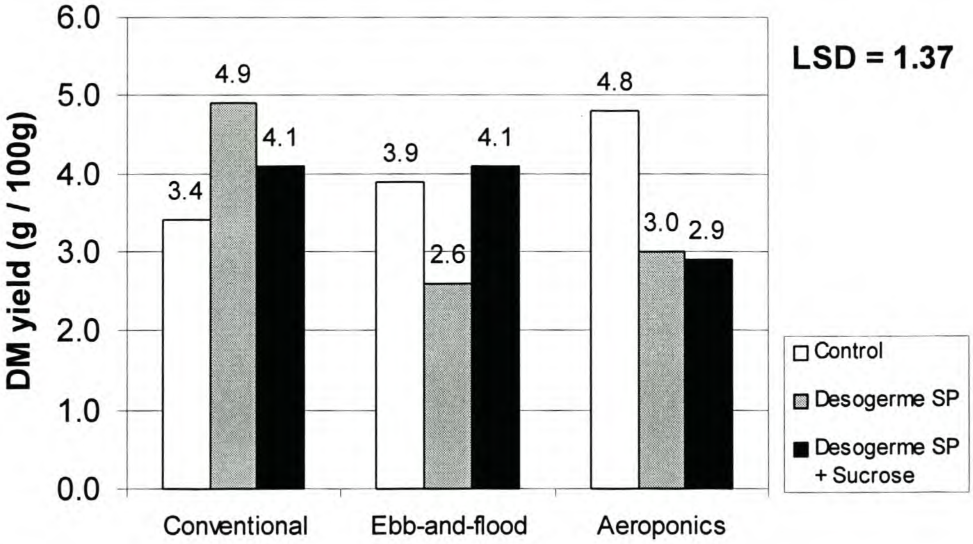

Figure 2 The interaction between three pre-forcing treatments and three irrigation methods on dry matter (DM) yield of chicons (g DM / 100 g fresh root weight) during forcing of witloof chicory roots.

Since DM describes a quality trait, these results compare well with those presented in previous work on irrigation techniques (Chapter 3). It was shown that there was no advantage to replace the conventional irrigation method with either ebb-and-flood or aeroponic irrigation in order to increase chicon quality, the same conclusion that can be made from this study.

3.2 Marketable chicon yield

Marketable yield is the more important parameter for the producer. The marketable chicon yield was significantly ($P = <0.0001$) reduced with sucrose present in the nutrient solution, compared to the control (Table 1). The treatment mean ($N = 27$) for yield, where roots were irrigated with the sucrose-rich nutrient solution, was 61.2 g / 100 g compared to 87.0 g / 100 g for the control. Apart from an increased risk of infections associated with addition of sucrose to the nutrient solution, an osmotic effect could also have restricted water uptake and lowered the fresh chicon yield.

From Table 1 it is apparent that the other factors (PS x IM) were involved in a significant interaction ($P < 0.05$). When compared to the control, there was no significant difference in chicon yield when roots were submerged in a 5% sucrose solution, irrespective of the irrigation method used (Figure 3). However, a pretreatment with 'Desogerme SP®' had a detrimental effect on chicon yield when forced using the ebb-and-flood technique. The reason for this can not be explained.

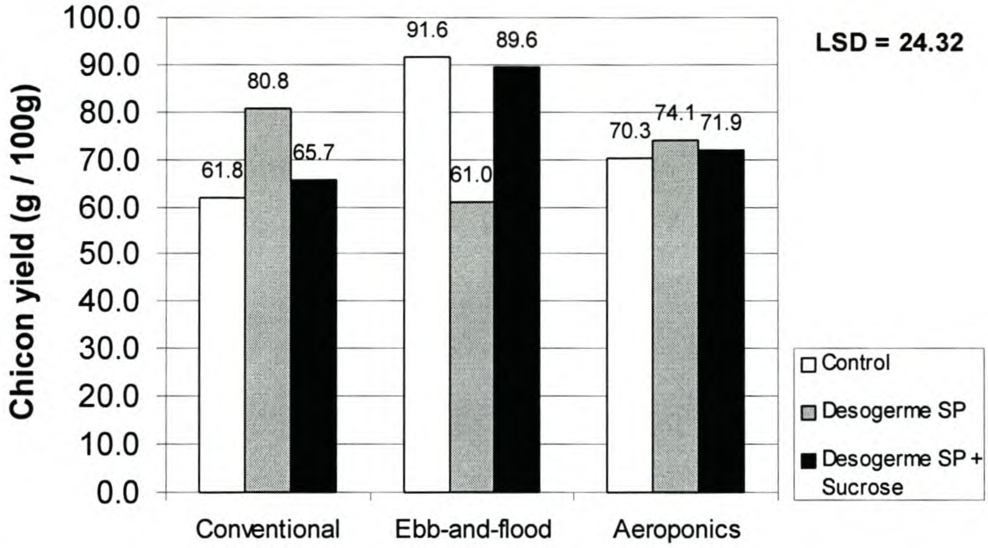

Figure 3 The interaction between three pre-forcing treatments and three irrigation methods on fresh chicon yield (g witloof / 100 g fresh root weight) during forcing of witloof chicory roots.

4 Conclusion

From this study it can be concluded that the presence of surcrose in the nutrient solution had a detrimental effect on chicon yield and it appears unlikely that sucrose was absorbed and converted into chicon dry matter. Friend *et al.* (1984), Ishioka *et al.* (1991) and Hadara (1966) reported sucrose absorption through the roots of young plants. The chicory roots used for forcing, however, are physiologically mature and probably lacking the absorptive qualities of young root tissue. This could be investigated in future studies by making use of moving isotopes. What did become clear was that the conventional method of irrigation was the most effective and could even be improved to some extent by treating roots with 'Desogerm SP®' prior to forcing by submerging them in a 5% solution for 30 mins. The prophylactic, disease-controlling character during forcing of the chicory roots should be investigated further as the results look promising and could even be of benefit to soil-less crop production in general.

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CHAPTER 6

Disease control with 'Desogerme SP®' during hydroponic witloof chicory production

Disease control with 'Desogerm SP®' during hydroponic witloof chicory production

Abstract

Sclerotinia sclerotiotum and *Phytophthora erythroseptica* have a detrimental effect on witloof chicory production in hydroculture. Bacterial rot often occurs in conjunction with these fungi and may cause slime formation in the nutrient solution resulting in decay of lateral roots. In the continuous search for alternative, environmentally friendly methods of disease control, 'Desogerme SP Vegetals®' (50.0 g L^{-1} N-Alkyl Dimethyl Benzyl Ammonium Chlorures + 20.0 g L^{-1} Poly Hydrochloryde) was identified as a possible solution to fungal and bacterial infections in hydroponics. A number of roots infected with *Sclerotinia* and *Phytophthora* were placed into the circulating nutrient solution together with the experimental units as a source of infection. An untreated control was compared with a 'Desogerme®' treatment where 10 ml L^{-1} was applied to the nutrient solution. At harvest, lateral root formation and marketable chicon yield were measured. Treatment of the solution had no significant effect on in lateral root formation. However, a significantly higher chicon yield (31%) was recorded for roots irrigated with the 'Desogerme SP®' treated nutrient solution. The increase in yield was promising and consideration for using 'Desogerme SP®' on a large scale in closed hydroponic systems should be further investigated.

Keywords: chicory, Desogerme SP®, *Phytophthora*, *Sclerotinia*, witloof

1 Introduction

Witloof chicory is a vegetable crop produced on a large scale in Belgium, the Netherlands and France. The production of witloof encompasses two distinct phases, growing of the taproot on the field followed by chicon growth (forcing) in hydroponic culture after vernalization. As is probably the case with most intensively cultivated crops, diseases have a detrimental effect on yield and quality. According to Van Harmont (1997) *Sclerotinia sclerotiorum* and *Phytophthora erythroseptica* are the fungi causing most damage during chicory production. Together with these and other fungi, bacteria such as *Pseudomonas* or *Erwinia* are often present as secondary plagues (Van Melckebeke, 1993). *Sclerotinia* and *Phytophthora* are both soil-borne diseases but no chemical substances are registered to control the former in the Netherlands during the field growth stage (Lamers, Plentinger & Gerlagh, 1999). This is as a result of prevailing strict environmental regulations (Miéville, 1999; Sarrazyn, *et al.*, 1995). While *Sclerotinia* is spread by contact only, the spores of *Phytophthora* have the potential of infecting the entire crop via the circulating nutrient solution. Furthermore *Phytophthora* may also develop once the chicory root is being forced (Van Harmont, 1997), making effective control thereof more complicated. Roots infected by fungi often cause a build-up of slime in the nutrient solution, which may result in decay of lateral roots (Van Melckebeke, 1993).

It is evident that chemical treatments can only be applied once the root is harvested, prior to cold storage for vernalization or during forcing. The aim should be to control these diseases in an environmentally friendly manner. Gerlagh (1997) and Plentinger & Lamers (2000) reported positive results for controlling *Sclerotinia* biologically. The authors were introduced to 'Desogerme SP Vegetals®' (Chapter 5), which is claimed to effectively control *Sclerotinia sclerotiorum, Phytophthora erythroseptica*, *Pseudomonas*, *Erwinia* and other diseases known to infect chicory. The active ingredients are 50.0 g L^{-1} N-Alkyl Dimethyl Benzyl Ammonium Chlorures and 20.0 g L^{-1} Poly Hydrochloryde. Furthermore the manufacturers claim that no residues are left. This in itself would make 'Desogerme SP®' an ideal environmentally friendly disease controlling agent in hydroponic systems since recycling of water has become a widely discussed issue over the past few years (Aaldering, 1997; Bruins, 1997; Tomassen, 1997a; Tomassen, 1997b). The goal of this study was to establish the effects of 'Desogerme SP®' on lateral root formation and marketable chicon yield.

2 Materials and methods

Chicory seed of the cultivar 'Focus' was sown in loamy soil in the traditional chicory producing area of South Africa, the Eastern Cape, on 13 June 2000. The roots were harvested by hand on 21 January 2001 and stored at 1°C for 12 weeks. Only roots with a diameter of 30 to 40 mm were used. Prior to forcing, the roots were trimmed to 180 mm in length and 24 experimental units, consisting of 10 roots each were prepared (total average weight of 10 roots was 1460 ± 50 g). All roots were irrigated conventionally with a continuously circulating nutrient solution (Deckers, 1991). Half of the experimental units were irrigated with a solution containing 10 ml L^{-1} 'Desogerme SP®' while the other half served as a control. In both cases five roots that were badly infected with *Sclerotinia* and *Phytophthora* during a previous forcing cycle were placed into the nutrient solution close to the inlet so that spores could easily spread throughout the system.

The chicons were grown for 20 days at water- and ambient temperatures set at 16°C and 14°C respectively. The pH was maintained at 6.8 while the EC was adjusted daily to a reading of 2 mS cm^{-1}. The relative humidity in the growth chamber was maintained at 91%. At harvest the lateral root index (LRI = [dry matter (DM) of lateral roots (g) / DM of taproot (g)] x 100) and the total marketable chicon yield was recorded as mass per 100 g fresh root weight. The data were statistically analyzed using SAS (1990) and Student's LSD (P = 0.05) was utilized to compare treatment means.

3 Results and discussion

According to Van Melckebeke (1993), roots infected by fungi often cause a build-up of slime in the nutrient solution, which may result in decay of lateral roots. However, no significant difference (P = 0.835, CV = 26.8) in lateral root formation was found in this study, irrespective of the presence or absence of 'Desogerme SP®' in the nutrient solution. Marketable chicon yield, on the other hand, benefited significantly (P = 0.021, CV = 26.5) when 'Desogerme SP®' was included in the nutrient solution. The treatment with 'Desogerme SP®' yielded 85.1 g witloof per 100 g fresh root weight while the roots forced in the absence of 'Desogerme SP®' yielded 65.0 g per 100 g roots forced. This amounted to a 31% increase in yield. Of interest was the fact that both nutrient solutions were milky from slime build-up at the time of harvest. The fact that there was no significant difference in LRI but a significant increase in chicon yield for roots treated with 'Desogerme SP®' may indicate that 'Desogerme SP®' lost its effect after some time allowing bacteria and spores to multiply. The manufacturers suggest that the nutrient solution should be treated with 'Desogerme SP®' once a week or even continuously. In this trial it was only applied once, at the beginning of the forcing period.

From these results 'Desogerme SP®' should be given serious consideration as a possible treatment against fungi such as *Sclerotinia, Phytophthora* and bacterial decay in hydroculture, while the effect thereof on organic produce requires further investigation.

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CHAPTER 7

Summary

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Witloof chicory is a new crop to South Africa and little work has been conducted on establishing this crop locally. Seeing that climatic and soil conditions are quite different in South Africa when compared to the traditional production areas of Europe, and considering that the cultivars used during the trials were specifically selected and bred for European conditions, it must be expected that the performance of such cultivars will invariably be different when grown locally. The logical first step would have been to undertake a comprehensive evaluation of European cultivars in order to establish which of them are the most suitable for South African conditions. Once these have been identified and the interactions between soil, nutrition and climate revealed, comparisons for yield and quality could be made with results gathered in Europe. The interests of the author were, however, focused on the second phase of witloof production, the forcing of mature roots in water culture. This meant that a large and very important part of witloof cultivation that could have serious implications on the results posted in this study, the production of high quality root material, was neglected and thus many factors not taken into account. It was assumed, for all practical purposes, that witloof chicory would grow equally well locally as in the traditional regions of Europe since chicory produced for the production of coffee is cultivated successfully and the species are the same.

The aim of the study was the evaluation of new production techniques during the second stage of witloof (chicon) production, also called 'forcing'. It was hypothesized that an increased lateral root formation along the axis of the *Cichorium* root could be increased by raising the nutrient solution level. Making use of a variety of irrigation techniques, this was indeed found to be the case (Chapter 2). It was further hypothesized that an increased lateral root formation would increase the yield of marketable witloof. In actual fact the opposite was true and it was speculated that o chicon development (Chapter 3). Sucrose was then added exogenously to the root before or during forcing to test whether the theory concerning the allocation of carbohydrates was

reasonable. No clear answer to this question was found but it was evident that sucrose had a negative effect on chicon quality, possibly as a result of fungal and/or bacterial infection, despite the fact that 'Desogerme SP®' was used to limit infection (Chapter 5). 'Desogerme SP®' was tested in greater detail and found to significantly improve marketable chicon yield when compared to the control (Chapter 6). The following conclusions were arrived at: 1) An increased lateral root formation was to the detriment of marketable chicon yield. 2) For commercial production purposes there seems to be no advantage in replacing the conventional method of irrigation with any of the others tested, even though the ebb-and-flood technique looked very promising in more aspects than one. 3) Sucrose supplied exogenously either reduced actual water and nutrient uptake as a result of its osmotic effect or sucrose formed a substrate for bacterial multiplication at levels that 'Desogerme SP®' was unable to cope with. 4) Adding 'Desogerme SP®' to the nutrient solution or treating the root prior to forcing as a prevention against fungal and/or bacterial disease proved beneficial.

Besides the fact that aeroponics did not result in convincing improvements for total leaf yield (Chapter 3) the author was fascinated by the possibilities of new production methods and reducing the risk of spreading disease, when making use of aeroponics. For this reason chapter 4 was included and the idea would have been investigated further if the differences in yield would not have been so extreme and to the detriment of commercial production.

A breakthrough was made with the development of the quality index (QI). The ongoing limitation of statistically analyzing quality data of chicons sorted according to quality-classes was overcome by making use of this tool. Despite the fact that the index was developed specifically for use on witloof, it is has the potential of being applied to quality data of a wide variety of crops.