Witloof chicory (*Cichorium intybus* L. var. *foliosum*) as a vegetable crop in South Africa.

By

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Declaration

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

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_24/11/1999_

Date

Abstract

Witloof chicory (*Cichorium intybus* L. var. *foliosum*) is a new vegetable crop to South Africa. It is a typical Belgian product and English literature on production of this crop is scarce. The first aim of this study is to compile a summary of relevant literature in the form of a manual for quick reference and practical use concerning chicon cultivation in hydroculture.

Endogenous gibberellic acid (GA) is known to play a pivotal role in the vernalization process of plants requiring a cold induction for flowering. The second goal of this study is to clarify the effect that an exogenous GA application has on the vernalization process of chicory roots grown for witloof production. Five cultivars of witloof chicory (*Cichorium intybus* L.) were treated by applying GA as a leaf and a root treatment, each at a high and a low concentration. After forcing the treated roots, the chicons were evaluated according to international quality standardization. Chicon quality was then used as an arbitrary indicator for completed root-vernalization. Irrespective of concentration, the GA leaf treatment showed no significant difference in chicon quality when compared to no treatment. A GA root treatment, on the other hand, had a strong retarding effect on chicon quality, again irrespective of the hormone concentration applied.

In a follow-up trial to which a cold treatment was added, no significant difference in chicon quality was found between GA treatments and a cold induction treatment. The control plants, however, produced significantly more high quality chicons when compared to those plants that received GA treatments. It was concluded that GA had no positive effect on advancing root-vernalization.

Further investigation then showed that root-vernalization may already occur during the vegetative growth period on the field as a result of high irradiance and high temperatures. In this case exogenous GA application would have no further effect.

Uittreksel

Witloof sigorei (*Cichorium intybus* L. var. *foliosum*) is 'n nuwe groentesoort in Suid-Afrika. Dit is 'n tipiese Belgiese produk. Engelse literatuur in verband met die produksie hiervan is skaars. Die eerste doelwit van hierdie studie is om 'n samevatting van relevante literatuur saam te stel wat kan dien as 'n handleiding vir die produksie van witloof in 'n waterkultuurstelsel.

Dit is bekend dat endogene gibberelliensuur (GA) 'n beduidende rol speel in die vernalisasie van plante wat 'n koue periode benodig vir blominduksie. Die tweede doelwit van die studie was om die uitwerking van 'n GA toediening op die vernalisasie van sigorei wortels, wat geteel is vir witloof produksie, na te vors. Vyf kultivars van witloof sigorei (*Cichorium intybus* L.) is behandel deur GA toe te dien as 'n blaar- en wortelbehandeling, elk by 'n hoë en 'n laë konsentrasie. Nadat die behandelde wortels geforseer is, is die witloof koppe volgens internasionale kwaliteitstandaarde geëvalueer. Kopkwaliteit is daarna as 'n arbitrêre indikator vir voltooide wortelvernalisasie gebruik. Die GA blaartoediening het by geeneen van die getoetse konsentrasies enige verskil in kopkwaliteit veroorsaak nie. 'n GA wortelbehandeling het egter die kopkwaliteit betekenisvol verlaag, weereens onafhanklik van die hormoon konsentrasie wat toegedien is.

In 'n daaropvolgende eksperiment waar 'n koue behandeling bygevoeg is, is geen beduidende verskil gevind in kopkwaliteit as GA toedienings vergelyk word met 'n koue behandeling nie. Die kontrole plante het egter betekenisvol meer hoë kwaliteit koppe gevorm in vergelyking met dié plante wat 'n GA behandeling ontvang het. Die gevolgtrekking is gemaak dat GA geen positiewe uitwerking gehad het op die bevordering van wortel vernalisasie nie.

'n Verdere ondersoek het getoon dat wortel vernalisasie al gedurende die vegetatiewe groeiperiode op die veld kan plaasvind as gevolg van hoë sonligintensiteit en hoë temperatuur. In sodanige gevalle sou 'n GA toediening geen verdere voordeel inhou nie.

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CHAPTER 1

Witloof chicory (*Cichorium intybus* L. var. *foliosum*) cultivation:

A summary of relevant European literature

Witloof chicory (*Cichorium intybus* L. var. *foliosum*) cultivation: A summary of relevant European literature

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The following literature was used as a basis for this paper and will not be cited each time that it is used. Additional literature is given for further reading at the end of the relevant paragraphs.

Bogaerts, J., Sarrazyn, R., Deckers, S. & Geypens, M., 1993.

De Proft, M., Van den Akker, G., Claessens, G. & Van Laere, A., 1993.

Goffings, G., Herregods, M. & Lips, J., 1993.

Sarrazyn, R., 1990.

Sarrazyn, R., 1991.

Van den Acker, W., Demeulemeester, M. & De Proft, M, 1993.

Van Nerum, K. & Pieron, S., 1993.

Vandendriesche, H. & Geypens, M., 1993.

1 INTRODUCTION

Chicory (*Cichorium intybus* L. var. foliosum), also known as Witloof (white leaf), is a vegetable related to the endive. It grows from an existing, fully grown chicory root and thrives in the dark. In 1873, a Belgian farmer stored some of these roots in his cellar and forgot about them. Then, after a few weeks, he discovered that white leaves sprouted from the top of these roots - white because of the absence of light. Some 23 years after this chance-discovery, chicory made its first appearance as a vegetable at an exhibition. However, it was not until 1930 that the product really caught on and gained in popularity.

Wild chicory is considerably older. It 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 was also used - sometimes for medicinal purposes and sometimes as a potion. In this way chicory coffee first appeared around the year 1775. This was prepared by roasting the roots and grinding them up, much the same way it is still done today. See additional literature for other interesting uses.

Additional Literature:

Fuchs, A., 1991.

Spiegel, J.E., Rose, R., Karabell, P., Frankos, V.H. & Schmitt, F.D., 1994.

In nature chicory completes its growth cycle in two stages: During the first year, the root is formed, followed in the second year by the appearance of the "above-ground" reproductive part. At the end of the first year the root is ready to be used for chicon / witloof cultivation also known as "forcing", where the head is produced. The roots are harvested, the individual green leaves removed and the roots stored in a cool place for vernalization. When the roots are transferred to a warm, dark environment, it is not long before the first new leaves begin to grow. These new, white leaves then form the characteristic tapered white head, the chicon. Twenty-five days later the final product is ready to be harvested.

From the above paragraph, it becomes quite clear that the cultivation of chicory is not all too complex. An understanding of the fundamental principles concerning plant morphology, physiology and production techniques, nevertheless, is essential for a successful harvest - therefore, these will be the topics dealt with on the following pages.

2 MORPHOLOGY AND PHYSIOLOGY

2.1 THE PLACE OF CHICORY IN THE BIOLOGICAL SYSTEM

Once the morphology and growth cycle of chicory becomes familiar ground, the foundation for satisfactory chicory cultivation has been laid. Interpreting the place that chicory holds in the biological system reveals a vast amount of information concerning the plant and will therefore be used as a platform to start from:

Chicory

Division		SPERMATOPHYTES or seed producing plants
	Subdivision:	angiospermae i.e. covered seeds
	Class:	magnolopsida / dicotyledonae
	Sub-class:	asteridae / sympetalae
	Family:	asteraceae or flowering plants (composites)
	Sub-family:	lactucoideae (all ligulate herbs with a milky latex)

Genus		*Cichorium*
	Specie:	*Cichorium intybus* L.
	Variety:	*foliosum* : witloof-chicory
		sativum : chicory for coffee production

2.2 THE NATURAL GROWTH CYCLE

The cultivation of chicory (*Cichorium intybus* L. var. foliosum) takes place in two stages:

1) Seed is sown in order to grow "forcible" quality roots which are then harvested. Here three phases can be differentiated:

➢ The first phase is characterized by predominant leaf growth.

➢ During the second phase, the rate of leaf- and root growth are equal, and

➢ root growth is predominant with the rate of leaf growth decreasing
   and even becoming negative during the third phase.

2) These roots then are "replanted" in a dark hydroculture growth chamber,
   where they are "forced" to form the chicory head.

To know exactly when to do this, it is not only important to understand the natural growth cycle of the plant, but also well as the reasoning and physiology behind chicory cultivation.

Chicory is a biennial plant. During the first year, the vegetative growth phase, a strong, deep-growing taproot is formed. Once a certain leaf mass is established, the assimilatory tissue (leaf) development gradually slows down while the rate at which carbon reserves are accumulated and stored in the form of inulin increases - the root thus takes on the role of a storage organ. This process is known as natural ripening. A root is, however, only considered ripe (forcible) once it is able to produce a well-formed Chicory head (see 2.4).

The leaf mass increases rapidly until approximately 45 days after sowing and reaches maximum development after three to four months. When the plant is about four months old, the leaf mass decreases, mainly because of the oldest leaves dying. Furthermore, the number of leaves reaches a maximum 90 days after sowing. From then on, the number of leaves remains constant, but the weight per leaf decreases after the fourth month, again as a result of the oldest leaves dying. It follows that the plant has grown sufficient leaf tissue during the first three months to produce an excess of photosynthates. Now any excess carbohydrates are channeled to the root, where they accumulate. The taproot begins to develop into a storage organ about two months after sowing and reaches its maximum diameter after four months. The amount of inulin has, at this point, also reached a constant level.
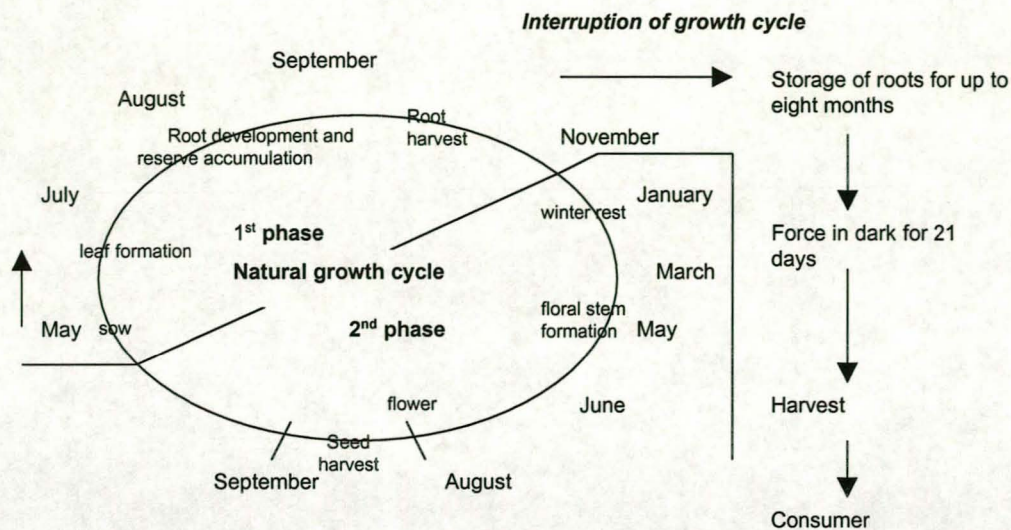
Figure 1: The natural growth cycle of *Cichorium intybus* L. in the <u>northern hemisphere</u>

During the second year of the natural growth cycle, the generative growth phase commences. This is usually the case once the plant has undergone a cold period during the winter - vernalization. Through the process of hydrolysis, the accumulated complex sugars (inulins) are changed into simple sugars (predominantly fructose). These, in turn, are transported to the growth point or apex (situated at the top of the root) in order to be used for the production of one or more flower bearing stems. Blue (sometimes white) flowers develop on branches forming from the stems. Chicory is a long-day plant, i.e. the plants flower at a day-length of 13 hours or more. One week after fertilization (pollen is available before the style is ready, ensuring cross-pollination), the seeds start to ripen and are scattered during the following month. Should the plant experience cold or water stress during the vegetative stage, however, the result may be the completion of both growth phases within the first growth year. This renders the roots useless for chicory production, as the growth point can only be used either for flower production or for chicon cultivation - not both.

<u>*Additional Literature:*</u>

Huygens, H. & Lips, J., 1985.

2.3   THE CULTIVATION (FORCING) OF CHICORY

For the production of chicory, the natural growth cycle has to be broken at the end of the first year. After vernalization (in most cases this is done in the absence of light in a cold-room), the root is placed in a dark growth chamber at conditions that will be discussed in greater detail later on. Under the influence of still little understood physio-ecological factors, the root begins to produce the beginning of a floral stem (later referred to as the core), which is surrounded by a closed system of white leaves - the chicory head or chicon. It is crucial to realize that the plant must be in a transition period, between the vegetative and generative growth phases, as this is when the carbohydrate reserves, required for the formation of the head, are easily accessible. The root is now considered ripe, or ready for forcing.

Additional Literature:

Gianquinto, G., 1997.

Gianquinto, G. & Pimpini, F., 1995.

2.4   THE CONCEPT OF RIPENESS

The question that arises at this point is: How does one know whether a root is suitable to be forced (ripe for forcing)? When using the term "forcing", what is in actual fact implied is, 'bringing a plant that is in biological rest into a situation where it will start growing at any point in time of a year where it would not do so in a natural situation'. In the case of forcing chicory, a rise in temperature usually triggers growth. It is, however, not difficult to imagine that not every root necessarily will be suitable for forcing - certain prerequisites have to be met. These will be discussed in the following few paragraphs.

2.4.1 SOURCES OF ENERGY

The role of the apical growth point on the root is to grow out in the dark and produce a chicon. In order for this to happen, the apex has to be intact and not damaged during harvest or infected by fungi or bacteria during storage. The vitality of the apex needs to be maintained between harvesting of the roots and forcing. In addition, in order for the growth point of a chicory root to grow, a variety of interactive processes have to take place. Leaves have to grow all around the apex - this happens by means of cell stretching and cell division. The energy required for this originates from the reserves accumulated in the root.

Sugars and proteins (amino acids) are the main sources of energy available to the root. Sugars take on the role of energy source and substrate for the formation of the basic building blocks needed for the production of a variety of cell compartments. Proteins, to a large extent, represent a source of organic nitrogen.

The sugars present are predominantly in the form of inulin, a fructan consisting of 35 to 40 units and a single glucose molecule on one end (it is soluble in warm water, non-reducing and hydrolyses in acidic substances). Inulins are found to be stored in the vacuoles (enclosed by a membrane) of the root cells. Seeing that this is the source of energy that becomes available, the inulins have to be split into simple sugars that are able to move out of the vacuole, through the cytoplasm and into the transport tissue of the root. Resulting from the break down of inulin by the enzyme inulinase, fructose is formed. Fructose, however, is not easily transported in chicory, and it is for this reason that it is transformed into sucrose (preferably in the cytoplasm) after which it can move from the root cells into the transport tissue. The ability of the root to complete these steps is an indicator as to how much energy, as well as basic building blocks for cell growth, will be available to the growth point.

Additional Literature:
Ernst, M., Chatterton, N.J. & Harrison, P.A., 1995.
Van den Ende, W. & Van Laere, A., 1995.

Van den Ende, W., Mintiens, A., Speleers, H., Onuoha, A.A. & Van Laere, A., 1995.

2.4.2 INDICATORS OF RIPENESS

Ripeness is directly correlated to the length of the growing period. As a rule of thumb 22 to 24 weeks of root growth produces a ripe root. Identifying one or two parameters that will enable the prediction of forcing results would be utopic. The factors that influence ripeness are endless and include soil conditions, emergence, climatic conditions throughout the field production period, daylength, frost, etc. However, there are a couple of indicators that may serve as indicators of ripeness.

% DM The dry matter content has to reach a level of at least 20%, before the roots are to be harvested. However, this value can easily be realized much sooner than the accepted average 160 day growth period, as early 80 to 90 days after sowing. At this point in time, however, the roots are certainly not ready to be forced. The conditions under which the sample for DM determination is taken, e.g. before or after a rain period, may also affect the DM content. When roots are able to realize a maximum water uptake, the % DM will be low, while the absence of maximum hydration will lead to a higher % DM. As can be seen % DM is not an ideal indicator.

Plant characteristics Characteristics of plants on the field may give an indication as to ripeness. Here are many possibilities, but it has to be taken into account that the genetic potential of the plant, as well as growth conditions, may have a significant impact. The number of leaves, length of the longest leaf and the ratio of root:leaf weight are some of the more reliable characteristics. A rather simple yet effective visual characteristic is to look at the vertical cross-section of the root (see also Figure 2).

➢ unripe   flat shoulders and no distinctive neck

➢ start of ripening   shoulders start moving up, a neck starts to develop and the inner hole begins to show

➢ ripe   clear neck and inner hole
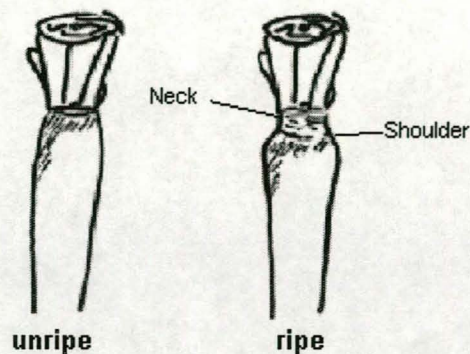
Figure 2: Visible outward indications of ripeness

Sugar metabolism   The French claim that a breakdown and analysis of the sugar metabolism gives a fairly reliable indication of forcibility. An increase of the fructose and sucrose content in a root are the first signs of conversion to ripeness. With ripeness the fructose concentration increases, as a result of the inulin breakdown, and will be equal to the glucose concentration at some point. This point of intersection was proposed as criteria for ripeness, i.e. also an indication for harvest timing. A cold treatment after harvest results in a dramatic increase in fructose and later in sucrose. Experience shows that a reading between 30 and 60 µmol/g fresh weight for fructose and from 30 to 100 µmol/g in the case of sucrose is sufficient for successful forcing.

Additional Literature:

De Proft, M., 1992.

"French method"   Furthermore it is possible to make use of the following tabulated advice given by French researchers (Table 1). France is a leader in chicory production and this standard has been used for predicting the time of harvest with much success.

Table 1: Advice to determine the optimum date for the harvest of roots taking percentage dry matter and root diameter as determining parameters

% roots on field with diameter 1.5 - 3 cm	average dry matter (DM) **per root** in gram	%DM < 22	% DM 22 - 25	% DM > 25
> 30%	< 30	**do not harvest**		
> 30%	30 -35	**do not harvest**	**harvest** (low chicon yield must be expected)	**harvest** (acceptable chicon yield is predicted)
> 30%	>35	**harvest** (results in average to good quality chicons)	**harvest** (results in average chicon yield with a high quality)	**harvest** (ideal for high chicon yield and quality)
< 30%	**do not harvest**			

With unripe roots almost no pith develops and the chicon leaves grow rapidly producing loose heads. In the case of over ripe roots, on the other hand, strong pith growth prevails, while the leaf growth is very uneven. This often results in open heads. In both cases the quality is compromised.

3 PRODUCTION TECHNIQUES

As already mentioned, the production of chicory takes place in two stages. The seed that is sown grows into a root, which is, in turn, harvested when it is in a transition stage between vegetative and generative growth. Then these roots are placed in cold storage (vernalization). After this they are placed into a dark growth chamber, where all the necessary nutrients are supplied by means of a hydroponic system. Under these controlled conditions the chicory head grows and is ready for harvest after about 23 days.

3.1 GROWING OF ROOTS

Additional Literature:

De Temmerman, L., Van Himme, M. & Van Melckebeke, J., 1993.

Croon, F., 1993 (a).

Croon, F., 1993 (b).

Croon, F. & Elsen, F., 1993.

It is not the aim of this paper to go into detailed explanations of how to grow root material (see additional literature above for more detail). N-fertilization, however is one crucial controllable aspect during root cultivation that will most certainly have a profound effect on the cultivation of chicons. Since the resulting effects cannot be reversed after harvest, they will have to be dealt with before that time. Care must therefore be taken of the basic principles of N-fertilization during root production.

It is generally accepted that chicory prefers relatively poor soils and that it has a low N and K requirement. It is also known that chicory is able to take up nitrogen, and to a lesser extent, also K and other nutrients (should they be at the disposal of the plant) to levels far above its normal requirement. Over-fertilization promotes accumulation of Ca, Mg, Na, K, P and N in the root while only Mg, Na, K, P and N accumulate in the leaf - the risk of a relative Ca-shortage in the leaf is obvious. This is true for

European conditions but to a lesser extent in South African climate as a higher transpiration rate facilitates Ca-movement to the leaf. Accumulation of nutrients to these high levels not only results in a decreased resistance of the plant against rot initiating parasites, that may even spill over into physiological rotting, but has an equally undesirable effect on root yield, ripening of the root and root storage. Furthermore, the emerging chicon tends to be much more sensitive towards sicknesses during forcing and it was observed that a high N-fertilization retards chicon formation and storage of the final product is limited to only a few days.

N-fertilization forms an important problem in chicory cultivation. As more N comes available to the plant, the leaf development increases, which is advantageous for a good root development (high photosynthetic activity and formation of a carbohydrate reserve pool). A too high N-level will influence the leaf weight and length negatively, however, with the root weight displaying a sigmoidal curve. A high level of N in the soil is detrimental to plant development resulting in an uneven growth pattern, plants with many leaves and small roots. NO_3 -fertilization promotes strong leaf growth to a larger degree than root development.

N encourages growth and root production, but can, at high levels, also have negative effects - it is for this reason that the precise amount of N has to be added during fertilization. This means that account has to be taken of the N-status of the soil, i.e. the N already in the soil as well as the N that will still be mineralized during the growth period.

Additional Literature:

Aaldering, T., 1997(b).

De Proft, M., Claessens, G., Schrevens, E. & Van Laere, A., 1991.

Keppens, W., 1994.

Reerink, J., 1992.

Santamaria, P., Elia, A., Gonnella, M. & Serio, F., 1997.

Vandendriesche, H. 1993.

3.2 HARVEST OF ROOTS

Additional Literature:

Lips, J., 1993.

The whole process of growing root material has not been discussed in this paper as it could be considered a "science" in its own right. However, growing of healthy quality roots is the basis for successful chicory cultivation and needs to be done with great care - after all, it can hardly be expected to grow high quality chicory from low quality roots.

Even though the harvest of roots only takes a relatively short time, a lot of the energy spent on growing root material can be lost during this process, as a result of negligence or ignorance.

Time of harvest	First of all, the time of harvest is of critical importance - the roots have to be ripe (see again 2.4.2). When unripe roots are forced, they tend to resume vegetative growth, resulting in loose chicons with a poor quality and yield. Over-ripe roots, on the other hand, display a reduced vigor in growth and tend to form more rosettes and a longer pith. As mentioned before, 22 to 24 weeks is an acceptable growth period.
Adhering soil	With mechanical harvesting there is always the danger of a soil layer remaining adhered to the root. Too much soil covering will have a negative effect on the cooling of the root in cold storage with the possibility of excessive heat production (up to 30°C) resulting from the intense heat producing metabolism of the roots. In this manner large amounts of stored roots can be lost as a result of fungi and bacterial infections. However, a

thin layer of soil will actually be of advantage as it protects the root against physical damage and rapid moisture loss.

The "leaf collar"

While harvesting, the leaves are removed about 3 cm above the root shoulder, leaving a "leaf collar". A longer collar will increase the risk of disease, both during cold storage and forcing. Cutting the leaves off too short may damage or completely remove the growth point, resulting in a "blind" root. The growth point of apical meritems of roots with a large diameter are located higher up (i.e. are more easily removed or damaged by cutting the leaves off too short) than the thinner roots.

Root length

The final root length is usually determined during harvesting as the roots are cut below the surface in the case of mechanical harvesting or hand cut immediately after hand-harvesting, in order to reduce the bulk to be handled later on. The minimum root length is 15cm, with the optimum being in the region of 18cm. In the case of hydroponics the length of the root does not seem to have a major effect on forcing results. Should the root tips be damaged or infected with fungi etc., there is still the possibility of removing these parts and having usable roots (with acceptable length). In order to ease handling of the roots easier, a homogeneous length is a prerequisite.

Root diameter

Maintaining a constant root diameter is another factor that can already be determined at harvest. The optimum root diameter is between 3 and 5cm. Roots smaller than this value produce too small chicory heads while roots larger than 5cm produce a relatively lower yield when comparing chicon mass to root mass. Roots that do not fit within these boundaries should be

sorted out before the roots are placed into cold storage, as they constitute extra bulk. Machines for this are available.

Additional Literature:
Huygens, D., 1997(b).

Moisture loss and "sunburn"	Lastly, but most certainly of utmost importance is the fact that roots left in the sun after harvesting suffer from moisture loss and "sunburn". Both have a profound negative impact on forcing results. For loss of moisture see 3.3.1. Sunburn damages the outer layer of cells on a root from which side roots need to develop, in order to take up nutrients from the hydroculture. If these side roots do not develop, the head will be smaller than the others, resulting in a reduced yield that could easily have been prevented.

3.3 STORAGE OF ROOTS

Cold storage of the roots is of major importance, especially in European conditions. As a result of the short growing season and the fact that the roots need to be harvested before the cold winter sets in, there are vast amounts of roots being harvested at the same time. They will only be used gradually over the following months. Cold storage of roots is not always for storage per se. As was mentioned before, a cold period (vernalization) is a prerequisite for chicon cultivation.

3.3.1 PROBLEMS DURING STORAGE

The fundamental problems when storing chicory roots lies in the possible loss of quality of the chicory heads after forcing the root. What has to be realized is the fact

that the root, even if it is no longer in the soil and the leaves are removed, is still a living entity that is respiring. As is the case with every living organism, the chicory root does not increase in quality indefinitely; after harvest it starts to deteriorate. It is also important that, once the root is harvested, it is no longer in its natural environment. It is out of the soil, no longer has nutrients to take up and has no leaves to produce additional carbohydrates. A loss of quality, to a certain degree, is thus unavoidable.

The main reasons for a loss in quality during storage can be traced back to the following three main factors.

> ➢ Drying out, or moisture loss, of the root during storage, which leads to a reduced yield (kg chicon per kg roots) and a decrease in quality.
> *Additional Literature:*
> Embrechts, A.J.M., 1989.
> Huygens, D., 1997(a).
> Van Kruistum, G., 1997.
> ➢ Infection by fungi, which can to a point, be limited by treating the roots with a fungicide before they are placed into the cold cell (see 3.6.1).
> ➢ The premature emergence of the growth point, mainly due to a too high temperature.

In order to gain further insight into these problem areas experienced during storage, it is advisable to take note of a few specific character traits of chicory roots.

Respiration warmth   The most prominent trait is the high respiration warmth of the root ($\pm$ 80-100W/ton at 0°C). This explains why roots that are not properly cooled (either as a result of an excessive adhering soil layer around the root (see 3.2) or due to an insufficient cooling system) tend to ferment easily. For proper storage it is

thus useful to know that the specific heat of roots is about 3.5 kJ/kg(fresh weight).K at a temperature of 0°C and higher. This increased heat may also cause surrounding roots to form chicons prematurely, rendering them unsuitable for future forcing.

Freezing point   The freezing point (where the first ice crystals start forming in the root tissue) is at 2.5°C below zero. Once this occurs, root cells can be damaged, resulting in a reduced yield, or no yield at all. Following from cell breakage is that the root becomes very susceptible to fungal and bacterial infection.

Water content   The water content of the root is approximately 75%.

Root density   The chicory root has a density of about 860 kg/m^3 but once roots are filled into crates the filling density will be only 450 kg/m^3. This information has to be taken into account when calculating whether the cooling capacity of a cold room is sufficient or not. (As a rule of thumb, there will be ±250kg of roots per 1 m^3 of cooling capacity, taking into account the spaces between the pallets allowing for air circulation.)

3.3.2 STORAGE CONDITIONS

Temperature   When discussing storage conditions there are three main aspects that come to mind. Only two of these are of real importance, however. The most obvious is temperature. Since a root generates heat, it is of great advantage if the roots can be placed in cold storage as soon as possible. In this way it is easier to cool the root (all the way to the center) down to the required temperature. The pattern in which the pallets are

placed in the storage cell, and therefore the way the air circulates between the pallets, will largely determine the effectiveness of the storage cell. When choosing the storage temperature, the length of time that the roots are to be stored must be taken into account:

➢ for a short storage time of a few weeks   4-2 °C

➢ for up to four months   0.5 °C

➢ for longer   - 1 °C.

One aspect has to be stressed - these temperatures are those measured within the root, not the air temperature in the storage cell. The latter is always a little higher.

Roots that were stored at -1°C for a long period should be defrosted at 3°C for 3 to 6 days prior to forcing.

Cultivars

To understand how storage time is decided upon, a little more background is required. Europe has a rather short growing season and, in order to utilize as much of it as possible, there are a variety of cultivars to cater for this situation.

➢ **Early** types are sown early in the season when it is still relatively cold. They can thus be harvested sooner and only need a short cold period before forcing.

➢ The **medium** types are planted in "exact" accordance with the season. After harvest a cold period of at least 14 days is required before forcing but they can be stored a few months longer.

➢ **Late** types can be sown later in the season but are also able to grow longer, even if the temperature and day-length have already decreased. Cold storage of about two months is advisable before forcing and this root material can easily be

stored until the beginning of the new season, i.e. <u>longer</u> than 4 months.

Additional Literature:

Biesheuvel, A.R., 1992.

Huygens, H. & Lips, J., 1985.

Sarrazyn, R., Vanderschelden, A. & Coysman, A., 1993.

Sukkel, W., 1997.

Post-harvest ripening   Another reason for cold storage is to create an opportunity for the unripe harvested roots still to mature. During this time the complex sugars in the root will start to be converted into simple sugars which are needed during chicon formation during forcing. The sooner this conversion process is started, the earlier chicon outgrowth can be expected. This can be achieved at a temperature of 3-4°C, for at least four days.

Relative humidity   The relative humidity (RH) of the cold cell air has to be kept as high as possible in order to minimize the loss of moisture from the roots to the environment (±95% should be the aim). A few technical aspects that are worth taking note of:

➢ Spraying water over the roots, introducing water under pressure (fog) or wetting the floor of the storage cell are all methods that help reducing moisture loss to a limited extent.

➢ It was mentioned already that a adhering soil layer forms a shield around the root reducing the loss of moisture from the root. A balance has to be maintained since a soil mantle also facilitates heat generating processes (fermentation).

➢ Fill the storage cell to capacity if possible - where cold cells are only partly filled, moisture loss from the roots increases significantly.

➢ Wrapping the pallets with plastic can also reduce moisture loss.

Additional Literature:

Brakeboer, T., 1998.

Claessens, G., 1994.

Air composition
Despite the fact that the air composition within the storage cell would appear to play an important role, this is not the case. The CO_2 and O_2 levels only have a very limited effect on the roots.

3.4 PREPARING ROOTS FOR FORCING

Once the roots are taken out of cold storage there are a few factors that need to be taken into consideration:

➢ During storage the root tips may have been damaged - these tips have to be cut off. In many cases all roots are cut in order to achieve a homogeneous size, which makes handling much easier. If this cannot be done, place the larger roots in the center of the tray and the smaller ones around them.

➢ Long leaf collars may have started to rot. These have to be removed in order to curb infection of bacterial rot to the chicons.

➢ Roots infected with fungi (see 3.6.1) have to be removed so that the spread thereof does not destroy the contents of a

whole tray of chicory during forcing. The warm, humid conditions in the growth chamber are also a perfect breeding ground for fungi and bacteria.

3.5 HYDROCULTURE- AND GROWTH CHAMBER SET-UP

Detailed plans and descriptions of a complete chicory cultivation set-up will not be discussed in this paper, but are available from the author.

Additional Literature:

Sarrazyn, R. & Croon, F., 1993.

History	In order to fully understand the principles behind the growth chamber, it may be helpful to take a brief look at the evolution thereof. In the beginning stages a furrow was dug in the ground, in which the roots were placed and then covered with soil as the medium for the roots to grow in. Production was, however, only possible during the summer, as the temperatures would not allow growth during winter. Later, horse manure was used as a sort of heat producing medium, to allow for a longer producing period. Underground heating with hot water, and later electricity, followed. It was not long before this whole set-up was placed under a mobile barn, in order to reduce the direct impact of the natural climatic conditions. Growing Chicory in soil yields a high quality product, but this production technique is very labour intensive and requires a lot of space.

Following this, was a fixed (permanent) barn, where the roots were still placed in the ground, but were no longer covered with soil. The furrows were now lined, to make them water proof, with the result that all added water and nutrients were available to the root and could not be lost. The climate in these barns was controlled (which is not easy to do) and remained closed permanently, in order to protect the now free-standing roots from light. Labour became less at the expense, however, of increasing costs for fixed assets.

evaluation
From this already controlled environment the idea of not using any growth medium at all and totally controlling the plant nutrition, temperature and relative humidity emerged. This is possible when making use of a hydroculture system in a controlled (smaller) room - the forcing or growth chamber. The most important advantage of this method is the improvement of labour conditions and the large saving in labour and energy costs. Furthermore, the chicons are clean in the absence of soil which also results in less waste (leaves that have to be removed because of soil stains, etc.). The major disadvantages are the high investments that need to be made and a slight decrease in quality when compared to the classical cultivation techniques.

Production cycle
In order to have an on going production, it is of critical importance to have not only all the facilities, but an established operation is also needed. All the facilities and machines will not be discussed in this paper as that is a topic of its own.

➢ Since the growing season in Europe is so short, use is made of different cultivars (see 3.3.2). These have to be stored at

different temperatures and it is advisable to have at least two separate cooling rooms.

➢ Forcing usually takes approximately three weeks. If there are four growth chambers available, one chamber can be harvested and filled again each week. This will allow continuous production.

➢ Cultivating chicory is a full-time undertaking, throughout the year. It is worth examining the possibility of having a third party grow the roots and then to buy them (preferably on a Rand per <u>usable</u> root basis).

Hydroculture

circulating nutrient solution

With hydroculture, water is the medium that transports nutrients to the roots. There are many different methods of doing this, but only the most common one will briefly be discussed here. The basis is that there are trays tacked one above the other with the nutrient solution being circulated continuously. The solution is pumped from a basin (where aeration takes place) into the top tray. From here it cascades under gravity into the next tray, ensuring that all roots are subject to fresh nutrients. Figure 3 gives a simple overview of this method. The outlet of each tray has to be placed in such a way that there will always be a residue (about 3cm) left at the bottom of the tray; as a safety measure, should the pump stop. The roots must not dry out at any stage as this risks damage to the fine root hairs.
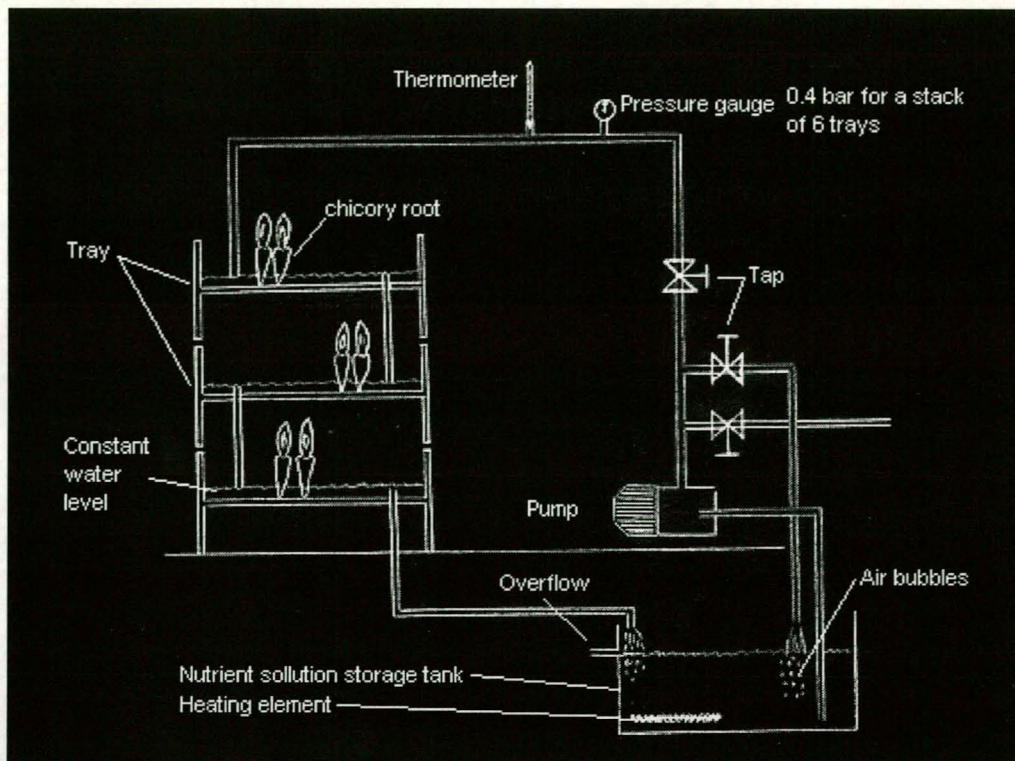
Figure 3: Hydroponic "cascade" set-up with a circulating nutrient solution for
chicon production

Additional Literature:

Sarrazyn, R., 1990.

3.5.1 CONDITIONS IN THE GROWTH CHAMBER

After the harvest and cold induction of the roots, they are placed in an environment
where the "heart" begins to grow to form a compact white mass of etiolated leaves -
the chicon, or chicory head. Besides being protected from light, what are the
conditions making up the "ideal" environment for the roots?

Temperature   The optimal forcing temperature is dependent on the
                     physiological ripeness of the roots. Older roots require a lower
                     temperature. For cultivars of Dutch origin, it is advisable to

allow for a root temperature 1.5 to 3°C higher than ambient temperature.   French cultivars are less bound to this temperature difference.

As a rule of thumb it can be stated that roots forced early in the season will be forced at a water temperature of 19°C and an air temperature of 17°C.   These values decrease slowly as the season progresses, respectively to 11.5°C and 10°C.

Relative humidity (RH)	Throughout the cultivation of chicory the RH has to be kept at 85 - 95%, with variation not more than 5%. Keeping the floor wet is an effective way of achieving this. It has to be remembered that RH is affected by temperature. At low temperatures a high RH will be reached with less water in the air than would be the case at a higher temperature. This implies that a rise in temperature (even for a short while) immediately leads to drying out of the root material and the emerging chicons.

The humidity, together with the salt concentration of the nutrient solution, determines whether "dry leaf edges" or glassiness could appear. A too high RH, in conjunction with a high temperature, may lead to bacterial infection.

Additional Literature:
Tomassen, E., 1997(b).

Ventilation	With strong ventilation there is a risk of the root neck drying out, resulting in heads with lower quality. The produced heat has to be removed and for this to be done the air within the

growth chamber has to be replaced between 2 and 3 times per day. Here the problem to be dealt with is that chicory is very sensitive to movement of air over the chicons, which may increase the risk of "dry leaf edges' . The air speed should therefore not exceed 0.1 - 0.3 m/s.

3.5.2 THE NUTRIENT SOLUTION

The basic requirement when preparing a nutrient solution, is to make use of water with good mineral and bacteriological properties. Since the composition of water is variable, regular analysis is recommended. Only a few facts will be discussed:

pH The pH of water usually lies between 6.5 and 8.5 and is, in most cases, too high for optimum uptake of nutrients. pH always needs to be interpreted in conjunction with the capacity of the buffer present. Bicarbonate is an important buffer at a pH between 5.5 and 7.5. When an acid is added to water containing bicarbonate, the H^+-ions will be neutralized and the change in pH will be limited for as long as HCO_3^- is still present. The pH-value aimed for is 6.5. At a higher pH, the formation of precipitates in the case of certain mineral nutrients e.g. calcium-phosphate, poses a problem. On the other hand, too low a pH causes burning of the root-hairs. As was mentioned, the pH has an influence on the uptake of the nutrients. The following figure (Figure 4) shows this in a simple way.
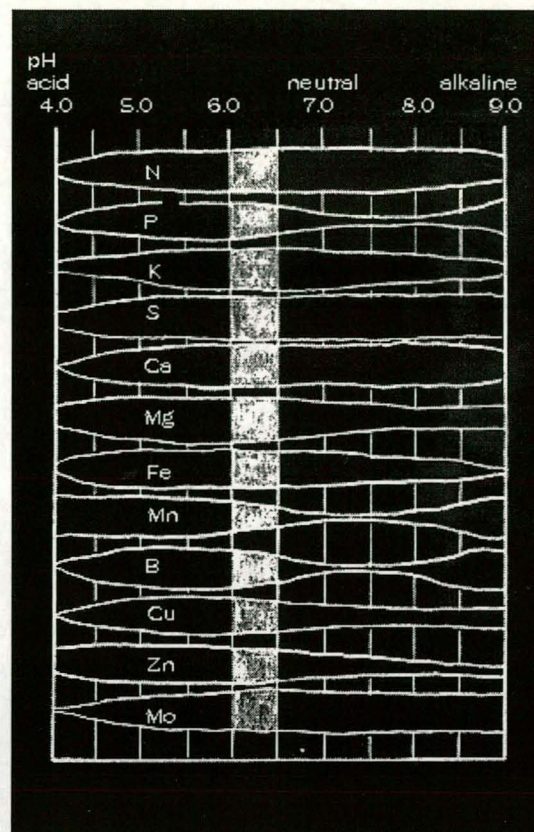
Figure 4: The influence of pH on root uptake of certain elements

EC

The electric conductivity (EC measured in units of $mS.cm^{-1}$) is a measure of the total amount of dissolved salts. Pure water has an EC of zero. Unfortunately, the EC does not give any information concerning the type or the relative ratios, of these ions. The most common ions in water are Na^+, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-} and bicarbonate (HCO_3^-). Some of these, e.g. Ca^{2+}, Mg^{2+}, and SO_4^{2-}, can be taken into consideration as nutrient elements as long as they do not exceed the permitted concentrations. The EC is temperature dependent, as can be seen in Table 2.

Table 2: Correction factors for EC at different Temperatures:

°C	Temperature factor
10	1.411
15	1.247
16	1.211
17	1.189
18	1.163
19	1.136
20	1.112
21	1.087
22	1.064
23	1.043
24	1.020
25	1.000

The EC of a nutrient solution is a measure for the concentration of nutrients. This is, however, only true in the case where ballast salts such as Na^+ and Cl^- in the water are limited. The higher the concentration of Na^+, Cl^- and other ions in the water, the higher the initial EC will be. Water with an EC beyond 0.5 $mS.cm^{-1}$ should be analyzed to determine the concentration of ions already present.

For Chicory the EC-value to strive for is 2 $mS.cm^{-1}$ (that is after the nutrients were added). The following values and ratings are generally accepted:

EC	Rating
< 0.8	low
0.8 - 1.5	acceptable
1.5 - 2.5	normal
2.5 - 3.5	high
> 3.5	very high

Preparation of a nutrient solution

In practice there is a wide spectrum of methods for making up nutrient solutions. A universal way of making one up from

scratch follows in Table 3. This nutrient solution is used with success commercially. Depending on the mineral make-up of the root, it is possible to adapt the concentration of the nutrients in relation to that of the root, i.e. if the root has a high potassium content, the concentration of potassium in the nutrient solution can be reduced.

Table 3: Elements and their concentrations required for the preparation of a universal nutrient solution (Boegaerts, *et.al.,* 1993)

Element	$mmol.L^{-1}$	$mg.L^{-1}$
Potassium	8	313
Magnesium	1.4	34
Calcium	4.2	168
Nitrate-N	13.7	192
Phosphate	1.5	47
Sulfate	2	192

<u>*Additional Literature:*</u>

Aaldering, T., 1997(a).

Deckers, S., 1991.

Fouldrin, K. & Limami, A., 1993.

Sarrazyn, R. & Deckers, S., 1991.

Titulaer, M. & Van Kruistum, G., 1991.

Van den Broek, R., 1996.

mixability   Not all nutrients can be mixed in their concentrated form. Calcium and sulphate, for example, form a precipitate of calciumsulphate at too high concentrations. Analog to this, high concentrations of Ca or Mg in the presence of phosphate

tend to form precipitates of calciumphosphate or magnesiumphosphate. A high pH also facilitates precipitate formation. In order to avoid these problems, concentrates should be mixed in two tanks, the so called A- and B tanks. As a standard procedure, there are no sulphates or phosphates dissolved in the A tank; in the B tank no nutrients containing calcium are added.

Additional Literature:

Deckers, S., 1993.

Water supply

In the case of hydroculture, water is the medium responsible for transporting the nutrients to the roots. On average ± 170 g of water is required for the production of 100g chicons. A constant flow is necessary and the advised water speed is approximately 1.25 L.min^{-1} per basin of 1 m^2. It might be of interest to study the uptake of water during forcing (Figure 5).

physiological explanation

Once the roots are placed into the growth chamber, they will be fed with the necessary nutrients by means of a hydroculture. Even though nutrients are available, the development during the first phase of growth depends wholly on the reserves available from the root as side roots first have to develop. (The extent to which these reserves can be tapped, strongly depends on the temperature and the osmotic value of the nutrient solution.) During the development of side roots, water-uptake will be limited. This, however, changes as the side roots develop. The last few days of cultivation show a dramatic increase in water use, mainly as a result of an increasing transpiration from the increased leaf area.
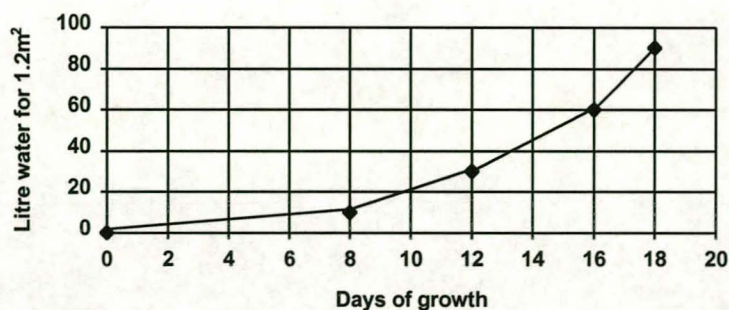
Figure 5: Uptake of water during forcing

Oxygen

Another point of major importance is the presence of oxygen in the nutrient water. A minimal oxygen enrichment already gives an extra yield of 6%. The most effective way of achieving this is by letting the water free-fall from one basin to the next in a cascade system.

3.6 PESTS, DISEASES AND PHYSIOLOGICAL DISORDERS

This seems to be the right stage to discuss the more common diseases found during chicory cultivation. Some of them may destroy the whole crop while others "only" affect the quality. Good production techniques during the growing of the roots, form the basis for healthy roots, and if these are handled properly the risk of any disease is very small. However, as was mentioned, much damage can be done to the roots during harvesting and storage. Damaged roots are most prone to cause problems. The questions that need to be answered at this point are: What are the visible symptoms and the effects of each disease, and what can be done about it? The most common ones will be discussed. Before this is done, however, a list of chemicals that are mentioned in the discussion will be given for easier reference (Table 4).

Table 4: Summary of chemicals used on Chicory (Van Melckebeke, 1993)

Active ingredient	Trade name and % active ingredient
1) Fungicides	
Fosethyl	*Aliette* (80%)
Iprodion	*Rovral* (50%); *Rovral Aqua Flo* (500g/L)
Metalaxyl + Mancozeb	*Ridomil Special* (10 +48%)
Propamacarb	*Previcure N* (722 g/L)
Thiabendazol	*Lirotect 40 F* (450 g/L)
Vinclozolin	*Ronilan DF* (50%); *Ronilan SC* (500g/L)
2) Insecticides	
Pirimicarb	*Pirimor* (9.5%)

3.6.1 FUNGAL INFECTIONS

Sclerotinia sclerotiorum The primary infection occurs on the field during root production. Infected roots can be identified by light brown marks, which are mostly on the root neck. Infected roots carry this sickness into the growth chamber. The warm and moist conditions allow the fungus to spread rapidly. An enzyme is produced which breaks up the pectin in the root. Even during cold storage this fungus can spread.

Preventative treatment: After placing roots in trays, spray the leaf collars with 3g/m^2 Iprodion or 1-2.1 g/m^2 Vinclozolin. Never place infected roots into trays. In order to prevent spread of this fungus during storage treat the roots with 10 g Vinclozolin/20L water/ton before placing them into the cold cell or dip them under in a solution of 120g Rovral/100L for ±2 minutes.

Additional Literature:

Gerlagh, T., 1997.

Van Balen, D., 1999.

Van Harmont, J., 1997.

Sclerotinia minor

Despite being closely related to the above, this fungus infects only the chicory heads. A white, slimy rot with small black beads, forms on the outer leaves of the heads. In conjunction with this fungus, a bacterial infection often leading to slime rot occurs. Contact with surrounding heads and not so much by water spreads it.

There is no cure, but a preventative measure would be to remove any infected roots before storage and again before placement into the trays.

Phytophtora erythroseptica

Infection is first noticed by a brown colouring of the root end. Under warm conditions this discolouration quickly moves upwards resulting in the whole root rotting and a discontinuation of head growth. The temperature within these roots easily rises to above 25°C and a strong smell is given off. It is spread is by spores in the nutrient solution and if left unattended for too long the whole nutrient solution will become slimy.

Potatoes and rape are host plants for this fungus and should not precede a field planting of chicory. This fungus grows best at temperatures of 22-24°C and forcing below 15°C keeps the infection under control, to a large extent.

Preventative treatment before cold storage by a mist treatment of 128g Fosethyl/20L water/ton or (4g Metalaxyl and 19.2g Mancozeb)/20L water/ton after removing excess soil. Before placing roots into the growth chamber, one of the

following leaf collar treatments is possible: 10g/m² Ridomil, 15g/m² Aliette in 4L water or 15ml Previcur/ 2L water. Furthermore one of the following can be added to the <u>nutrient solution</u>: 9g Propamocarb/100L -, 375g Aliette/100L -or 125ml Previcur/1000L nutrient solution can be added.

Once the whole nutrient solution has become slimy, it has to be exchanged on a regular basis.

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Phoma exigua   This is a disease that typically infects damaged roots and mainly establishes itself during cold storage. It is not transferred through the nutrient solution. The symptoms are dry, black marks that may start rotting later. The infected areas on the root do not form side roots and thus the head formation is retarded.

Preventative measures include harvesting the roots when the soil is moist as less roots will break and be damaged. For roots that have to be stored for longer than one month a treatment with 40.5g Thiabendazol/20L water/ton or dipping the roots into 112.5g Thiabendazol/100L for ±2 minutes is advisable.

3.6.2 BACTERIAL INFECTIONS

Bacterial rot   Bacterial rot is mainly caused by *Pseudomonas* and *Erwinia*. In many cases they are secondary infections, in addition to e.g. *Sclerotinia*. During forcing the roots start rotting away, while still producing a small head. The chicon in many cases simply falls off the root at harvest. The core of the chicon will show a black colouring, which makes it unacceptable for the market. The outer leaves also start rotting.

Ways of handling this problem are by holding a high standard of hygiene, letting the root dry properly before placing them into the trays and forcing them at a low temperature. Removing long leaf collars also reduces the risk of infection. Treatment of the 1000L water (used for the nutrient solution) with 1L of 100% hydrogenperoxide. Dipping the roots in a 2 to 4% calcium chloride solution for two hour also shows promising results.

Additional Literature:

Schober, G., 1998.

Van den Broek, R., 1995.

Slime formation

The formation of slime in the nutrient solution is a secondary implication of rotting material. Roots in such a solution do not form side roots and those that already exist start dying. A strong smell of anaerobic rotting material follows.

Treatment is best done by flushing large amounts of fresh water (0.1% hydrogen peroxide) through the trays in order to lower the temperature and supply sufficient oxygen. The circulating system has to be interrupted in order to stop spores of Phytophthora to spread.

3.6.3 PHYSIOLOGICAL DISORDERS

Physiological disorders have dramatic implications for the viability and profitability of chicory production. The harvest of heads may be very good in weight terms but in quality and, eventually, in Rand terms, the loss may be devastating - much of the crop

has to be discarded. This is especially the case in Europe, where the minimum standards (see also 3.7) are extremely high.

Blue Chicory	The white leaves of the chicory head have a distinctive blue to black shine to them, which makes them unappetizing and extremely bitter. This is not at all acceptable to the market. It has been suggested that this phenomenon is brought about by the dying of cells in the parenchyma tissue and the fact that air, in place of water, is now incorporated into this intercellular leaf tissue. This is helped along by:

> *The pH of the water is too low; scarce formation of side roots; high salt concentration; influence of the cultivar. Furthermore it goes hand in hand with a low Ca- content and a relatively high content of non-soluble Fe and Al as a result of an inadequate water uptake.*

Red Chicory	The chicory root, as well as the chicory head, contain a white milky sap with a bitter taste. The bitter taste results from intybine (a red pigment), which is concentrated mainly in the core of the head.

The leaves of the chicon head take on a red tint, mostly only three to four days after harvest. The exact reasons for this are not known but redness most commonly appears when the cell contents, but mainly the cell sap, comes into contact with light and O_2, (oxidation). It is most prominent during early forcing, a stage when growth is at its strongest. Uptake of nutrients is high and it is hypothesized that the growth of the cell walls are unable to keep up (inadequate Ca import) and break, releasing cell sap into the intercellular spaces. Ideas of handling this matter are as follow:

Roots need to be ripe; treat roots with boron before forcing; curb water-uptake by increasing the salt concentration (EC) of the nutrient solution; high nitrate contents of the root promotes reddening; high Ca- and K- contents of the root decrease reddening; harvest chicons early.

<u>*Additional Literature:*</u>

Anonymous, 1993.

Van Kruistum, G., 1992.

Veen, B. & van Kruistum, G., 1997.

Veen, B. & van Kruistum, G., 1999.

Burst Chicory	With tight heads, the leaves tear lengthwise shortly before they are ready for harvest. Given reasons follow:

> *Large temperature variation; large difference between root- and head zone temperatures. The root takes up more water than what can evaporate from the leaves, resulting in bursting and glassiness.*

Glassiness	The leaves appear translucent. This is explainable by a strong flow of water to the head, combined with a low transpiration rate. Ways of working against this are:

> *Reduce air humidity; increase ventilation; increase the salt concentration.*

"point noir"	During forcing, black necrotic tissue forms on the top of newly emerging leaves which force the healthy tissue to grow around it. This results in a leaf with a distinctive "comma" shape. These marks are not only on the outer leaves of the rosette, but,

in many cases, also on leaves of more central rosettes. This phenomenon is as result of a drying out of the leaf tips.

To prevent this from occurring, increase the RH.

Brown core

This is probably the most annoying problem during chicory production. As the name says, the core of the chicon head is discoloured brown; in many cases going hand in hand with tissue mortality. A reduced mobility of Ca from the root to the growth point induces a Ca shortage. Ca is essential for strong cell walls. Since brown core can already be noticed after the second day of forcing, the underlying problem has to be sought before forcing. Ways in which to prevent this physiological disorder are:

*Choice of correct witloof variety; correct root growth (avoiding high N-, K- and Mg-soils); roots of average diameter (3-4cm) are less affected than thicker roots. Treating the roots with **CaCl₂** relieves the problem to an extent - dipping roots in a solution of 2-3 kg CaCl₂ in 100L water before cold storage for 1-3 hours, or at least 14 days before placing into growth chamber. The leaf collars of roots, ready to be forced, can be sprayed once more with 30g CaCl₂ per m².*

Additional Literature:

Den Outer, R.W., 1989.

Lapage, E., 1995.

Limami, A. & Fiala, V., 1989.

Pamphlet.

Vansteenkiste, H., 1996.

Loose Chicory	The leaves are loose as there is no real core to which they are attached. The reason for loose heads is unripe roots.

Store roots in cold until they are ripe for forcing and increase the temperature, as well as the EC.

Open Chicory	The leaves of these heads are not tightly packed, i.e. the head is filled with spaces and the leaves do not close sufficiently at the top of the head. These chicons have to be downgraded by at least one class, which leads to an unnecessary financial loss. This disorder usually occurs with over ripe roots. Thick roots show this problem more readily than average sized ones. There are a few scenarios:

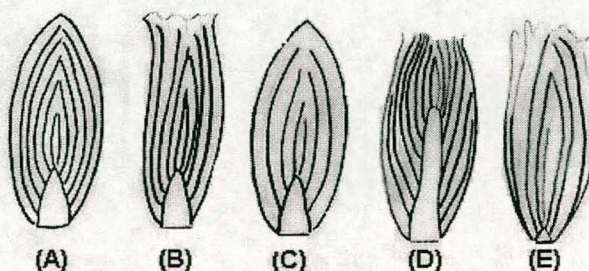|	
closure and growth manipulation	➤ *Heads with a normal core length but lack of closure - lower the EC while keeping the temperature unchanged.* ➤ *Heads with a short core but a good closure - increase the temperature while keeping EC unchanged.* ➤ *Open heads with an extremely long core - both the EC and the temperature need be lowered.*

Figure 6: Cross-sections of the chicon. (A) well formed, properly closed chicon, (B) open chicon, (C) loose chicon, (D) chicon with long pith – usually open, and (E) loose, open chicon with short pith

3.7 HARVEST AND POST-HARVEST ACTIVITIES

Harvest

Harvesting the chicons is very simple. The head is simply taken gently between the fingertips and broken from the root with a little jerk. The break-line, where the head was attached to the root, needs to be cut with a sharp knife, to form a smooth surface. Any loose leaves have to be removed (with the fingers, not a knife, as this may damage the next leaf, allowing the cell sap to leak out and oxidize, leaving a red discolouration) and for this action it is essential to have dry and clean hands. Be sure not to apply too much pressure, as resulting pressure points tend to turn red/brown soon. In hydroculture the chicons do not need to be washed.

Sorting

Proper sorting is a job that requires practice and will not be discussed in detail in this paper. There are four classes that chicory can be sorted into. These are given in Table 5 (without all the extra requirements or toleration). Class Extra and class I have to display perfect closure on the top of the chicon!

Table 5: Classing of chicons according to dimensions only
(Sarrazyn, 1991)

Sorting parameters	Class		
	Extra	I	II + III
Min. diameter for			
-chicon with length <14cm	2.5	2.5	2.5
-chicon with length >14cm	3	3	2.5
Max. diameter	6	8	-
Min. length	9	9	9
Max. length	17	20	24

minimum requirements

Not taking into account the detailed description of each class and the amount of variation allowed within this class, there are certain minimum requirements that have to be met, no matter which class chicory is allocated to. The head needs to be:

➢ intact and undamaged by insects etc.;
➢ healthy - the heads may not be infected by bacterial rot or any other disorder that makes it unsuitable for consumption;
➢ free from pressure damage;
➢ free from a core longer than 3/4 of the chicon's total length;
➢ free from any foreign bodies, i.e. leaves;
➢ of good clear colour (white to slightly yellow);
➢ neatly cut at the base;
➢ fresh;
➢ free from abnormal moisture;
➢ free from foreign smell or taste; and
➢ fully developed, in order to survive transport and handling.

Packaging
There is a wide variety of packaging available. This depends on the demand of the consumer. Preferably, packaging should allow for the chicory to remain protected from light as long as possible (dark wax paper). This is easiest if it is sold loose. Wax paper conserves moisture, so does plastic wrapping if Chicory is sold in packets.

Additional Literature:
De Putter, H., 1998.

Shelf life
Keeping chicory on the shelf at 12°C for a period of 7 to 8 days is not a problem, provided they are shielded from light. Lowering this temperature will prolong the shelf life by as much as a week. The type of packaging and the cultivar also has a significant influence on these results.

Additional Literature:
Tomassen, E., 1997(a).

4 CONCLUSION

As is the case with most agricultural products, nature will always have a major influence on the production results of chicory. This is especially true for the first stage of the production cycle, i.e. the growing of the roots. However, once a healthy root is available for further cultivation, the growing conditions can be controlled and the growth of the chicon manipulated. A fundamental knowledge of these manipulatory production techniques is essential in order to produce high quality chicons. Taking the information in this paper as a platform, putting it into practice and learning as one goes along makes further cultivation of chicory roots not only interesting, but also very rewarding.

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CHAPTER 2

The influence of exogenous gibberellic acid treatments on chicon quality
and lateral root formation of witloof chicory

The influence of exogenous gibberellic acid treatments on chicon quality and lateral root formation of witloof chicory

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Abstract

Endogenous gibberellic acid (GA) is known to play a pivotal role in the vernalization process of plants requiring a cold induction. In order to establish the effect of an exogenous GA application on the vernalization process of chicory roots, GA was applied to five cultivars (two "late" types and three "early" types) of witloof chicory (*Cichorium intybus* L.). GA treatments were applied as a leaf and a root treatment, each at a high and a low concentration. After forcing the treated roots, chicon quality was measured and used as an arbitrary indicator for completed vernalization. Lateral root formation was also noted as an indicator for damage to the root epidermis. Irrespective of concentration, the GA leaf treatment showed no significant difference in chicon quality when compared to no treatment. A GA root treatment, on the other hand, had a strong retarding effect on chicon quality, again irrespective of the hormone concentration applied. Concerning lateral root formation, no GA treatment had any effect but a significant difference was observed between cultivars. It was concluded that exogenous GA treatments, at the levels used in this study, did not facilitate chicon quality and thus vernalization.

Keywords: gibberellic acid, vernalization, witloof chicory

1 Introduction

Witloof chicory (*Cichorium intybus* L.) completes its natural growth cycle in two years. During the first year vegetative growth prevails. Excess carbohydrates produced during this phase are transported basipetally to the root, where they are accumulated and stored for use during the generative growth phase in the second year. For chicon production (forcing of the root in a dark room), the chicory root is harvested after the first growing season, in a state of transition, where the plant is in physiological rest (Gianquinto, 1997; Van den Acker, Demeulemeester & De Proft, 1993). In European countries, with their short growing season, this dormancy is broken before forcing by storing the roots at temperatures ranging from 4°C to -1°C (Goffings, Herregods & Lips, 1993) for a minimum period of between two weeks and two months, depending on the cultivar. Furthermore, the nature of the European winter will impair a successful harvest as a result of mechanical limitations, once the soil becomes frozen or too muddy. Therefore cold storage of the harvested roots at low temperatures becomes necessary during the winter months in order to allow a continuous supply of roots for forcing in this period. A new root crop can then be grown on the field in the new season. Since not all varieties can be stored for long periods and still produce high quality chicons, different cultivars become a necessity when the aim is chicon production throughout the year (Nerum & Pieron, 1993).

Despite the fact that large amounts of chicory are grown for the production of coffee surrogate in South Africa, witloof chicory is an unknown crop to the local market. Generally the growing season is significantly longer in South Africa than in Europe, the winter very mild and problems with harvesting as a result of climatic conditions absent in the chicory-producing area, the Eastern Cape. In theory the roots could therefore remain in the soil throughout the winter and then be used directly for forcing as they are required (Brakeboer, 1998). This scenario could lend itself to the possibility of cutting out the need for a wide spectrum of cultivars and limiting the required cold storage facilities to a minimum since large-scale storage of roots becomes unnecessary. Whether this is viable on a large scale has yet to be established. If it were, one aspect worth investigating would be, how to break the physiological rest of the roots harvested early in the season by means other than a

cold treatment. The winter temperatures are not low enough and artificial cold induction requires high capital and energy expenditure.

In an effort of finding a commercially viable alternative to a cold treatment, attention will be given to gibberellic acid (GA). Many studies were carried out measuring endogenous GA concentrations in various vernalized and nonvernalized plants (Abdala, Guiñazú, Tizio & Pearce, 1995; Rood, Mandel & Pharis, 1989; Suge, 1970; Zanewich & Steward, 1995). The results are not conclusive but endogenous GA is understood to play a pivotal role in vernalization in many plant species. In vernalized plants the endogenous GA concentration increases in the shoot tip. The observed higher endogenous GA concentrations in vernalized plants led to research on the effect of an exogenous GA application on plant vernalization (Demeulemeester, Voet & De Proft, 1995; Fernández, Bañón, Franco, Gonzálea & Martínez, 1997; Hazebroek Metzger & Mansager, 1993; Takaaki, Katsura, Koshioka, Yamazaki & Mander, 1997;) showing that an exogenous GA treatment promotes stem growth and flowering even in the absence of a cold induction period. Since chicory also requires a cold period in order to complete the phase transition from vegetative to generative growth, it is of interest to establish whether a foliar GA application to growing chicory plants or a root treatment to the harvested roots will not have a similar effect, cutting out the cold period required for vernalization and yet producing quality chicons. Seeing that this hormone is widely used commercially in breaking dormancy by exogenous application in plants such as potatoes (Vermeulen, 1997) and the suggestion by De Proft & Morgan (1995) that GA may play a signal role in the vernalization process of the chicory storage root, it is the aim of this paper to examine the above hypothesis.

2 Materials and methods

In a completely randomized experiment, five cultivars of witloof chicory (*Cichorium intybus* L.), Focus, Vitessa, Totem, Final and Tabor, were grown under controlled conditions in a glass house. Plants were grown in well-drained containers, filled to a depth of 400mm with river sand (Particle size: ±2.00mm). The plants were fertigated with a standard nutrient solution (Combrink, Jacobs, Agenbag & Maree, 1996). The

irrigation frequency was controlled by a solar integrator (set at 4.184 MJ.m^{-2}). Irrigation volume was set to allow a run-off of at least 10%. Five GA treatments were used, two leaf treatments, two root treatments and an untreated control. After 150 days of growth, two leaf treatments of gibberillic acid were applied, each to five plants of each cultivar. The treatments of 5 ppm (0.08ml Progibb per 500ml pure water) and 10 ppm (0.16ml Progibb per 500ml pure water) were applied by spraying 20ml per plant. All plants were left to grow for another week before the roots were harvested. Two root treatments of gibberillic acid were also applied to plants that did not receive a prior leaf treatment. This was done by submerging the roots in a hormone solution of 10 ppm (4.8ml Progibb per 15L water) and 100 ppm (48.0ml Progibb per 15L water) respectively, for 15 minutes. Five untreated roots per cultivar served as a control. All roots were stored at 4°C for three days and then placed in a dark chamber for forcing. Roots (average diameter was 41mm) were cut to a length of 18cm and then placed into separate containers (160mm in height and 90mm diameter). The nutrient solution used was as advised by Deckers (1991). The containers were emptied every day and refilled with 500ml fresh nutrient solution. After 25 days the chicons were harvested and classed into four classes, Extra, I, II and III, as a measure of chicon quality (Sarrazyn, 1991). All roots that did not produce any chicon (blind eyes) or only very small ones (there was no loss of material resulting from rot or disease) were classed as III in order to achieve a holistic picture of yield. Furthermore, at the same time, lateral root formation was noted on a scale from one to five. This was used to act as a simple indicator measuring whether the root GA treatment in any way damaged the epidermis / pericycle of the root. Such a reduction in lateral root formation could detrimentally affect the chicon size / quality.

By comparing the five mentioned cultivars, another interesting comparison is made. Two groups of cultivars were used; "late" and "early" types. Final and Tabor belong to the "late" type, while Totem, Focus and Vitessa fall into the category of "early" type (Rassensassortiment, 1995). The early types can already be expected to produce quality chicons after a short vernalization period. Should, therefore, only the "early" types react positively to GA treatments (chicon quality was taken arbitrarily as a descriptive indicator for completed vernalization), this will be a good indication as to which type can best be used under local conditions.

3 Results

3.1 Influence of exogenous gibberellic acid treatments on chicon quality (grading)

A generalized linear model with a logit link function was fitted for the analysis of the ordinal chicon quality data. From Table 1 it is evident that there was no significant main effect interaction nor any significant difference between the two GA concentrations applied. The only significant difference (SL = 0.006) concerning this parameter is observed in the case where a GA-leaf treatment was compared to a GA-root treatment.

Table 1. Sequential analysis of deviance table for chicon quality

Effect	Df	Deviance	Approx. SL (Significance level)
Cultivars	4	1.89	0.7558
Control vs. Rest of Treatments	1	1.61	0.2048
Leaf GA-treatment vs. Root GA-treatment	1	11.71	0.0006
Low GA-concentration vs. high GA-conc.	1	0.14	0.7087
Interaction	1	2.93	0.0869
Error	16	21.41	0.1631
TOTAL	24		

Since there were no significant differences between the GA concentration levels for the root- or the leaf treatments (SL = 0.7087), the original data can be summarized as in Table 2. Applying a shortfall test on ordinal data was not possible with the technology available. However, examination of Table 2 does give a clear picture. Almost no difference was found between the control and leaf GA treatment. However, a significant reduction in chicon quality can be seen in the high percentage of class III chicons where roots were treated with GA.

Table 2. Chicon quality expressed as percentage chicons in each class for different GA treatments

GA-treatment	% Extra	% Class I	% Class II	% Class III
Leaf	10.2	34.7	24.5	30.6
None	12.5	29.2	25.0	33.3
Root	4.3	15.2	15.2	65.2

3.2 Influence of exogenous gibberellic acid treatments on lateral root formation

The same model as above was fitted to the ordinal data for lateral root formation (Table 3). Since there were no noteworthy main effect interactions nor significant differences between any of the GA treatments, it was accepted that GA treatments had no evident effect on lateral root formation.

Table 3. Sequential analysis of deviance table for lateral root formation

Effect	Df	Deviance	Approx. SL (Significance level)
Cultivars	4	26.80	0.0001
Diff. between early and late cultivars	*1*	*1.68*	*0.1947*
Differences within late cultivars (1)	*1*	*3.55*	*0.0597*
Differences within early cultivars (2)	*1*	*4.60*	*0.0321*
Differences within early cultivars (3)	*1*	*17.00*	*0.0001*
Control vs. Rest of Treatments	1	3.18	0.0747
Leaf GA-treatment vs. Root GA-treatment	1	0.09	0.8088
Low GA-concentration vs. high GA-conc.	1	0.25	0.6201
Interaction	1	1.37	0.2416
Error	16	7.23	0.9686
TOTAL	24		

(1) compares Final with Tabor
(2) compares Focus with Vitessa
(3) compares Totem with Focus and Vitessa

However, from Table 3, strong evidence (SL = 0.0001) exists against the hypothesis that the five cultivars do not differ in lateral root formation. The early cultivars, especially when comparing Totem with Focus and Vitessa, differed significantly (SL = 0.0001) regarding their lateral root forming abilities. Comparing the early types with

the late ones shows that there was no meaningful difference (SL=0.1947) and the difference between the two late cultivars, Final and Tabor, was only significant at a 6% testing level. Again a shortfall test is not possible. Nevertheless, use can be made of calculated location values as in Figure 1, in order to establish which of the five cultivars showed the strongest lateral root formation. The extent of variation is also illustrated by the spacing of the plotted values.
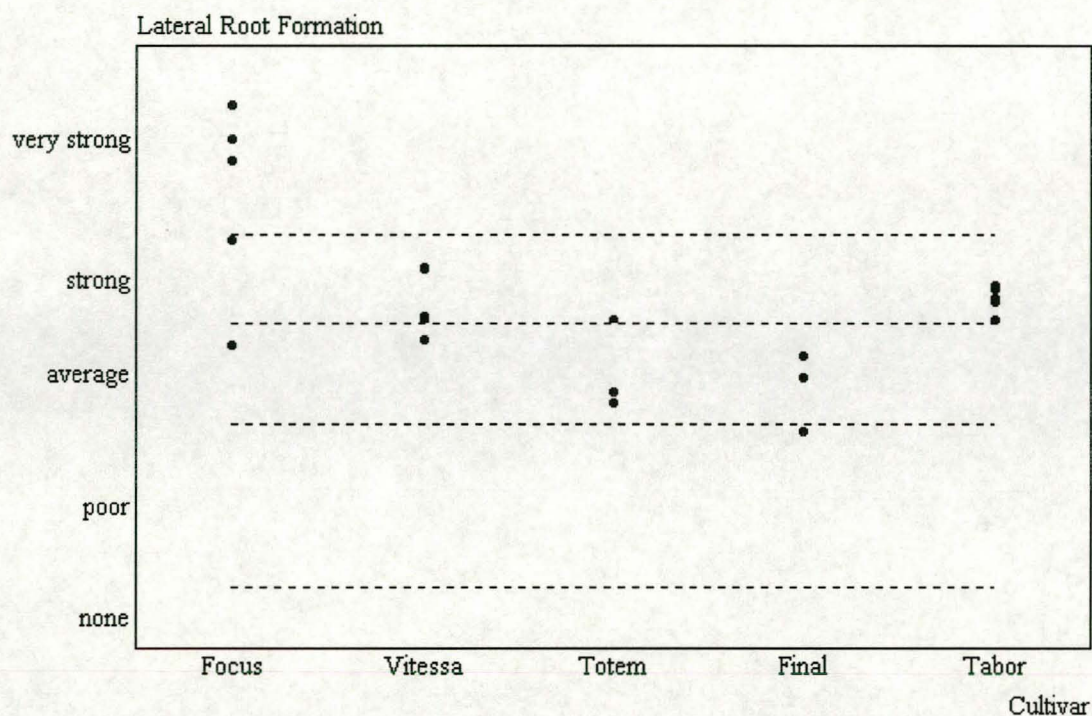

Figure 1. Lateral root formation for cultivars

4 Discussion

From the results presented in Table 2, it can be stated that no meaningful chicon quality difference occurred between a GA leaf treatment and no treatment. Untreated roots yielded a marginally higher percentage of class "Extra" chicons, whereas the roots that received the GA leaf treatment yielded more class I chicons and a smaller proportion of the less desirable class III. Comparing a GA root treatment with a leaf treatment, however, presented a clear difference. More than twice as many chicons were found in the class III in the case were the roots were treated with GA. Furthermore, the chicon yield for the desired classes, "Extra" and class I, was less

than half of that realized when a GA leaf treatment was applied. The clear implication is that a GA root treatment had a strong restricting effect on chicon quality.

The degree of lateral root formation was noted in order to establish whether the GA root treatment had any damaging effect on the epidermis and / or pericycle of the root and thus on the chicon quality and yield. This would be of interest, especially in the light of the poor performance of the roots that received a GA root treatment. From Table 3, it is evident, however, that this was not the case as there was no significant difference in lateral root formation between a leaf and root GA treatment (SL = 0.8808). The reason for the extremely poor chicon performance with a GA root treatment could therefore not be ascribed to poor lateral root development per se. Perhaps in future studies a histological or anatomical assessment of direct damage to the epidermis cells by a GA root treatment will produce more conclusive answers.

Focus, Totem and Vitessa are considered to be "early cultivars" requiring only a short cold treatment while Final and Tabor are grouped as "late cultivars" that require a longer vernalization period for successful forcing. The reasoning for the choice of cultivars (and the three day cold storage period before forcing) in this study was, that the early types would show signs of completed vernalization earlier than the late types. It was expected that this would then manifest itself in a higher chicon quality or yield, and perhaps in stronger lateral root formation. Table 1 clearly shows that there were no significant chicon quality differences between cultivars (SL = 0.7558), and therefore between early and late types. Figure 1 depicts how each of the cultivars performed, concerning lateral root formation. From this figure and Table 3 it is apparent that there was a significant difference between cultivars (SL = 0.0001) but no significant difference (SL = 0.1947) between the group of early and the group of late cultivars. Appreciating these results, it is clear that GA had no meaningful effect on vernalization since the early types did not perform any better than the late ones. Whether chicon quality is the most effective indicator to describe vernalization can as yet not be said.

In this study no cold induction treatment was included. The idea was to launch a separate experiment should a significant positive effect on chicon quality and yield be found compared to no treatment. This possible follow-up experiment would then have

compared a chilling treatment to a GA treatment. However, since the results were negative this exercise becomes unnecessary. Roots exposed to a cold induction period, as is done during normal production procedures, are expected to show a better yield and quality than the control in this study.

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CHAPTER 3

The influence of exogenous gibberellic acid treatments on the relative pith length and quality of witloof chicory

The influence of exogenous gibberellic acid treatments on the relative pith length and quality of witloof chicory

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Abstract

Two cultivars of witloof chicory (*Cichorium intybus* L.) were grown in a fertigated sand medium. Two levels of gibberellic acid (GA) were applied to the leaves in one case and to the roots in another. A chilling treatment was applied as a fifth treatment, while the control was left untreated. The roots were forced in a dark chamber and the relative pith length was measured. Very short piths were noticed in earlier trials which, when compared to pith lengths from trials done on the same varieties in the Netherlands, were less than half the length, no matter what the treatment was. It was found that exogenous GA application was not responsible for short piths. Furthermore, the quality of the resulting chicons was assessed by sorting them into four classes. GA treated roots did not perform better than the control and / or those that received a chilling treatment. Cold treated roots performed poorly compared to the control.

Keywords: Gibberellic acid, pith length, witloof chicory

1 Introduction

This paper follows directly on a study done and reported in the previous chapter on the influence of exogenous gibberellic acid treatments on chicon quality of witloof chicory (*Cichorium intybus* L.). For that experiment chicons were classed purely by form and size. During that trial a few chicons were halved and it was noticed (but not recorded) that the piths of the chicons were extremely short. The question that arose was whether the exogenous GA was responsible for this retarded pith growth.

Gibberellic acid is known to play a pivotal role during vernalization of long day plants, as well as in stem elongation and flowering (Joseph, Seigneuret, Touraud & Billot, 1983). The stem, that grows in the center of the witloof head during forcing under conditions of total darkness can be considered to be a modified flowering stem, also known as the pith (Demeulemeester, 1995). GA was found to stimulate stem growth in vitro (Demeulemeester, Voet & De Proft, 1995). However, no literature was found on the effect of exogenous GA application on the relative pith length of the final witloof chicon produced.

According to Sarrazyn (1991), chicons without a pith usually go hand in hand with poor closure and are commonly realized from unripe roots. Taking into account that varieties developed for temperate latitude countries were grown in an "unnatural" sub-tropical climate, in a sand medium fertigated with a nutrient solution and were then treated with GA, it becomes evident that there may be many other factors manifesting in much the same way as unripe roots do. The reason for launching this study was twofold: First, the aim was to find whether a relationship exists between exogenous GA treatments and the relative pith length of chicons. Secondly, it was to be used to serve as a follow-up trial for the one done previously where chicon quality was used as an arbitrary indicator for completed vernalization, and no cold storage treatment was included.

2 Materials and methods

Two cultivars of witloof chicory, Bea and Flash, were planted in two sand basins of 17.5m x 1m. The basins were filled with river sand (Particle size: ± 2mm) to a depth

of 450mm. Coarse washed gravel and a perforated drainage pipe were placed below this level to allow for adequate drainage. Four rows of seed, two rows of each cultivar per basin, were hand sown directly into the sand at a depth of ± 5mm. The rows were 250mm apart. After three weeks the seedlings were thinned out so that the plants within each row were spaced 80mm. 120L of a nutrient solution (Combrink, Jacobs, Agenbag & Maree, 1996) (EC=2.0mS.cm^{-1}) was applied three times per day by means of overhead micro sprinklers, fixed 300mm above the sand level, for the first three months. The EC was then reduced to 1mS.cm^{-1} and the micro sprinklers lowered to the sand level for the remaining two months of root growth.

In both sand basins each cultivar was divided up into two blocks and each block again into six units. These units were then randomly treated by applying one of six treatments. The roots of one unit were harvested two weeks before the rest and placed into cold storage at +1°C after the green leaves were removed. On the same day leaf-treatments of a low and a high GA concentration were applied to two further units. This was done by spraying on average 10ml of a 5 ppm solution (0.16ml Progibb per 1000ml pure water) and 10ml of a 10 ppm solution (0.32ml Progibb per 1000ml pure water) respectively, directly onto the leaves of each plant. All plants were left to grow for a further two weeks, after which all roots were harvested and the leaves removed. The roots from two of the three untreated units remaining were treated by submerging them in a 10 ppm (3.2ml Progibb per 10L water) and 100 ppm (32.0ml Progibb per 10L water) GA-solution respectively for 5 minutes. Roots from one unit were left untreated, as a control. The two cultivars were kept apart, but all roots from the four blocks (two blocks from each basin) that received the same treatment were well mixed in order to obtain properly randomized root material eliminating differences that might have occurred within the basins.

For forcing in the dark chamber (ambient- and water temperature were 17°C and relative humidity 85%), a special set-up was created. A PVC pipe with a diameter of 80mm was cut into segments of 160mm in length. A 10mm hole was drilled into the cylinders, 80mm from the bottom. These cylinders were then glued into place on a square PVC board (650mm x 650mm) in such a way that the holes of four adjacent containers faced each other; in total there were 64 containers per PVC board. In the center of the space created by each group of four cylinders, a 12mm hole was made

through the PVC board. Nutrient solution was supplied to each container separately by means of spaghetti tubing, completely cutting out spread of disease. The nutrient solution thus filled each container until it reached the drainage hole. Any excess nutrient solution then drained out of the containers and away through the holes in the PVC board.

For this study, four of the above structures were used to serve as blocks (repetitions) in the growth chamber. In each case four adjacent cylinder containers served as an experimental unit, each holding two roots, thus a total of eight roots per experimental unit. Each of the six treatments of the two cultivars were allotted randomly to the experimental units per block. Once daily 300ml of fresh nutrient solution (Deckers, 1991) was added to that already present in each container. After 25 days the chicons were harvested and sorted into four categories, classes I to III and rejects. After sorting, the length of the pith was measured and expressed as relative pith length taking the overall chicon length as basis.

The data was analyzed with SAS (SAS, 1978) making use of a logit function in the case of the ordinal chicon quality data. Single degrees of freedom were attained by formulating contrasts as follows: (1) No treatment vs. all GA treatments, (2) cold storage treatment vs. the rest of the treatments, (3) root GA treatments vs. leaf GA treatments, (4) high vs. low GA treatments applied to the roots and (5) high vs. low GA treatments applied to the leaves (see Tables 1 and 2).

3 Results

3.1 Relative pith length

No interaction between cultivars and treatments was identified (SL=0.9520), nor was there a significant difference found between the two cultivars (SL=0.2515). The two data sets for relative pith length were therefore merged and presented as in Figure 1. The higher GA concentrations tended to realize a longer pith than the lower concentrations for both , the root- and the leaf treatments (Fig. 1). However, no statistically significant difference in relative pith length between high and low GA concentrations for either root or leaf treatments were found, as the significance levels

of 0.8778 and 0.2705, respectively, show.   Also, the control compared to these treatments did not differ significantly (SL=0.7643).   Nonetheless, the roots that received a chilling treatment responded with a significantly (SL=0.0156) longer pith when compared to the rest of the treatments.   Further analysis using the LSD, however, shows that the only meaningful difference concerning relative pith length is found between the roots that had a chilling period and those that received a low concentration GA treatment, be it by application to the leaves or the root (Fig. 1).
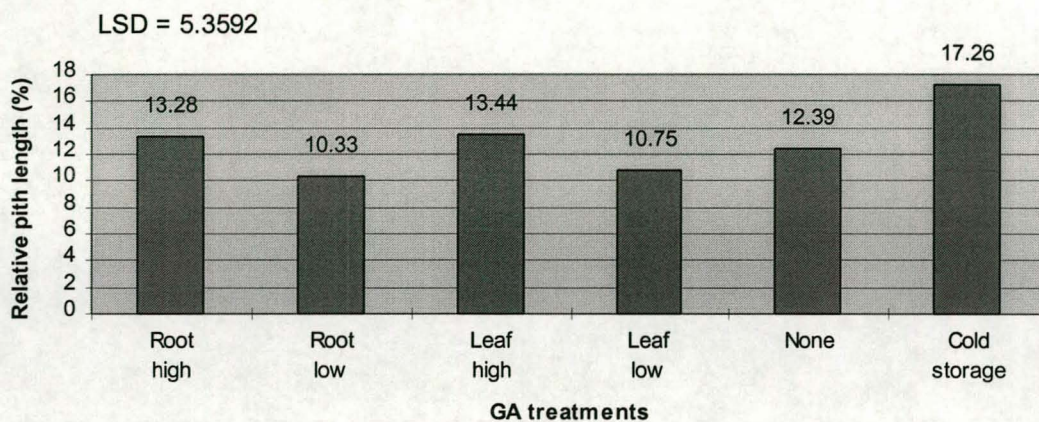

Figure 1: Relative pith length of chicons as a factor of GA treatments

3.2 Chicon quality

Chicon quality was evaluated, using the outward appearance and the size of the chicon head, according to the standards laid down in Muyldermans, Lambrechts & Steenberghen (1993). Size was by no means a problem but because of very poor closure, many chicons had to be down graded by at least one class. The results are presented in Figure 2, showing which percentage of the yield fell into each of the four quality categories. Since there was no interaction or meaningful difference between the two cultivars (SL=0.740), the treatment means were used. The only significant difference found, was indicated by the contrast, measuring the difference between the control and the rest of the treatments (SL=0.047). All remaining significance levels were above 0.228. It is not possible to do shortfall testing on ordinal data, but it can be seen from Figure 2, that the control performed better than the rest, yielding the highest percentage of class I chicons and the lowest number of rejects.
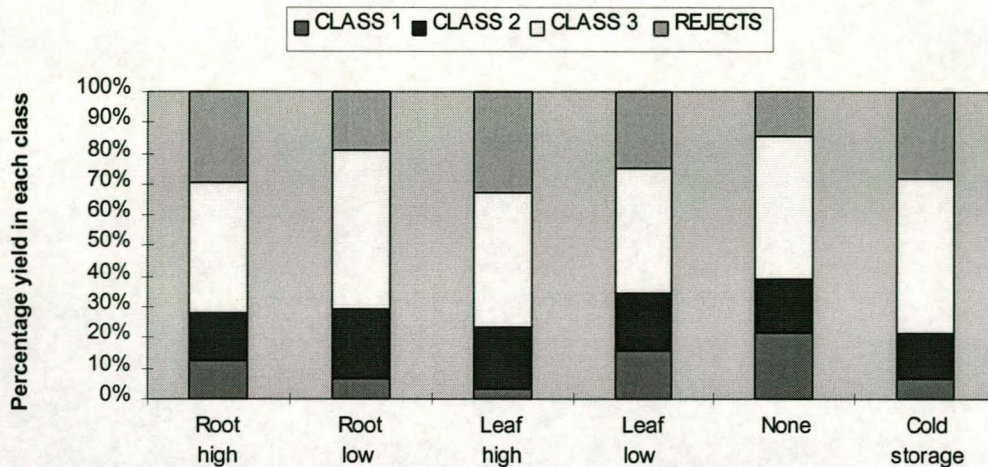
Figure 2: Chicon quality expressed as percentage chicons in each class

4 Discussion

Biesheuvel (1992) reported a relative pith length of 37 and 38 percent for Bea and Flash respectively. Kruistum (1999) came up with similar values. In both cases other varieties were also evaluated. Bea and Flash were found to have among the shortest piths, with other cultivars having piths in excess of 50 percent of the total chicon length. Compared to these findings, the relative pith lengths realized in this study (Figure 1), were indeed extremely short, in all cases less than half of that reported in above mentioned studies. In the light of this, even the significant difference found when comparing cold induced roots to roots that received other treatments, loses significance. Since there was no difference between the control and the GA treatments, it must be concluded that GA cannot be held responsible for the short relative pith length. There are a manifold of other factors that may lead to these results. Yield and quality is directly impacted by the conditions that the roots were grown in (Vandendriesche & Geypens , 1993). Remembering the unusual conditions in which the vegetative growth phase of the roots took place, the question now to be answered is, whether these varieties would perform significantly different when grown in field trials. It must, however, not be forgotten that the cultivars were

actually bred for European conditions and that the performance of these varieties in South Africa may show distinct differences in growing patterns.

Witloof chicory is a long day plant that requires a cold period for vernalization. In the previous study chicon quality was used as an arbitrary measure for completed vernalization and it was found that there was no difference in chicon quality between GA treated roots / leaves when compared to a control. It was not possible, however, to say how GA treatments compared with a cold treatment, as this treatment was not included in that experiment. One of the two aims of the present study was thus to explore whether there was a meaningful difference between GA treatments, the control and a chilling treatment. Both cultivars used were of the "early type", requiring only a short chilling period for vernalization to be completed. It was thus expected that the roots from the two-week chilling treatment would produce a higher percentage of high quality chicons than the control. Quite contrary, however, the control performed significantly better than the rest of the treatments.   A comparison of the chilling treatment with the rest of the treatments showed no meaningful difference. Why this would be the case cannot be explained since a cold storage period is usually a prerequisite for successful forcing. The one conclusion that can, however, be made is that GA treatments do not increase chicon quality under these conditions.

It was mentioned above that most chicons had to be down graded by at least one class. Compared to the usual class I yields of 69 and 65 percent respectively for Bea and Flash (Kruistum, 1999) the overall class I yield in this experiment was extremely poor. Taking the short relative pith length together with the poor quality into account, it appears as though the roots were not ready for forcing. Early types generally can be harvested for forcing after 120 days (Sarrazyn, 1991). The roots used in this study were harvested after 166 days (except those that were harvested after 152 days for the chilling period). Furthermore, the visible signs of ripeness were obvious; distinctive shoulder formed and an inner cavity in the top center of the root. All roots were of an diameter of above 36mm.

It thus seems unlikely that the poor chicon quality and grade I yield point to unripe roots. Also, it is evident that GA is not responsible for the short pith lengths

recorded. The underlying limiting factors have to be found elsewhere - so too, why cold treated roots performed so poorly when compared to the control roots.

Table 1: ANOVA table for relative pith length in witloof chicory

Source	DF	Type I SS	Mean Square	F Value	Significance level
Block	3	119.00	39.67	1.43	0.2518
Cultivars	1	37.81	37.81	1.36	0.2515
Treatments	5	247.59	49.52	1.78	0.1434
None vs. rest	1	2.54	2.54	0.09	0.7643
Cold storage vs. rest	1	180.53	180.53	6.50	0.0156
Root GA vs. leaf GA	1	0.67	0.67	0.02	0.8778
Root: high vs. low [GA]	1	34.86	34.86	1.26	0.2705
Leaf: high vs. low [GA]	1	28.99	28.99	1.04	0.3142
Interaction	5	26.04	5.21	0.19	0.9520
Error	33	4749.12	27.76		
Total	47	1346.36			

Table 2: ANOVA table for chicon quality

Source	DF	Type I SS	Mean Square	F Value	Significance level
Block	3	3.119	1.040	0.564	0.643
Cultivars	1	0.207	0.207	0.112	0.740
Treatments	5				
None vs. rest	1	7.830	7.830	4.246	0.047
Cold storage vs. rest	1	0.718	0.718	0.389	0.537
Root GA vs. leaf GA	1	0.249	0.249	0.135	0.716
Root: high vs. low [GA]	1	0.580	0.580	0.315	0.578
Leaf: high vs. low [GA]	1	2.783	2.783	1.509	0.228
Interaction	5	8.325	1.665	0.903	0.491
Error	33	60.851	1.844		
Total	47				

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CHAPTER 4

Witloof chicory cultivar evaluation - bolting

Witloof chicory cultivar evaluation - bolting

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Abstract

Bolting of witloof chicory (*Cichorium intybus* L.) renders the roots unusable for chicon production. In Europe bolting mainly results from a cold induction early in the season. This problem can be overcome to a certain extent by selecting and breeding cultivars that are bolt resistant, i.e. that do not bolt when planted at low temperatures. Contrary to this, high temperatures and irradience are found to be responsible for the problem of bolting in South Africa. The aim of this paper was to identify cultivars, other than the one mainly used locally (Focus), that promise to be less prone to bolting during hot growing seasons with high irradience. It was concluded that there are better options than Focus for local production.

Keywords: bolting, witloof chicory

1 Introduction

In order for chicory roots to produce quality chicons, their quantitative cold requirement for vernalization needs to be met (Reerink, 1992). In previous trials with witloof chicory (*Cichorium intybus* L.) it was found, however, that roots that received a cold treatment did not produce higher quality chicons than those that were placed directly into the dark growing chamber after harvesting. According to Evans (1971), a variety of alternative pathways may achieve the same result as vernalization in the cases where meristem activation is the limiting process. Evans further proposed that high temperatures may substitute for vernalization, while Sarrazyn (1991) noted that it was possible for chicory to flower and form seed during the first growth year as a result of any growth retarding factor. Gianquinto & Pimpini (1995) and Gianquinto (1997) showed that plants can be induced to flower merely by long day exposure and relatively high irradiance. This poses a practical problem since the roots of plants that bolt and form flowers during the first growing season become useless for chicon production (Demeulemeester, 1995).

The varieties of witloof chicory that are presently used for chicon production in South Africa are all imported from Europe. They are selected and bred in order to perform optimally in maritime climate of Belgium, the Netherlands and France (Nerum & Pieron, 1993). It is thus not surprising that chicory planted in the warm Western Cape easily moves through the transition phase from the vegetative to the generative growth stage resulting in a high percentage of roots bolting before they are ready to be harvested for chicon production. The same problem is experienced in Europe, with the difference that a cold induction early in the season causes the plants to bolt during the first year (Croon, 1993). The focus in this paper will be on identifying the varieties that are least sensitive to bolting under high temperature conditions and high irradience.

2 Materials and methods

Two fundamentally similar trials were conducted over two seasons, 1998 and 1999. The first was conducted in the open with cultivars Focus, Vitessa, Final, Tabor and

Totem, while the second was done in a glass house with cultivars Flash, Bea, Pax and Focus. Focus was included in both trials as this variety is the one that was commonly used by the few producers of witloof in South Africa. Pax, however, is presently rapidly replacing Focus. Seed was sown into well drained containers, filled to a depth of 400mm with river sand (Particle size: ±2mm). Throughout the growing period of 140 days, the plants were fertigated with a nutrient solution as described by Combrink, Jacobs & Agenbag (1996). The irrigation frequency was controlled by a solar integrator set at 4.184 MJ.m^{-2}. At harvest the leaves were cut off 30mm above the root-top. In this way it was possible to sort the roots into those that had a clearly visible growth point and those that have already formed stems. With the latter, the growth points were removed together with the leaves - these were considered to have bolted.

3 Results and discussion

The results of the two trials are shown in Figures 1 & 2. A large variation can clearly be seen. It is evident that there were significant differences between the cultivars in both of the trials. During the first trial (Fig. 1), the performance of Tabor was most promising with only 15.6% of the plants bolting.
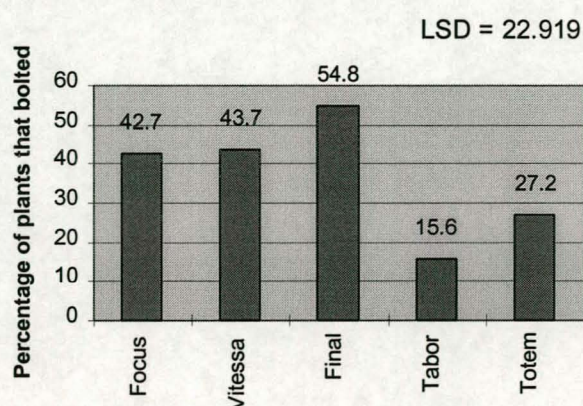

Figure 1: Comparison of bolt-percentages for chicory plants of cultivars used in 1998
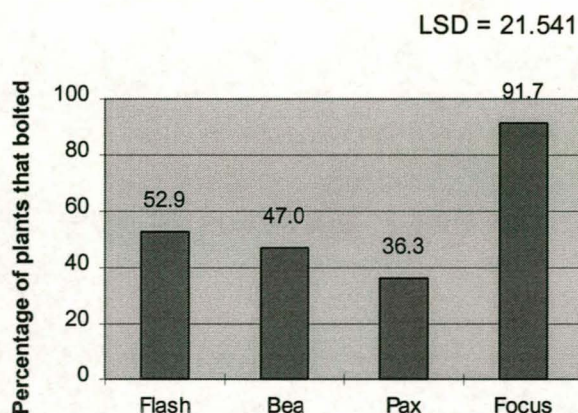
LSD = 21.541

Figure 2: Comparison of bolt-percentages for chicory plants of cultivars used in 1999

The results of the second trial were different from those of the first for cultivar Focus. The reason for this could have been the extremely hot season, few cloud covered days and the fact that the plants were grown in a green house where temperatures rose beyond 41°C during the last three weeks of growth. This happened when the ventilation system broke down and high temperatures probably induced the morphological changes as described by Gianquinto & Pimpini (1995). Although the results may not be representative for natural growing conditions, a highly significant difference between Focus and the remaining varieties is evident (Fig. 2).

The aim of this study was to identify some witloof chicory cultivars that promised to be most resistant to bolting under local conditions. From the 1998 trial Tabor, with only 15.6% of the plants bolting, seriously needs to be considered. The 1999 trial shows Pax with a bolt percentage of 36.3% leading the way. Even though such values are unacceptably high, these varieties performed significantly better than Focus. Before these promising cultivars can be recommended, however, they also need to be evaluated under field conditions.

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