INFLUENCE OF TEMPERATURE ON YIELD AND QUALITY OF CARROTS (*Daucus carota* var. *sativa*)

By

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Submitted in fulfillment of the requirements for the degree Magister Scientiae Agriculturae

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Bloemfontein

November 2011

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DECLARATION

I declare that the thesis hereby submitted by me for the degree Magister Scientiae Agriculturae at the University of the Free State is my own independent work and has not previously been submitted by me at another university/faculty. I furthermore cede copyright of this thesis in favour of the University of the Free State.

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ABSTRACT

INFLUENCE OF TEMPERATURE ON YIELD AND QUALITY ON CARROT

(*Daucus carota* var. *sativa*)

The influence of temperature on yield and quality of carrots were examined using two pot trials that were conducted in the glasshouse and growth chambers at the Department of Soil, Crop and Climate Sciences, on the Bloemfontein campus of the University of the Free State in 2009 and 2009/10.

In the first trial the influence of four temperatures (10, 18, 26 and 32°C) on the growth, yield and quality of two pre-pack carrot cv's. Nectar and Star 3002 were studied. Carrot seed were sown in 0.34 m x 0.34 m x 0.35 m pots, filled with topsoil of the sandy loam Bainsvlei form. Pots were kept in the glasshouse at 20°C (±1°C) for four weeks to allow the seedlings to establish and reach the first true leaf stage whereupon they were moved to the controlled environment chambers at different temperatures for 20 weeks. Growth parameters such as leaf number, plant height and leaf growth were significantly influenced by temperature and all these parameters performed the best at 10°C at the end of the growth season irrespective of cultivar. Root fresh and dry mass did not differ significantly between the two cultivars but the affect of temperature was significant. The highest root fresh mass for both cultivars was also obtained at 10°C, with "Star 3002" with the highest mass (39.12 g) followed by "Nectar" (34.26 g). Both cultivars exhibited the highest root dry mass at the lower temperature treatment (10°C) with "Star 3002" having a higher root dry mass (4.15 g) than "Nectar" (3.87 g). External quality parameters such as root length and diameter differed significantly between the temperature treatments and only the length of carrot roots did not differ significantly between the cultivars. Both "Nectar" and "Star 3002" exhibited the longest roots at 10°C and the shortest roots at 18°C. Root diameter for both cultivars was significantly greater at 10°C than at 18°C. The only defects observed were green shoulder and misshapen roots. Although not significant, the percentage green shoulders and misshapen roots were higher at 18°C than at 10°C. Carrots were significantly firmer at the low temperature (10°C) than at 18°C. The total soluble solid content of carrots however, grown at 18°C was significantly higher than those grown at 10°C.

In the second pot trial the influence of four dual temperatures (15/5, 24/10, 28/20 and 35/25°C) on the growth, yield and quality of two pre-pack carrot cultivars "Nectar" and "CS 1006" was studied. Based on the results of this study, temperature influenced leaf number and plant height of both cultivars, although not always significantly, during the 32 weeks of growth. Leaf number and plant height of carrot plants were greater at 15/5°C treatment. Yield parameters and the external quality parameters such as root length; diameter and absence of defects were also influenced significantly by temperature. Carrot root length and diameter were significantly influenced positively by lower temperatures (15/5°C) and absence of defects such as green shoulder and hairiness were significantly influenced negatively by higher temperatures (28/20°C). Some of the internal quality parameters such as firmness, total soluble solids, carotene, β-pinene and caryophyllene were also significantly affected by temperature. Firmness, total soluble solids and carotene were significantly influenced by lower temperature (15/5°C) whereas β-pinene and caryophyllene were significantly influenced by higher temperatures (28/20°C).

Free choice profiling (FCP) was carried out in order to investigate how semi-naïve panelists described and perceived carrot samples cultivated under different temperature conditions. This method allowed participants to use their own attributes to describe and quantify the food product. The FCP procedure generated six descriptors on the attribute taste and one on aftertaste. The two carrot cultivars grown at the higher temperatures (24/10 and 28/20°C) had descriptors like bitter, sour, bland and chemical, with a definite aftertaste while carrot cultivars grown at lower temperatures (15/5°C) had descriptors such as sweet and carrot taste.

Keywords: leaf number, plant height, leaf fresh mass, leaf dry mass, yield, root fresh mass, root length, root diameter, defects, firmness, TSS, carotene, terpene, sensory analysis, free choice profiling

DEDICATION

THIS DISSERTATION IS DEDICATED TO MY WONDERFUL SON

PHEELLO RANTSATSI

AND

MY LATE GRANDFATHER

TIPI SIMON MANOSA WHO RAISED ME TO BE THE PERSON I AM TODAY.

ACKNOWLEDGEMENTS

There are a number of people without whom this thesis might not have been a success, and to whom I am greatly indebted.

I would like to express my sincere gratitude to the Almighty God for giving me strength and faith:

- I wish to thank my supervisor Dr. G. Engelbrecht for her guidance, support and valuable contribution during the preparation of this dissertation.
- To my co-supervisor Dr. J. Allemann, I appreciate his vast knowledge and his assistance in writing of this dissertation.
- This thesis would have not been complete without the assistance by Me. C. Bothma for her valuable support and time to help me perform the sensory analysis.
- I also wish to thank Prof. A. Hugo for his statistical analysis expertise on the sensory work.
- My thanks also go to Prof. C.C. du Preez, the head of Department of Soil, Crop and Climate Sciences for his support throughout my studies.
- Very special thanks go to Prof. S. Walker whose motivation and encouragement truly made a difference in my life.
- I also wish to thank my family for the support they provided me through my studies and in particular, I must acknowledge my husband and best friend, Mr. Lebohang Rantsatsi, without his love, encouragement, and statistical advice at times of critical need and editing assistance, I would not have finished this thesis.
- I owe a debt of gratitude to my precious son Pheello Rantsatsi who inspired me in my studies and of course for his patience while I was not there when he needed me most. Thank you once again my boy.
- To my parents Mr. Letuka and Mrs. ‘Mats’ele Manosa for their never-ending love and support in all my efforts, and for giving me the foundation to be who I am. Thank you, Mom and Dad. Mom, you have been with me every step of the way, through good and bad times.

- To my mother-in-law Mrs. ‘Malebohang Rantsatsi for always encouraging and motivating me in everything that I went through.
- To my brothers and sisters for their love and support throughout the years. Thank you for the laughing and the fighting, and everything in between.
- I would also like to thank all my friends and colleagues for our philosophical debates, exchanges of knowledge, skills, and venting of frustration during my post graduate program, which helped enrich my experience. The last two years have been quite an experience and you have all made it a memorable time of my life. I will miss all of you. Good luck to each of you in your future endeavors.
- I would also like to thank everyone who contributed to the success of this work being it physical, emotional, psychological or in any other way. I thank you all.
- In conclusion, I recognized that this research would not have been possible without the financial assistance of ICART/SADC and I would like to express my sincere gratitude to this project for funding my studies.

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CHAPTER 1

INTRODUCTION

Carrot (*Daucus carota* var. *sativa*) is a biannual crop that belongs to the Umbelliferea (Apiaceae) family. It obtained its name from the French word *carotte,* which comes from the Latin word *carota* meaning a perennial plant widely cultivated for its long conical orange edible root (Rubatzky *et al*., 1999; Bhale, 2004; Luo *et al*., 2004; Northolt *et al*., 2004). The genus *Daucus* to which the carrot belongs, contains 25 species, and is currently estimated to be the largest genus in the family Umbelliferea (Rubatzky *et al*., 1999). Carrots originated in south Asia, in what are now known as Afghanistan, Iran and Pakistan. Today this vegetable is cultivated in many countries throughout the world such as the Americans, Europe, south-west Asia and Africa (Rubatzky *et al*., 1999). In all these countries, carrots are one of the vegetables cultivated for their high nutritional value (Al-Harbi *et al*., 1997; Munro & Small, 1997).

Carrot is generally a minor crop, but in northern countries it is one of the main field crops cultivated (Suojala, 2000a). During 1998, 18.5 million tones of carrots were produced on 794 000 hectares worldwide (FAO, 1999 cited by Suojala, 2000b). Carrot production slowly increased in Africa and South America over the past 30 years, whereas production in Asia (primarily China) displayed a very rapid increase in 1997 to displace Europe as the leading production region (Anon., 2008a).

Temperature influences growth, yield and quality of carrots in many different ways. Growth parameters among others include, leaf number, plant height and leaf growth. Yield parameters include root fresh and dry mass. Quality of carrots can be classified by external quality parameters such as root length, diameter, colour and absence of defects, as well as internal quality parameters such as firmness, sensory quality, carotene, sugars and terpene content (Mazza, 1989; Rubatzky *et al*., 1999). Yield and quality characteristics of carrots benefit from cooler growing conditions (10 to 15°C). Moderate day and relatively low night temperatures during storage root formation improve carbohydrate accumulation in carrots. At temperatures above 25°C during storage root formation, the respiration rate of the plant increases, resulting in lower yields (Rubatzky *et al*., 1999). South Africa has different climatic agricultural regions for carrot production, with specific cultivars utilized for pre-packing.

Recently, consumers are paying more attention to the physical and chemical properties of carrots. If carrots are grown under high temperatures, terpene synthesis increases, resulting in carrots with a bitter taste or aftertaste (Rosenfeld *et al*., 2002). Terpenes comprise out of a vast diverse group of natural products and are present in various forms in most organisms where they fulfill a broad range of functions. It ranges from volatile monoterpenes to steroid hormones, carotenoids and polymers, such as rubber (Harrewijn *et al*., 2002). Terpenes blocks the sweet taste of carrots (Rosenfeld *et al*., 2004) and some, when present at a high concentration cause carrots to taste bitter, not favoured by consumers (Rosenfeld *et al*., 2002). Bitterness is a quality defect and successful marketing depends on lowering the occurrence of bitter carrots (Kleemann & Florkowski, 2003). Bitterness is one of the four common taste sensations recognized by man (Rouseff, 1990) and is detected on the back of the tongue, the back of the hard palate and in the pharynx and this is tasted strongest as an aftertaste (Fenwick *et al*., 1990).

Temperature has an effect on the growth, yield and quality of carrots. There is limited information available on the influence of temperature on carrots and lack of new carrot cultivars. Therefore there is a need for further research on the influence of temperature on the qrowth, yield and quality of carrots.

The general aim of this study was to determine the influence of different temperatures on pre-pack carrots. Sub-objectives were:

- To investigate the growth of different pre-pack carrot cultivars at different temperatures.
- To study the yield and quality (external and internal) parameters of different pre-pack carrot cultivars at different temperatures.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Carrot (*Daucus carota* var*. sativa*) is a cool season vegetable crop, performing well under cooler weather (10 to 25°C) (Joubert *et al*., 1994; Rubatzky *et al*., 1999). Carrots have been cultivated under different temperatures and in different soils influencing the growth, yield and quality in different ways. According to Rubatzky *et al*. (1999), temperature is the most important climatic factor affecting the production of carrots. It has an effect on plant growth mainly on the rate of chemical reactions, and consequently the usage of photosynthetic products (Rubatzky *et al*., 1999; Suojala, 2000a). Joubert *et al*. (1994) indicated that a yield of 30 to 40 tons ha^{-1} is regarded as a good average, although successful farmers often achieve 60 tons and more.

In this literature review four areas of interest to the study are reported on: firstly, the optimum temperature requirements of carrots; secondly, the growth parameters of carrot as influenced by temperature; thirdly, the yield and quality of carrot as influenced by temperature and fourthly the characteristics of the three pre-pack carrot cultivars ("Nectar", "Star 3002" and "CS 1006").

2.2 CLIMATE REQUIREMENTS

Climate has the most important influence on crop production (Rubatzky *et al*., 1999). Sustainable production of carrots can only be attained under favourable climate conditions. There is limited information available on the effect of climate on growth development of pre-pack carrot cultivars in South Africa. As a result, many scientists conducted research on the influence of climate on growth, yield and quality of carrots. Climatic factors influencing carrot production include temperature, rainfall, moisture, and to a lesser extend, day-length and light intensity (Nortjè & Henrico, 1986).

2.2.1 Temperature

Carrots are a cool-season root crop, although they can tolerate high summer temperatures. Quality and yield however, are the best under cooler conditions (Alam *et al*., 2004; Petzoldt, 2008; Alam *et al*., 2010). Carrots belong to the moderately hardy group of vegetables that are not sensitive to winter cold and frost (Joubert *et al*., 1994). The optimum temperature for growth, yield and quality range between 10 and 25°C (Joubert *et al*., 1994; Rubatzky *et al*., 1999). Alam *et al.* (2004) also indicated that the optimum day and night temperatures for plant growth are between 21 and 22°C and 18 and 20°C, respectively. Carrots can be grown throughout the year, except in extremely cold areas, where there is almost no growth during winter and in very hot regions. In summer it is difficult to attain a good stand (Joubert *et al*., 1994; Rubatzky *et al*., 1999; Anon., 2008a).

Carrots in the seedling phase will endure frosts and temperatures as low as -7°C. The top growth is slow at temperatures below 4°C, and consecutive severe frosts will cause the leaves to die (Joubert *et al*., 1994; Anon., 2008b). Furthermore, once the soil freeze, crown damage occurs as small hairlines and horizontal splits on the surface of the storage root (Anon., 1997).

Carrot storage roots are more vulnerable to frost damage when the plants are mature. Still, storage roots will withstand severe frost if they are not showing above the soil and also provided the soil does not freeze. Frost-damaged roots tend to be of a poor quality (Anon., 1997). The yield and quality of carrots are reduced when mean temperatures are above 25°C and /or below 10°C. Temperatures as low as 4°C also influence quality characteristics such as root length, diameter and shape. The brittleness of carrot roots increases with cooler soil temperatures, and the roots crack. Nantes carrot types, largely because they do not have strong central core development, split or crack more easily in extremely cold weather than other carrot types (Anon., 1997). Extremely high temperatures (>40°C) cause a bitter taste, reducing sweetness and increasing fibrous texture of the storage root (Rubatzky *et al*., 1999).

2.2.2 Rainfall

Rainfall is the most essential climatic factor for plant growth therefore irrigation is required throughout the season (Rubatzky *et al*., 1999). Water affects the physiological metabolic functions of the plant. Suojala (2000a) and Mader (1993) stated that through precipitation, water is made available to plants as surface water, soil water or groundwater. Plants comprises out of about 70-90% water or even more on a fresh mass basis. It is generally believed that, carrots are more tolerant to drought than other vegetable crops due to their extensive root system (Suojala, 2000a; Lada & Stiles, 2004). Tindall (1968) mentioned that carrots are tolerant to too little or too much irrigation. However, the availability of soil moisture throughout the growing season is one of the most vital production requirements for carrots (Rabatzky *et al*., 1999; Suojala, 2000a). South Africa is a semi arid country with unreliable rainfall and carrots are therefore planted under irrigation.

Excessive or deficient soil moisture can affect the quality of the roots (Anon., 2008b). Inadequate soil moisture results in long and thin roots, while excessive soil moisture in short, thick and pale coloured roots (Joubert *et al.*, 1994; Fritz *et al*., 1998; Rubatzky *et al.,* 1999; Anon., 2008b). Furthermore, low soil moisture will force the plants to invest in root extension growth rather than storage root development resulting in a reduction in root yield (Lada & Stiles, 2004). According to Fritz *et al*. (1998) moisture stress is reported to cause woody and poorly flavoured roots. Carrot yields and root length were more influenced by the water content during the vegetative period (Henkel, 1970; Millette, 1983). Water stress during root development causes cracking of the roots (Anon., Undated a). Suojala (2000b) also reported that low precipitation at the end of the growing season may promote dying of the oldest leaves.

Lada & Stiles (2004) indicated that the highest water demand of carrots is during the root enlargement phase. Carrots require a steady supply of moisture and available soil moisture needs to be maintained above 50% of plant available water throughout the growth season. Carrots require approximately 25 mm of water per week but under warm, dry conditions 50 mm will be required (Anon., Undated a). According to Lada & Stiles (2004) young carrot seedlings are very vulnerable to physiological damage if their moisture requirements are not met. Long intervals between irrigations can cause the development of thinner roots (Nortjè & Henrico, 1986). Frequent irrigations also discourage good root colour formation (Nuńez *et al*., 1997). Watering should gradually be reduced to prevent longitudinal splitting of the roots when the crop approaches maturity (Anon., 2003). Siddiqui (1995) indicated that proper scheduling of irrigation is one of the major agro-techniques for maximizing the yield of carrot. Joubert *et al.* (1994) stated that soil that is well drained and regularly irrigated ensures uniform development and thus carrots of the best quality.

2.2.4 Photoperiod

Photoperiod or day length varies according to season of the year and latitude. It varies from a nearly uniform 12 hour day at the equator (0 latitude) to continuous light or darkness throughout the 24 hours for a part of the year at the poles (Decoteau, 1998). One important plant response to day length (photoperiod) in species such as carrot, beetroot and radish is flowering or the formation of storage organs (Anon., 1998; Decoteau, 1998; Kang, 2010). The importance of photoperiod was emphasised by Rosenfeld *et al.* (1998b) who grew carrots at constant temperatures (9,12, 15, 18 and 21°C) under controlled climate conditions with a 16 h of artificial fluorescent light and found a significant increase caused by both temperature and photoperiod in most chemical and physical variables of the roots.

Carrots are tolerant to long days but need low temperatures to induce flowering (Anon., 2008b). Hence, Suojala (2000a) showed that a long photoperiod (16 h) was more effective on carrot leaves than a short photoperiod (8 h). According to Hole & Dearman (1993), a constant photoperiod compared to a short and long day photoperiod had no clear effect on shoot fresh mass or leaf area in carrots. The internal quality of carrot roots, particularly sugar content, improves with long photoperiods. Samuolienè *et al.* (2008) reported that the amount of sucrose increased in the apical meristems of carrots during flower initiation especially under long day (16 h at 21/17ºC) treatments and a decrease in sucrose was observed under short day treatments (8 h at 4ºC). The colour of carrot roots also reduced when the number of light hours is reduced and temperatures are above or below the optimum (10 to 25°C) (Anon., 2008b).

2.2.5 Light intensity

Photosynthetically active light is the practical measurement of light in plant biology. It is a well-known component of the growth environment contributing to more than 90% of the dry matter of the plant through photosynthesis (Decoteau, 1998; Suojala, 2000a; Antonious & Kasperbauer, 2002; Holley, 2009). Light intensity is a major factor governing the rate of photosynthesis in plants. The quality or amount of light received by plants in a particular region is affected by the intensity of the incoming light and length of the day (Decoteau, 1998). Light energy influences almost all the aspects of plant life directly or indirectly. Thus, it controls plants structure, form, shape, physiology and growth, reproduction, development and local distribution (Kang, 2010). The intensity of light changes with elevation and latitude. It also varies with the season of the year, as well as other factors such as clouds, dust, smoke or fog (Anon., 1998; Decoteau, 1998).

Antonious & Kasperbauer (2002) concluded that at warmer temperature, the effect of light intensity on carrot plants was more significant than at cooler temperature. The process of photosynthesis in many plants increase as temperature increases. The rate of photosynthesis in carrots was much higher at 25°C than at 15°C at high light intensities meaning that carrot growth increased (Hall & Rao, 1999). Decoteau (1998) indicated that carrot growth was high under low light intensities at cooler temperatures, but Hole & Dearman (1993) found that carrot shoot dry mass, as well as the fresh and dry mass of storage and fibrous roots were reduced under low light intensities. On the other hand, Hole & Sutherland (1990) obtained plants with a higher fresh mass at low light intensities and 20°C. The effect of light on carrot growth was also experimented with by Albayrak & Camas (2007) who found that light intensity had no significant effect on leaf area at high temperature (20°C).

2.4 EFFECT OF TEMPERATURE ON DEVELOPMENT OF CARROT PLANTS

Growth is an increase in the size of an organism or part of an organism, usually as a result of an increase in the number of cells. Sustained plant growth is dependent on the availability of moisture, light, temperature, nutrient minerals and carbon dioxide (Rubatzky *et al.*, 1999).

2.4.1 Morphology of the carrot

Leaf number, plant height and leaf growth are all indicators of carrot growth (Rubatzky *et al*., 1999). The carrot plant consists of a stem, leaves, roots and flowers. The stem of the plant, as with many vegetable umbellifers is just above the ground during its vegetative state and is compressed so that the internodes are not clearly discernible. The apical meristem is slightly convex. The leaves of carrots develop alternative from the apical meristem forming a rosette at the base. Petioles bases are expanded and sheath-like at their basal attachment. New leaves develop centripetally in a spiral within the basal clasping of preceding petioles. Carrots have compound leaves, each leaf consisting of several finely divided leaflets. Leaf blades are two to three pinnate, the leaflets being repeatedly divided (pinnatifid) with small highly lobed segments that are oblong or linear and acute (Rubatzky *et al*., 1999; Ravishankar *et al*., 2007: Anon., 2000). Floral initiation involves a morphological shift from the stem's relatively flat apical meristem producing leaves to an uplifted conical meristem capable of producing a stem elongation and an inflorescence (Borthwick *et al*., 1931 cited by Rubatzky *et al*., 1999). Rubatzky *et al*. (1999) indicated that in general, carrot flowers are perfect, small and white or occasionally greenish white or light yellow. Flowers consist of five petals, five stamens and an entire calyx.

2.4.2 Growth and development

Temperature influences the composition of plant tissues during growth and development. The total available heat and the extent of low and high temperatures are the most important factors determining growth rate, chemical composition and consequently the yield of horticultural crops (Rubatzky *et al*., 1999; Bonhomme, 2000; Lee & Kader, 2000). As mentioned earlier, the optimum temperature for growing carrots is between 15 and 20ºC (Joubert *et al*., 1994; Rubatzky *et al*., 1999; Kluepfel & Smith, 2002; Anon., 2006). Quagliotti (1967) reported an increase in carrot vegetative growth at 20 and 26°C compared to that at 14°C. Saito (1934) (cited by Suzuki, 1978), however, reported that growth during the early development stage of root crops such as radish was reduced when plants were subjected to warmer temperatures a week after seeding, indicating that there is a sensitive period to warm temperature in the early growth stage of radish. It can be concluded that temperatures above 28°C and below 10°C during the early vegetative stage reduces foliage growth of carrots (Nuńez *et al*., 1997; McGiffen *et al*., 1997; Anon., 2006). If temperatures fall below the optimum during the early vegetative stage, unwanted flower stalks may appear (bolt) (McGiffen *et al*., 1997; Anon., 2006).

Different carrot cultivars perform differently at different temperatures and locations. Hence, the development of cultivars adapted for cultivation in both summer and winter seasons on all continents has allowed all year round availability of carrots (Simon *et al*., 2008). For example, in South Africa carrot cultivars such as “Nectar”, “Star 3002”, “CS 1006”, “Cape Market”, “Chantenay Karoo” and “Kuroda” are cultivated in summer while carrot cultivars such as “Adelaide” and “Darling” favour winter season cultivation (Anon., 2009a; Anon., 2009b).

2.4.3 Yield and quality

Growing conditions such as temperature, soil moisture, rainfall, light intensity and day length have a significant effect on the yield and quality of carrot roots (Bloksma *et al*., 2003). The influence of varying temperatures on yield and quality parameters of carrots has been a topic for research during the last three decades (Rosenfeld & Samuelsen, 2000). Simon *et al*. (1982) stated that the growth temperature of carrots affects the level of volatiles, as well as the sugar, carotenoids and texture of the roots. The best quality carrots were obtained when weather conditions favour regular uninterrupted growth (Anon., 2008a).

2.4.3.1 Yield

The yield of any crop is the chief indicator of productivity. It is a quantitative characteristic, which results from the interactions of many components such as plant height, root diameter and fresh and dry mass (Ali *et al*., 2003). Several factors such as temperature, light intensity, day length, rainfall and soil moisture have a significant impact on the yield of carrots. In order to attain the highest potential yields, the crop should be grown in an environment that meets these requirements (Decoteau, 1998). Poor cultivation practices and the lack of high yielding carrot cultivars may be reasons for low yields (Siddiqui, 1995; Alam *et al*., 2010). The fresh mass of carrots (yield ton ha^{-1}) consists out of 85-90% water and 10-15% dry matter (Odebode & Unachukwu, 1997). The dry matter of carrots consists of nitrate, amino acids, amides proteins and carbohydrates (Northolt *et al*., 2004). According to Niedziocha (2011) one raw medium carrot weighing 78 g contains only 25 calories, of which, 23 cal or 5.84 g are from carbohydrates. These carbohydrates consist of 2.89 g of sugar, while the remainder come from fiber. As a result, Dolson (2011) stated that carrots are among root vegetables with the lowest charbohydrate content.

Temperature is one of the most vital climatic factors affecting carrot yields. Carrots that were planted under 12ºC had larger and wider taproots and a higher dry matter content (20%) than those grown at 25ºC (González *et al*., 2009). Rosenfeld *et al*. (1998a) and Rosenfeld *et al*. (1998b) grew carrots at constant temperatures of 9, 12, 15, 18 and 21°C and obtained the highest root dry mass at 12 and 15°C. Olymbios (1973) (cited by Benjamin *et al*., 1997) also found a decrease in root dry mass of 47% at temperatures between 15 and 25°C. Hole (1996) suggested that the carrot storage root favours lower temperatures than the leaves. It is clear that the optimum temperature for yield is between 12-15°C.

2.4.3.2 Quality

2.4.3.2.1 External

Shape, root length and diameter

Carrot cultivars are classified according to shape and root length. Roots can either be conical, spherical or cylindrical. According to Rosenfeld *et al*. (1998a), carrot root shape is determined primarily by genotype but can also be influenced by climate conditions during root growth. Petzoldt (2008) reported that good quality roots, judged by shape and length, develop at soil temperatures of between 15.5 and 21.1°C. Temperatures below 15°C encourage thin, long, conical pointed roots (Joubert *et al*., 1994). Carrot root tips were more round and less cylindrical at temperatures above 25°C (Rosenfeld, 1998; Rubatzky *et al*., 1999). High temperatures (>25°C) also change root shape by increasing sloping of shoulders, slightly lifting up the stem giving it the appearance of a neck, whereas at favourable temperatures root shoulders have a slightly rounded, level or square-like appearance (Rubatzky *et al*., 1999). At temperatures higher than 25°C, storage roots will also be shorter (Joubert *et al*., 1994; Rubatzky *et al*., 1999) whereas low temperatures (10 - 15°C) increase root length (Joubert *et al*., 1994). Results show that optimum temperature for root length and diameter is between 12-15°C.

Defects

Defects of carrot roots include physiological disorders such as forking, cracking, splitting, bruising, misshapen, green shoulder, internal greening and diseases. Forked and cracked roots are more common in summer when temperatures are high than in the cooler times of the year (Valenzuela & Lai, 1991; Joubert *et al*., 1994; Alam *et al.*, 2004). In summer carrots develop a rough appearance or they tend to be misshapen when the warmer temperatures limit the quality of the storage root. Green shoulder and internal greening are physiological disorders in carrot roots caused by chlorophyll accumulating at the crown due to exposure to sunlight and extending internally to the core tissue (Ravishakar *et al*., 2007). Greening affects root appearance and quality by making the roots unfit for consumption due to its bitter taste (Ravishakar *et al*., 2003).

A number of diseases can diminish both the yield and the quality of the roots. Roots intended for the fresh market must be almost blemish-free and the leaves of bunched carrots must be free of any damage. A large number of pathogens can attack the foliage of carrots (Joubert *et al*., 1994; Alam *et al.*, 2004). While tops are not an issue for pre-pack carrots, healthy tops are significant for easy harvest since the undercut carrots are often mechanically removed by the leaves. Disease infection can cause wasteful harvesting, yield and quality losses of carrots. A number of bacteria such as hairy root (*Agrobacterium rhizogenes)* and bacterial soft rot (*Erwinia chrysathemi*) can cause misshapen roots and direct yield losses. A variety of nematodes can cause damage to the roots (Davis, 2007). For example, root knot nematode (*Meloidogyne hapla*) damage can result in crop losses when temperatures are between 12 and 18ºC during the growth season. The damage caused by nematodes makes plants susceptible to drought stress and mineral deficiencies resulting in surrounding root cells swelling or dying (Anon., 2011).

Fungal diseases such as *Alternaria* blight (*Alternaria dauci*), black root rot (*Thielaviopsis basicola*), brown root (*Phythium spp.*), phytophthora root rot (*Phytophthora megasperma*) occur in late summer and autumn, when temperatures are warm, the humidity is high and heavy dew occur. Leaf blight (*Xanthomonas campestris*) affects the carrot leaves. Leaf blight appears as a black ring at the top of the root (Anon., 2008b). Soil temperature is usually a serious factor for soil borne problems on vegetable crops (Koike *et al*., 2003). Cooler soil temperatures generally slow pathogen growth and lessen the severity of the crop for the diseases. Under warmer temperatures, pathogens grow and develop quickly and can cause more infection. Huang & Ploeg (2001) indicated that at a soil temperature of 25ºC needle nematode (*Longidorus africanus)* affects carrot yields considerably and eventually the quality of the roots. Symptoms of damage consist of swelling of the root tips, which may result in forking of the tap root, thus rendering the crop unmarketable (Ploeg, 1999).

2.4.3.2.2 Internal

Consumption of carrots has increased mainly due to their high nutritional value, as well as the development of new cultivars with enhanced flavour (Rubatzky *et al*., 1999; Gajewski *et al*., 2007). Valenzuela & Lai (1991) indicated that quality carrots should be sweet, firm, fresh and generally well coloured.

Climatic conditions have a considerable influence on the texture of carrots (Baardseth *et al*., 1995). Texture is a complex but significant aspect for the quality of root vegetables (Herppich *et al*., 2005). Bhale (2004) mentioned that high temperatures may cause heat damage or injury to plant tissue that may influence the texture and structure. The texture of root crops is mainly determined by the structural composition of cellular tissues. Carrot firmness may be increased in response to low, non-freezing temperatures (4°C) without the variation in root water status (Gómez & Sjöholm, 2001). Temperature's influence on firmness depends more on the overall tissue structure (genetic) and the stage of development of the produce (Johnson *et al*., 2001).

Vegetables are vital for a healthy diet, and their texture along with physical appearance and attributes such as colour is essential to the consumers. Kilcast & Fillion (2001) indicated that textural traits are of great importance in the enjoyment of vegetables, and even minor differences can result in the consumer rejecting the food. Characteristics such as crispness and crunchiness are considered as key components of desirable texture for many vegetables, but baseless theories are often made when identifying the key sensory attributes that are important to consumers. There is evidence that measurements made using a penetrometer are good predictors of sensory texture attributes (Harker *et al*., 2002).

Sistrunk *et al*. (1967) reported that the concentration of sugars vary considerably among carrot cultivars and is influenced by climate conditions. The total sugar content in carrots roots, ranges from 3.5 to 10.7% (Alabran & Mabrouk, 1973) with sucrose, glucose and fructose the major sugars present (Alabran & Mabrouk, 1973; Kjellenberg, 2007). Sugars and amino acids (nonvolatile compounds) are the taste-bearing compounds of carrots (Alabran & Mabrouk, 1973). Kjellenberg (2007) mentioned that the quantity of sugar in carrots has a clear correlation to the perception of sweetness and can also contribute in masking bitter taste in carrots. Northolt *et al*. (2004) reported that higher temperatures of between 20 and 25°C and drought had a positive effect on sugar concentration in carrot roots. Rosenfeld *et al*. (1998a) found that the sweetest carrots, grown under a low constant temperature of 9ºC, contained more glucose and fructose than sucrose. Even though sugars alone do not account for variation in sweetness of raw carrots, higher sugar levels and increased sweetness are desirable in improving flavour (Simon *et al*., 1980).

Colour is an important attribute for both internal and external quality of cultivated orange carrot varieties (Geoffriau *et al*., 2005). Colour is largely due to genetic factors but can also be influenced by climatic conditions and can certainly vary between stages of plant development (Kjellenberg, 2007). A uniform, bright orange colour is a major quality characteristic for carrots. Overall, poor root colour or uneven colour development has been known as a production defect that influences the external quality of carrots. Rubatzky *et al*. (1999) distinguishes between two types of carrots, the eastern (or Asiatic) and the western carrots on the basis of root colour.

Eastern carrots have reddish purple or yellow roots while Western carrots have orange, yellow, red or white roots. These colours are still found today, although the orange or orange-red colours are by far the most popular (Anon., 2008b). Northolt *et al*. (2004) indicated that the colour of carrot root is more orange or reddish in dry, warm summers than in wet, cold summers.

Bhale (2004); Anon. (1997) and Islam *et al*. (1998) stated that the deep orange colour found in vegetables like carrots are caused by the high carotene content, or provitamin A. β-carotene assists in the human immune system and is a powerful antioxidant that may decrease the incidence of cardiovascular diseases and certain forms of cancer (Alam *et al*., 2004; Bhale, 2004). Suslow *et al*. (1999) and Dris & Jain (2004) have indicated that the total carotene content and distribution at harvest is influenced by genetic and climatic factors. The optimum temperature for carotene synthesis is between 15 and 21°C (Joubert *et al*., 1994; Rubatzky *et al*., 1999; Suslow *et al*., 1999; Anon., 2008b). When temperatures are below 10ºC and above 30ºC carrots become lighter in colour (Ware & McCollum, 1975; Suslow *et al.*, 1999; Rosenfeld, 1998; Kjellenberg, 2007).

Rosenfeld *et al*. (1998a) reported that a temperature of 18°C favoured carotene production when compared to 9ºC**.** Nortjè and Henrico (1986) explained that higher α- and β-carotene carotene levels were achieved at a low soil moisture content. This, however, appeared to be caused by the higher soil temperature (18°C) that developed during the day under dry soil conditions. They also indicated that the inhibiting effect of high soil moisture content on the β-carotene content of the developing roots under high soil temperatures (18°C) during the day, lowering the colour intensity of the carrot. Carotene levels in carrot roots also vary with cultivar, location and soil type. The carotene concentration of Nantes (59 mg g^{1-} fresh mass) and Chantenay types (41 mg g^{1-} fresh mass), for example are lower than 'Danvers 126' and 'Imperator 58' (Table 2.1).

Table 2.1: Carotene concentration of several carrot types/cultivars (Simon & Wolff 1987)

Type/cultivar	**Total carotene content (mg g^{-1}) fresh mass)**
Chantenay	41
Nantes	59
'Danvers 126'	71
'Imperator 58'	78

Volatile terpenes are responsible for the distinctive odour (Hampel *et al*., 2005) and typical carrot taste, as well as harsh flavours (Simon *et al*., 1980; Kjellenberg, 2007). The taste of carrots is a unique composition between sweet, fruity and more harsh or bitter flavours. Kleemann & Florkowski (2003) explained that flavour is the sensation that is appreciated when food or beverage is placed in the mouth. It is derived from the chemical senses of taste and smell, although other senses such as touch, pain, cold and warmth may play a minor part.

Simon *et al*. (1980) indicated that flavour is an important component of the overall quality of carrots. A number of factors influence the balance between the different flavours and consequently contribute to the final taste of carrots. The sweet, harsh and bitter taste of a carrot can be determined by the genotype and environmental conditions (Simon, *et al.,* 1980; Simon *et al*., 1982). The flavour variables such as carrot flavour and terpene flavour as indicated by De Bellie *et al*. (2003) were largely influenced by climatic factors. Consumers generally prefer sweet carrots without a harsh, aftertaste or bitter taste (Simon *et al*., 1980). Rosenfeld (1998) indicated that prolong hot weather conditions late in the development of the carrot causes an undesirably strong flavour in the root.

A number of terpenes such as α-pinene, β-pinene, caryophyllene, limonene, myrcene, terpinene and terpinolene are found in carrots. Terpenes are more common in the upper part and in the phloem of the root. High temperatures (18 and 21 °C) led to more terpenoid volatiles in carrots thus resulting in flavours such as; terpene , green, earthy, bitter and an aftertaste (Rosenfeld *et al*., 1998a; Rosenfeld *et al*., 1998b; Rosenfeld *et al*., 2002). Terpinolene, one of the terpenes, decreased with an increase in growth temperatures, but it probably only plays a minor role in masking the sweet taste of carrots (Simon *et al*., 1982; Rosenfeld *et al*., 2002). Despite the importance of terpenes for carrot flavour little information is available on terpene biosynthesis in carrots (Hampel *et al*., 2005).

The eating quality of carrots can be measured directly by sensory techniques or indirectly by chemical, mechanical or visual measurements. Sensory quality as stated by Suojala (2000a) is an increasingly essential aspect of vegetable quality. The contribution of diverse components to the sensory quality of raw carrots has been studied but is still not entirely understood. Taste as one of the sensory qualities, is the sensation which is cherished by the taste-buds, and is based on the balance between sugar and terpenes in carrots (Kleemann & Florkowski, 2003).

Carrot taste is dependent on the cultivars genetic composition, cultivation location and climatic conditions. (Hogstad *et al*., 1997; Kjellenberg, 2007). Carrot roots from different altitudes of the north and the south of Norway were analysed, and it was concluded that the taste was influenced more by climate than the type or cultivar. According to Rosenfeld *et al*. (1998b) temperature among other climatic factors, was the most important factor determining sensory attributes and chemical composition. The sensory profile of carrots grown in controlled climate chambers corresponded well with those of field grown carrots (Rosenfeld *et al.,* 1997).

Martens *et al*. (1985) observed that the sensory quality of carrots was influenced by the temperature during growth. A bitter taste was experienced in roots grown at 21°C, while those grown at 9°C were sweeter (Rosenfeld *et al.,* 1997). Low constant growing temperatures (9, 12 and 15°C) favoured the sweet taste, acidic taste, crispness and juiciness of carrots whereas high growing temperatures (18 and 21°C) resulted in a bitter taste and increased firmness of roots grown in phytotrons (Rosenfeld *et al*., 1997; Rosenfeld *et al*., 1998b).

It can be concluded that lower temperatures between 12-15°C increased carrot yield and some quality (external and internal) parameters significantly. Whereas higher temperatures between 18-21°C increase presence of defects and some terpenes.

2.5 CHARACTERISTICS OF SELECTED CARROT CULTIVARS

The three cultivars selected for the project are Nantes types, which reach maturity approximately 90 to 120 days after sowing in summer and 110 to 150 days in winter (Joubert *et al*., 1994). They are primarily used for pre-packing. There are four common temperate carrot types grown worldwide, and these are Nantes, Imperator, Chantenay and Danvers. Nantes is mainly cultivated for home use, farmer market or foliage that is weakly attached to the crown. The root is moderately long (Rubatzky *et al*., 1999; Fritz *et al*., 1998). Nantes types are (18 to 22 cm) long with a uniform diameter (2.5 to 3 cm) along the length and a rounded tip when mature. They require loose soil in order to grow straight and not fork. For instance, common cultivars in the Nantes type are “Nectar”, “Star 3002”, “CS 1006” and “Scarlet Nantes”. The root surface is thinner and easier to scar. The highly pigmented core is poorly developed making roots brittle and it matures early. Nantes is less suitable for long-term storage owing to the fact that roots have higher sugar content, lower in terpenoids and lower dry matter (Anon., 2010; Anon., 2009a; Anon., Undated a, Anon. Undated b). The Chantenay type is a short, thick carrot that is perfect for shallow plots such as window boxes, or container gardening. The average length of the Chantenay carrot is between 7.62 and 15.24 cm, with a diameter of approximately 5.08 cm. Some common cultivars for the carrots of this type include “Kurota Chantenay”, and “Red Core Chantenay”. Chantenay cultivars are fairly fast-maturing carrots that reach peak length at about 70 days (Anon., 2008b; Anon., 2010). There is limited information available on the effect of temperature on yield and quality of these cultivars in South Africa.

2.5.1 “Nectar”

“Nectar” has a cylindrical shape, a diameter of 3 cm and root length is approximately 20 cm. It is well suited for mechanical harvesting and is perfect for pre-packing of 1 kg as well as 5 kg packs. “Nectar” is strongly recommended for cultivation under hot conditions which make it suitable for early to late summer sowing (Anon., 2009a).

2.5.2 “Star 3002”

“Star 3002” is a very high yielding cultivar with uniform, long and cylindrical roots (18 – 22 cm), well stumped at maturity. The exterior is smooth with good internal colour and a narrow core. It has a short to medium leaf height with a medium leaf attachment. It has a high level of bolting tolerance after a cold winter and is an ideal pre-pack cultivar. It also has intermediate resistance to *Alternaria.* “Star 3002” is recommended for cultivation under cool conditions (Anon., 2009b).

2.5.3 “CS 1006”

“CS 1006” roots have a cylindrical shape with approximate dimensions of 20 x 3 cm. This cultivar is highly recommended for cultivation under hot conditions, making it suitable for early to late summer sowing. “CS 1006” is well suited for mechanical harvesting and is perfect for pre-pack carrot for 1 kg as well as 5 kg packs (Anon., 2009a).

2.6 CONCLUSION

According to literature it can be concluded that temperature together with other climatic factors such as rainfall, light intensity and photoperiod play a major role on the growth, yield and quality (internal and external) of carrots. Therefore the optimum temperatures for carrot growth, yield and quality is between 12-15°C. Limited information is available on the influence of temperature on the selected cultivars and therefore there is a need for further research.

CHAPTER 3

MATERIAL AND METHODS

3.1 GENERAL

To study the influence of temperature on the yield and quality of carrots, two pot trials were conducted in the glasshouse and growth chambers of the Department of Soil, Crop and Climate Sciences, on the Bloemfontein campus of the University of the Free State in 2009 and 2009/10.

3.2 SOIL COLLECTION AND PREPARATION

Topsoil from a fine sandy Bainsvlei form (Soil Classification Working Group, 1991) was collected, dried at room temperature, sieved through a 5 mm screen, mixed manually several times and stored. A soil sample was sent to the Soil Analyses Laboratory at the ARC-Small Grain Institute in Bethlehem for physical and chemical analyses prior to planting (Table 3.1). The phosphorus and potassium content of the soil (9 and 72.6 mg kg^{-1} respectively) were far lower than the minimum requirement of 30 and 120 mg kg^{-1} recommended for vegetable production by the FSSA (2007). This was rectified prior to planting (Section 3.4).

Table 3.1: Some physical and chemical properties of the soil used in both pot trials (2009 and 2009/10)

Property*	
Physical properties	**(%)**
Sand (0.02-2 mm)	86
Clay (0.002 mm)	10
Loam	4
Chemical properties	
$pH_{(KCl)}$	5
CEC	3.55
Nutrients	**(mg kg^{-1})**
P (Bray 1)	9.0
K (NH_4OA_c)	72.6
Ca (NH_4OA_c)	362.0
Mg (NH_4OA_c)	188.1
Na (NH_4OA_c)	2.9

***Determined using standard methods (The Non-Affiliated Soil Analysis Working Committee, 1990)**

3.3 TREATMENTS AND EXPERIMENTAL DESIGN

For the first pot trial in 2009, two pre-pack carrot cultivars "Nectar" and "Star 3002" were used. These two cultivars were selected because they are commonly grown by farmers in the Free State (Section 2.6.1 and 2.6.2). "Nectar" is strongly recommended for cultivation under hot conditions which makes it suitable for early to late summer sowing (Anon., 2009a).

Plants were exposed to four constant temperatures (i.e. no diurnal variation) treatments of: 10, 18, 26 or 32°C for the duration of the trial. Each treatment combination was replicated four times and eight extra pots per treatment combination were planted to provide material for plant and sensory analysis. The trial was laid out as a factorial experiment in four growth chambers using a completely randomized experimental design, each growth chamber was set to a specific temperature treatment.

The trial was repeated during 2009/10 with some important changes. Seed of "Star 3002" was no longer available and this forced the selection of a new cultivar, "CS 1006", which is also used for the pre-pack market (Section 2.6.3). This cultivar is highly recommended for cultivation under hot conditions, making it suitable for early to late summer sowing (Anon., 2009a).

As the carrot plants at the two highest temperature treatments (26 and 32°C) died during the 2009 trial it was decided to expose plants to diurnal temperature variations during this trail. Temperature treatments were selected based on the average minimum and maximum monthly temperatures and relative humidity for 30 years in the Bothaville area (SAWS, 2002). This area is well known for carrot production in the Free State. The four day/night temperature regime treatments used were 15/5, 24/10, 28/20 and 35/25°C. The trial layout and design used were the same as for the first experiment. Treatment combinations used in the two trials are shown in Table 3.2. The relative humidity was not controlled precisely in the growth chambers.

Table 3.2: Treatments used during the 2009 and 2009/10 plantings

Cultivar	**2009**				**2009/10**					
C_1	Nectar				Nectar					
C_2	Star 3002				CS 1006					
Treatment	**Temperature (°C)**	**Relative humidity (%)**	**Photo period (hour)**		**Temperature (°C)**		**Relative humidity (%)**		**Photo period (hour)**	
			day	**night**	**day**	**night**	**day**	**night**	**day**	**night**
T_1	10	47	12	12	15	5	47	36	12	12
T_2	18	53	12	12	24	10	53	37	12	12
T_3	26	63	12	12	28	20	63	54	12	12
T_4	32	86	12	12	35	25	86	65	12	12

3.4 EXECUTION OF POT TRIALS

In order to achieve the optimal nutrient status for carrot production and to achieve a yield of 40 t ha^{-1}, nitrogen, phosphorus and potassium equivalent to 209 kg N ha, 178 kg P ha^{-1} and 237 kg K ha^{-1} were added to the soil in the form of di-potassium hydrogen sulphate and ammonium nitrate. Half of the nitrogen and all the phosphorus and potassium were mixed with 20 L water and evenly applied to the soil surface using a knapsack sprayer. Following application the soil was thoroughly mixed to ensure an even distribution of nutrients. Six weeks after sowing the second half of the nitrogen fertilizer was applied in solution to the soil using ammonium nitrate as source. The required amount of ammonium nitrate 1.21 g was dissolved in 250 ml H_2O and was poured evenly over the surface of each pot.

Pots of 0.34 x 0.34 x 0.35 m with a surface area of 0.1156 m^2 were used for both trials. After the pots were filled with soil they were watered to within 150 ml of volume required to wet the dry soil to field capacity. The soil's water content at field capacity was determined gravimetrically prior to sowing. Seeds were sown at a depth of 1.5 cm in four rows (8.5 cm apart) in each pot. The pots were kept in an air conditioned glasshouse at 20/16°C (±1°C) day/night temperature regime under natural daylight conditions for the seed to germinate and seedlings to establish. Three weeks after sowing the seedlings were thinned to 4.8 cm in the row resulting in 28 seedlings per pot at a spacing of 8.5 X 4.8 cm.

Four weeks after sowing the pots were moved to the growth chambers where they stayed until harvest. In 2009 the seedlings/pots were exposed to the required temperature treatment immediately, without allowing the seedlings to gradually acclimatise to the specific temperature. This was thought to be one of the reasons why plants at the two highest temperatures died during the trial. In 2009/10 a different strategy was followed and seedlings were acclimatised by gradual exposure to higher or lower temperatures. Temperatures in the respective growth chambers were increased or decreased over a period of 18 days to acclimatise the carrot seedlings to heat or cold (Table 3.3).

Table 3.3: Temperature settings over a period of 18 days in the growth chambers during 2009/10 season

Days	Day/ night temperature (°C)			
	Cabinet 1	**Cabinet 2**	**Cabinet 3**	**Cabinet 4**
0	18/16	18/16	20/18	20/18
4	18/16	22/14	24/18	25/20
7	18/13	23/12	25/20	28/21
11	18/10	23/11	26/20	31/22
14	17/7	23/10	27/20	33/23
18	15/5	24/10	28/20	35/25

Pots were watered daily in the glasshouse, while watering took place according to the water consumption in the growth chambers the soil was kept moist at all times. Pest and disease control was carried out as required. Red spider mite was noticed on plants in the 32°C chamber, eight weeks after planting in the first trial. No pesticide is registered to control this pest on carrots in South Africa, but tetradifon (Redspidercide®) was applied weekly to all plants, even though the pest was not detected in the other temperature treatments. Powdery mildew occurred on plants in the 26°C and 18°C treatments 9 and 10 weeks after planting, respectively. All the plants were thereafter sprayed on alternate weeks with dimethyldidecylammonium chloride (Sporekill®) and copper hydroxide (CopStar®) to control this disease. During the 2009/10 planting, red spider mite and powdery mildew again caused problems on plants at the 28/20 and 24/10°C treatments. The same spray program used in 2009 was applied from seven weeks after planting for control purposes.

Carrots were harvested when the root diameter below the collar was between 1.8 and 2.2 cm and the leaves started to yellow, which is a sign of maturity. At harvesting, 80% of carrots had attained the root diameter between 1.8 and 2.2 cm.

3.4 DATA COLLECTION

3.4.1 Growth parameters

Growth parameter data were collected from the same 10 randomly selected plants per pot from 6 – 20 weeks after planting during 2009, and from 6 – 32 weeks after planting during the 2009/10 trial.

3.4.1.1 Leaf number

Number of fully developed leaves were counted every 2nd week for the duration of the growing period during both years.

3.4.1.2 Plant height

Plant height of carrot plants was determined every 2nd week by measuring from the ground level to the tip of the longest straightened leaf using a ruler.

3.4.1.3 Leaf growth

The fresh mass of leaves was determined at harvest after leaves were cut off from the root just above the shoulder, after which drying took place at 60°C for a period of 13 days, after which dry mass was determined.

3.4.2 Yield parameters

Yield data from both trials (2009 and 2009/10) was collected only from those treatments where the plants did not die. This was done on the same 10 randomly selected plants per pot used for collecting growth data.

3.4.2.1 Fresh and dry mass

Washed and dried roots were weighed to determine their fresh mass, after which they were cut into small pieces and dried at 60°C for 13 days before determining the dry mass.

3.4.3 Quality parameters

External and internal quality parameters were only determined for temperature treatments where plants survived. At harvesting carrots from 10 randomly selected plants in each pot were harvested, washed with distilled water to ensure that roots were free of soil particles and other extraneous material.

3.4.3.1 External quality parameters

3.4.3.1.1 Root length and diameter

The root length was determined by measuring from shoulder to root tip using a ruler. Shoulder diameter was measured 2 cm below the collar using a model CD 8 caliper.

3.4.3.1.2 Defects

The number of carrots with defects such as green shoulder, twisted/ skewed (misshapen) and hairiness (carrots with excessive root hair) were counted. The presence of defects was then expressed as the percentage.

3.4.3.2 Internal quality parameters

3.4.3.2.1 Firmness

Firmness was determined by using a constant load penetrometer (Model 1719, Stanhope Seta Limited, England) automatically controlled by a Seta-Metic penetrometer controller (Model 1720). Four of the 10 randomly selected carrot roots per replication were used. The top and bottom of the root were removed after which the central third was split longitudinally so as to provide a flat surface. Samples were placed on the penetrometer table so that they rested on the cut surface. This ensured that the sample remained stable when a load of 50 g was dropped to force a needle into the carrot tissue. A constant load of 50 g was allowed to puncture carrots for 10 seconds and the depth of penetration was recorded. Three measurements per carrot were made along the longitudinal axis for each carrot and the average calculated (Workneh *et al.*, 2003).

3.4.3.2.2 Total soluble solids

Four of the 10 randomly selected carrots per replication were peeled and approximately 0.27 mm at each end of the carrots was cut off and discarded. The total soluble solids content

(TSS) was obtained using the juice of four blended carrots discs weighing 3 g taken from the centre portion of the root and was measured using a hand refractometer (RFM 330, Bellingham & Stanley Ltd, England) (De Belie *et al*., 2003). The TSS was measured from two drops of the carrot juice placed on the refractometer and directly recorded in °Brix. Two readings per carrot were recorded.

3.4.3.2.3 Carotenoids

Carotenoid analysis was done at the laboratories of Dr's Du Buisson, Kramer, Swart & Bouwer Inc., Esoteric Science Laboratory in Pretoria. Samples were analyzed according to the method used by Takahata *et al*. (1993). Another four randomly selected carrots per pot were washed with distilled water and placed in glass jars which were covered with aluminum foil. The glass jars containing the samples were placed in a cooler box filled with crushed ice to keep them cool during transportation. Carrot samples were cut in two longitudinally and peeled and cut into small pieces for freeze-drying. The freeze-dried samples were milled until they passed through a 500 μm mesh sieve to form a fine flour. These samples were stored at -30°C until used for analysis. A 500 mg sample of the flour was extracted with 50 ml of acetone-hexane solution (50:50, containing 0.1% BHT) in a volumetric flask and allowed to stand overnight in the dark. A 20 ml aliquot was evaporated to dryness and redissolved with 1 ml of chloroform and filtered through a 0.50 μm membrane before High Performance Liquid Chromatography (HPLC) determination.

The HPLC analysis was performed on a JASCO (Japan Spectroscopic Co., Ltd) 800 series equipped with a UV-vis diode array detector MD-980, using a JASCO Finepak SIL C18 T-25 (4.6 mm x 25 cm) column. Solvent system A consisting of acetonitrile/methanol/THF (58:35:7) was pumped at a flow rate of 1 ml min^{-1} (Bushway, 1985). Solvent system B consisting of acetonitrile/dichloromethane/methanol (70:20:10) was pumped at a flow rate of 1 ml min^{-1} (Heinonen, 1990). Ten μL portions of both samples and the standard solution were injected.The detection was set at 460 nm for lycopene, α⁻, β⁻, and y⁻ carotene and 260 nm for phytoene. The running temperature was 30°C for both solvent systems. Identification of the peaks was peformed with authentic standards based on their retention times and UV-vis species.

3.4.3.2.4 Terpenoids

Terpenoid analysis was done at Esoteric Science Laboratory in Pretoria. Four randomly selected carrots per pot were used for analysis using the method described by Rosenfeld *et al*. (2004) with some modification. Samples were rinsed with distilled water and placed in glass jars covered with foil, and were placed in a cooler box filled with crushed ice to keep them cool during transportation.

Samples were weighed and frozen in 2 ml methanol at -21°C in sealed headspace vials immediately after reception. Before analysis the samples, still in the sealed vials, were defrosted and subjected to an ultrasonic bath for 1 hour and then placed in an oven at 70°C for 12 hours. After 12 hours samples were removed from the oven and again placed in an ultrasonic bath for 1 hour, after which they were cooled at 4°C and the methanol extracted and analysed using the Gas Chromatography Mass Spectrometry (GCMS).

Analysis of volatile terpenes was performed by a dynamic GCMS headspace technique. Chromatographic analysis of volatile compounds was performed by using a Hewlett Packard (HP) 6896 plus GC, equipped with a mass selective detector, HP 5970 (Hewlett Packard Company, Avondale, PA). Identification was made by comparing mass spectra of the components with those in a reference library (Wiley 130K Mass Spectral Database, John Wiley and Sons Inc., USA, 1986) (Rosenfeld *et al*., 2004).

3.4.4 Sensory analysis

Of the 8 extra pots planted per treatment combination 200 carrots were harvested and sent for sensory analysis.

3.4.4.1 Free choice profiling (FCP) panel

A group of 24 semi-naïve panelists (consumers of carrots, but never used on a trained panel) were selected to participate in the FCP study, based on their taste and smell acuity, interest, ability to discriminate between the four basic tastes and availability for the entire study. The panelists ranged from 22 to 64 years of age and included 16 female and 8 male participants.

Vocabulary development was carried out in an informal setting, with groups of five assessors being interviewed simultaneously, to taste the six samples and generate as many terms as possible to describe the taste and after taste. An unstructured line scale, with appropriate anchors, ranging from 0 (none), 10 (very high), was constructed and used to evaluate the different samples. In order to ensure that panelists were not influenced in any way, no information regarding the nature of samples was given. Panelists were informed not to use cosmetics (like lipstick) and to avoid exposure to foods and fragrances for at least one hour before the evaluation sessions.

3.4.4.2 Sample preparation, serving and evaluation procedures

All samples were served and evaluated according to the sensory principles and methods described in the ASTM Manual on Descriptive Analysis Testing for Sensory Evaluation (ASTM, 1992).

Panelists received one slice (1 cm x 2.5 cm) from the middle of carrot per treatment combination. This size, slightly larger than average bite size, was used to ensure that sufficient sample was available to evaluate the two categories. The samples were stored at 2-6°C, and allowed to reach room temperature, approximately 22°C, over a period of 30 minutes prior to assessment. The samples were served: on white polystyrene trays at 22°C in individual sensory booth lit by white fluorescent light. All samples were served blinded, coded using three digit codes and in a randomized serving order to exclude any bias due to position. Bottled water, at room temperature, was provided as a palate cleanser before the start of the evaluation and between samples. One evaluation session was scheduled on each of three separate days, resulting in a total of three evaluation sessions per product. During one session six samples were evaluated. Three replications were considered the absolute minimum to ensure reliability and validity of results.

3.4.4.3 Test methodology

With reference to the objective of the study, FCP was used in order to determine whether differences existed between the six carrot samples and to determine the direction of the differences. A general training programme, consisting of one 30 minute session to develop an idiosyncratic list of appropriate descriptive terminology for the carrot samples, was used. Attributes were grouped together according to sensory characteristics of taste and aftertaste. No formal definition was developed for each attribute by each panellist, however, each one had to be able to explain all their attributes. A lexicon was compiled for each panellist, based on all the terms and definitions necessary for that person to describe the six carrot samples (Annexure 1). Samples were thus scored on unstructured line scales, using the assessors' own vocabularies, anchored at the ends by the terms "none" and "very high". Data were recorded on paper ballots and entered into worksheets for analysis.

3.5 STATISTICAL ANALYSIS

An analysis of variance was carried out on all measured parameters, with the exception of sensory data using the SAS 9.1 statistical program (McLeod, 2005). Significance of differences between means of treatments was evaluated using Turkey's test for the LSD ≤ 0.05 (Turkey, 1953)

For the sensory data the recorded data was entered into a Microsoft Excel 2007 worksheet and analyzed using Generalized Procrustes Analysis (GPA) (Gower, 1975), using XLStat (Version 7.5.2). GPA was used to provide information on the inter-relationships between samples and assessors (Arnold & Williams, 1986; Oreskovich *et al.*, 1991), the main objective was to obtain an insight into the basic cognitive factors that consumers used to distinguish between treatments, as well as the relationships between treatments in these factors (Hauser & Koppleman, 1979). The GPA consisted of three logically distinct steps: the centroids of each assessor's data matrix were matched to eliminate the effect of use of different parts of the scales; isotropic scale changes removed differences in the scoring range used by different assessors; and configurations were matched as closely as possible by rotation and reflection of the axes (Arnold & Williams, 1986). A perceptual space was produced for each assessor which was matched as closely as possible with that of other assessors. A consensus configuration was then calculated as the average of individual configurations and simplified to a reduced dimensional plot by principal component analysis (PCA).

The interpretation of descriptive sensory evaluation was simplified with the assistance of the multivariate statistical procedure, PCA. With PCA the smallest number of latent variables, called principle components, was identified. These principle components explained the greatest amount of observed variability. Residual errors, or the distances between the assessors' individual configurations and the consensus, were then used to calculate co-ordinates for plotting the assessors, to identify outliers or groups (Jack, 1994).

CHAPTER 4

INFLUENCE OF TEMPERATURE ON THE GROWTH OF CARROTS

4.1 INTRODUCTION

The most important climatic conditions affecting plant growth are temperature, light, day length and rainfall (Morison & Lawlor, 1999). In general, the temperature response curve for plant growth rises rapidly from 0 to 15°C followed by a steady increase above 15°C to an optimum between 20 and 30°C (Reddy, 2010). However, optimum temperature range depends on the particular crop. For most vegetable crops, growth declines when temperature increase above 35°C and thermal death point is reached when temperature nearing 50°C (Sutcliffe, 1977; Reddy, 2010). Went (1953) suggested that the temperatures at which most physiological processes normally occur in plants range from 0 to 40°C. Photosynthesis occurs at its highest rate at temperatures ranging from 18 to 27°C, and decreases at temperatures above or below this range. The optimum temperature range may be defined as the temperature range within which maximum photosynthesis and normal respiration take place throughout the life cycle of the crop, and thus highest marketable yield is realized. For most crops the optimum functional efficiency occurs mostly between 12 and 24°C (Reddy, 2010) or between 18 and 27°C (Anon., 2009b).

Carrots are a cool season crop that performs best at temperatures between 15 and 22°C with a base temperature of 5°C (Al-Harbi *et al*., 1997; Krug, 1997; Rubatzky *et al*., 1999; Alam *et al*., 2004; Simon *et al*., 2008). Optimum day temperatures for carrot plant growth range between 21 and 22°C while optimal night temperatures are between 18 and 20°C (Alam *et al*., 2004). Carrots can, however, endure warmer temperatures making it possible to plant carrots nearly throughout the year. In South Africa carrots are cultivated under a range of climatic conditions in various regions of South Africa for the fresh (pre-packed and bunched) and processing (dehydrated and frozen) markets (Nortjè & Henrico, 1986; Joubert *et al*., 1994). From a physiological point of view, growth of carrots depends largely on the climatic conditions and cultivar choice.

At temperatures lower than the optimum growth is slow due to a decline in metabolic reactions (Sutcliffe, 1977).The exact manner/mode by which temperature affects growth is not always clear, as both photosynthesis and respiration are affected by temperature (Van Iersel &

Seymour, 2003). Since photosynthesis is slow at low temperatures plant growth is also slow, and can ultimately result in lower yields. At temperatures below optimum, both photosynthesis and respiration decrease, thus photosynthesis decreases the most. Further, the rate of protein synthesis in the development of new cells is also slow. Few carbohydrates are available for growth and development of the crop and hence, yield is reduced markedly. The response of the stomata and photosynthesis to temperature is not the same (Morison & Lawlor, 1999) and especially under cooler conditions the response of the stomata is slow. Immature tissues of the vegetable crops are liable to freezing injury if they are grown persistently under low night temperature conditions (<5°C) (Reddy, 2010). No damage occurs at the minimum temperature because growth rate can still recover as temperatures increase. The metabolic activity of plants decreases to a minimum at temperatures just above freezing point (Beck *et al*., 2007). Growth of carrot plants is slow at 10°C and becomes more rapid as temperatures increase to 25°C (Rubatzky *et al*., 1999). However, extremely low temperatures during the growth period may damage or even kill the carrot leaves (Joubert *et al*., 1994; Anon., 2008b; Reddy, 2010).

High temperature during the summer months is a major limiting factor for the growth of cool-season crops such as carrots (Huang *&* Ploeg, 2001). Air and soil temperatures during mid-summer are often too high for optimum carrot growth (Liu *et al*., 2002), which may cause an elastic change in plant growth but prolonged exposure may cause permanent damage. High summer temperatures (>25°C) during the growing period can cause a decrease in the fresh mass of carrot leaves (Morison & Lawlor 1999). Water stress can also be associated with temperature stress. A rapid photosynthesis rate and a simultaneous increase in respiration rate under high temperatures may lead to plant starvation and death (Sutcliffe, 1977). As the temperature increases above the optimum a decline in assimilates occur that is exceptionally rapid in C_3-plants such as carrots and leads to low yields as extreme temperature jeopardizes the translocation of assimilate to the harvestable portion. Vegetative growth of carrots increase at temperatures of 20 and 26°C but final plant size was larger at 14°C (Quagliotti, 1967), indicating that high temperatures early in the growth stage of carrots favour vegetative growth, although carrots are a cool season crop.

Carrots are sown from August to October and from the end of January to March in the Free State (Joubert *et al*., 1994). Growth and development occurs slowly during the hot spring and summer months. The period from May until the end of July is critical to the development stage of carrots. If carrots have not developed well by late July, there is a significant likelihood that the crop will bolt before the roots have developed to marketable size. Although carrots are predominantly a cool season crop cultivars have been developed that are better adapted to higher temperatures so that they can now be cultivated during warmer periods as well. This has resulted in carrots being available on the market throughout the year. The aim of this study was to investigate the response of some pre-pack carrot cultivars to different temperature regimes.

4.2 RESULTS AND DISCUSSION

Leaf number, plant height and leaf growth were recorded to determine the growth of carrot plants as influenced by different temperatures. Measurements were taken every two weeks commencing six weeks after planting, and are presented in both table and graph form. Tables were used to indicate the $LSD_{T(0.05)}$ values for each week of measurement, while figures illustrate the growth response over the trial period.

4.2.1 Leaf number

A summary of the analyses of variance that was done to determine the influence of different temperatures on the leaf numbers of "Nectar" and "Star 3002" from 6 to 20 weeks after planting in 2009 and of "Nectar" and "CS 1006" from 6 to 32 weeks after planting in 2009/10 are presented in Table 4.1.

Table 4.1: Summary of the analyses of variance results indicating the significance of temperature and cultivar on leaf number from 6 up to 20 weeks after planting in 2009 and from 6 to 32 weeks after planting in 2009/10

Weeks after planting	Cultivar (C)	Temperature (T)	CxT
	2009		
6	*	*	ns
8	*	*	ns
10	ns	*	ns
12	ns	*	ns
14	ns	*	ns
16	ns	*	ns
18	ns	*	ns
20	ns	ns	ns
	2009/10		
6	ns	*	ns
8	ns	*	ns
10	ns	*	ns
12	ns	ns	ns
14	ns	ns	ns
16	ns	ns	ns
18	ns	ns	ns
20	ns	ns	ns
22	ns	ns	ns
24	ns	*	ns
26	ns	*	ns
28	ns	*	ns
30	ns	ns	ns
32	ns	ns	ns

$LSD_{T(0.05)}$ *=Significant differences ns= No significant difference

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Temperature significantly influenced leaf number during the first eighteen weeks, while cultivar only had a significant influence on the number of carrot leaves at weeks six and eight. The interaction between cultivar and temperature did not significantly influence the number of leaves at any stage (Table 4.2), meaning that cultivars reacted the same to different temperature treatment.

Six weeks after planting the highest number of leaves was produced by plants at 26°C, significantly greater than those at 32°C. The leaf numbers at the 10 and 18°C treatments were intermediate to the high temperatures, but did not differ significantly from each other or 26°C treatment.

At eight weeks the highest leaf number was again obtained at 26°C and this was significantly more than that produced at 10 and 32°C. Leaf number of plants at 10 and 32°C was significantly lower than at 18°C. During weeks 6 and 8 “Nectar” produced significantly more leaves than “Star 3002” but this trend did not continue.

The highest number of leaves recorded at week 10 was at the 18°C treatment and plants at this temperature produced significantly more leaves than those at the 10 and 32°C treatments. Leaf number at the 18 and 26°C treatments however, did not differ significantly from each other. A drastic decrease in leaf number occurred in both cultivars at 32°C from week 10. All the “Nectar” plants at 32°C were already dead by week 12. The highest number of carrot leaves was produced by plants grown at 18°C in both weeks 10 and 12. During week 10 no differences in leaf number were noted between plants at the 18 and 26°C treatments, but by week 12 plants at the 26°C treatment had significantly fewer leaves than those at 18°C. Plants expose to the 32°C treatment had fewer leaves than those at either 18 or 26°C. At 10 weeks the leaf number of plants in the 10°C treatment was significantly lower than that of plants at 18°C, but this difference was no longer significant at week 12.

Table 4.2: Influence of temperature on carrot leaf number from 6 to 20 weeks after planting in 2009

Cultivar (C)	Temperature (T)				Mean
	10°C	18°C	26°C	32°C	
		6 weeks after planting			
Nectar	3.65	3.75	3.85	3.33	**3.64**
Star 3002	3.03	3.13	3.38	2.88	**3.14**
Mean	**3.34**	**3.44**	**3.70**	**3.10**	
$LSD_{T(0.05)}$		**T = 0.50**	**C = 0.27**		**CxT = ns**
		8 weeks after planting			
Nectar	4.40	5.50	5.53	3.55	**4.74**
Star 3002	3.66	4.80	5.30	2.48	**4.06**
Mean	**4.04**	**5.15**	**5.41**	**3.01**	
$LSD_{T(0.05)}$		**T = 1.11**	**C = 0.59**		**CxT = ns**
		10 weeks after planting			
Nectar	5.25	6.18	5.48	2.53	**4.86**
Star 3002	4.58	6.30	6.58	2.23	**4.93**
Mean	**4.91**	**6.24**	**6.03**	**2.40**	
$LSD_{T(0.05)}$		**T = 1.25**	**C = ns**		**CxT = ns**
		12 weeks after planting			
Nectar	6.13	5.73	3.60	0	**3.86**
Star 3002	5.33	6.33	3.92	0.10	**3.92**
Mean	**5.73**	**6.03**	**3.76**	**0.05**	
$LSD_{T(0.05)}$		**T = 1.12**	**C = ns**		**CxT = ns**
		14 weeks after planting			
Nectar	6.53	4.75	2.53	0	**3.45**
Star 3002	6.23	5.15	2.70	0.08	**3.54**
Mean	**6.38**	**4.95**	**2.61**	**0.04**	
$LSD_{T(0.05)}$		**T = 1.20**	**C = ns**		**CxT = ns**
		16 weeks after planting			
Nectar	6.15	4.80	1.93		**4.29**
Star 3002	6.20	4.73	2.03		**4.32**
Mean	**6.18**	**4.76**	**1.98**		
$LSD_{T(0.05)}$		**T = 1.17**	**C = ns**		**CxT = ns**
		18 weeks after planting			
Nectar	6.53	5.05	0.90		**4.16**
Star 3002	5.95	5.83	0.30		**4.03**
Mean	**6.24**	**5.44**	**0.60**		
$LSD_{T(0.05)}$		**T = 0.79**	**C = ns**		**CxT = ns**
		20 weeks after planting			
Nectar	6.56	5.23			**5.93**
Star 3002	6.05	5.75			**5.90**
Mean	**6.31**	**5.51**			
$LSD_{T(0.05)}$		**T = ns**	**C = ns**		**CxT = ns**

From week 14 to 18 the highest number of leaves was produced by plants at 10°C, significantly higher than that of plants at all other temperature treatments. All plants expose to the 32°C treatment had died by week 16. Leaf number of plants at the 26°C treatment continued to decrease during this period, and all plants at this treatment were dead by week 20. At this stage there were no longer any significant differences in the leaf number from plants at the 10 and 18°C treatments.

2009/10 Planting

Neither cultivar nor the interaction between cultivar and temperature had a significant effect on leaf number. This parameter was, however, significantly affected by temperature at weeks 6-10, and weeks 24-28 (Table 4.1). Even though diurnal temperature variation was introduced a 100% mortality of plants from both cultivars occurred at the 35/25°C temperature by week 12 (Table 4.3).

During the first three weeks that measurements were taken the highest leaf numbers were found on plants at the 24/10 and 28/20°C treatments. The differences in leaf number between these treatments did not differ significantly. At week 8, no significant difference in leaf number were noted for plants exposed to 15/5, 24/10 and 28/20°C treatment. From week 24 to 28 plants exposed to the 24/10°C treatment produced significantly more leaves than those at 28/20°C, while at the 15/5°C treatment leaf number were not significantly different from those produced by plants at the two highest temperatures.

Interestingly, plants survived the 28/20°C day/night temperature treatment during 2009/10 whereas those exposed to the constant 26°C temperature in 2009 died at week 20.

Results from both plantings showed that temperature had a greater influence on carrot leaf number than cultivar. Cultivar differences in leaf number were only noted during initial growth under constant temperature conditions where “Nectar” had significantly more leaves than “Star 3002”. No differences between “Nectar” and “CS 1006” were noted at any stage where diurnal temperature variation was used. However, “Nectar” plants appeared to be more sensitive to high temperatures (32°C) than “Star 3002”, but there did not appear to be any difference in sensitivity to the high temperature treatment (35/25°C) between “Nectar” and “CS 1006”. Although “Nectar” is highly recommended for cultivation under warm conditions (Anon., 2009a) it is clear that high day (>30°C) and night temperatures (>20°C) had a negative effect on leaf growth of this cultivar.

Table 4.3: Influence of temperature on carrot leaf number from 6 to 32 weeks after planting in 2009/10

Cultivar (C)	Temperature (T)				Mean
	15/5°C	24/10°C	28/20°C	35/25°C	
		6 weeks after planting			
Nectar	2.08	2.03	2.68	2.13	**2.23**
CS 1006	2.18	2.35	2.50	2.13	**2.29**
Mean	**2.13**	**2.19**	**2.59**	**2.13**	
$LSD_{T(0.05)}$		**T = 0.43**	**C = ns**		**CxT = ns**
		8 weeks after planting			
Nectar	3.18	3.58	3.53	2.33	**3.15**
CS 1006	3.20	3.25	3.23	1.93	**2.90**
Mean	**3.19**	**3.41**	**3.38**	**2.13**	
$LSD_{T(0.05)}$		**T = 0.50**	**C = ns**		**CxT = ns**
		10 weeks after planting			
Nectar	4.05	4.68	5.13	0.18	**3.51**
CS 1006	4.23	4.95	4.98	0.55	**3.69**
Mean	**4.16**	**4.81**	**5.05**	**0.36**	
$LSD_{T(0.05)}$		**T = 0.48**	**C = ns**		**CxT = ns**
		12 weeks after planting			
Nectar	4.85	4.83	5.23		**4.97**
CS 1006	5.30	5.77	4.55		**5.21**
Mean	**5.08**	**5.30**	**4.89**		
$LSD_{T(0.05)}$		**T= ns**	**C = ns**		**CxT = ns**
		14 weeks after planting			
Nectar	5.38	5.30	5.33		**5.33**
CS 1006	6.08	6.60	4.43		**5.70**
Mean	**5.73**	**5.95**	**4.88**		
$LSD_{T(0.05)}$		**T= ns**	**C = ns**		**CxT = ns**
		16 weeks after planting			
Nectar	5.25	5.43	5.55		**5.41**
CS 1006	5.65	6.45	3.90		**5.33**
Mean	**5.45**	**5.94**	**4.73**		
$LSD_{T(0.05)}$		**T = ns**	**C = ns**		**CxT = ns**
		18 weeks after planting			
Nectar	5.43	5.48	5.50		**5.47**
CS 1006	5.88	6.63	3.83		**5.44**
Mean	**5.65**	**6.05**	**4.66**		
$LSD_{T(0.05)}$		**T = ns**	**C = ns**		**CxT = ns**
		20 weeks after planting			
Nectar	5.80	5.93	6.15		**5.96**
CS 1006	5.85	6.58	4.25		**5.56**
Mean	**5.83**	**6.25**	**5.20**		
$LSD_{T(0.05)}$		**T= ns**	**C = ns**		**CxT = ns**
		22 weeks after planting			
Nectar	5.83	6.05	5.98		**5.95**
CS 1006	5.90	6.78	4.28		**5.65**
Mean	**5.86**	**6.41**	**5.13**		
$LSD_{T(0.05)}$		**T = ns**	**C = ns**		**CxT = ns**
		24 weeks after planting			
Nectar	5.76	6.23	5.90		**5.97**
CS 1006	5.90	7.08	4.03		**5.67**
Mean	**5.84**	**6.65**	**4.96**		
$LSD_{T(0.05)}$		**T = 1.42**	**C = ns**		**CxT = ns**
		26 weeks after planting			
Nectar	5.83	6.50	6.08		**6.13**
CS 1006	6.00	7.35	3.98		**5.76**
Mean	**5.92**	**6.93**	**5.03**		
$LSD_{T(0.05)}$		**T = 1.50**	**C = ns**		**CxT = ns**
		28 weeks after planting			
Nectar	6.43	6.66	6.25		**6.45**
CS 1006	6.65	7.18	4.30		**6.04**
Mean	**6.54**	**6.93**	**5.28**		
$LSD_{T(0.05)}$		**T = 1.54**	**C = ns**		**CxT = ns**
		30 weeks after planting			
Nectar	6.48	5.30	6.58		**6.12**
CS 1006	6.50	6.50	4.60		**5.87**
Mean	**6.49**	**5.90**	**5.59**		
$LSD_{T(0.05)}$		**T = ns**	**C = ns**		**C xT = ns**
		32 weeks after planting			
Nectar	6.56	5.23	6.65		**6.12**
CS 1006	6.63	5.08	4.35		**5.54**
Mean	**6.59**	**5.40**	**5.50**		
$LSD_{T(0.05)}$		**T = ns**	**C = ns**		**CxT = ns**

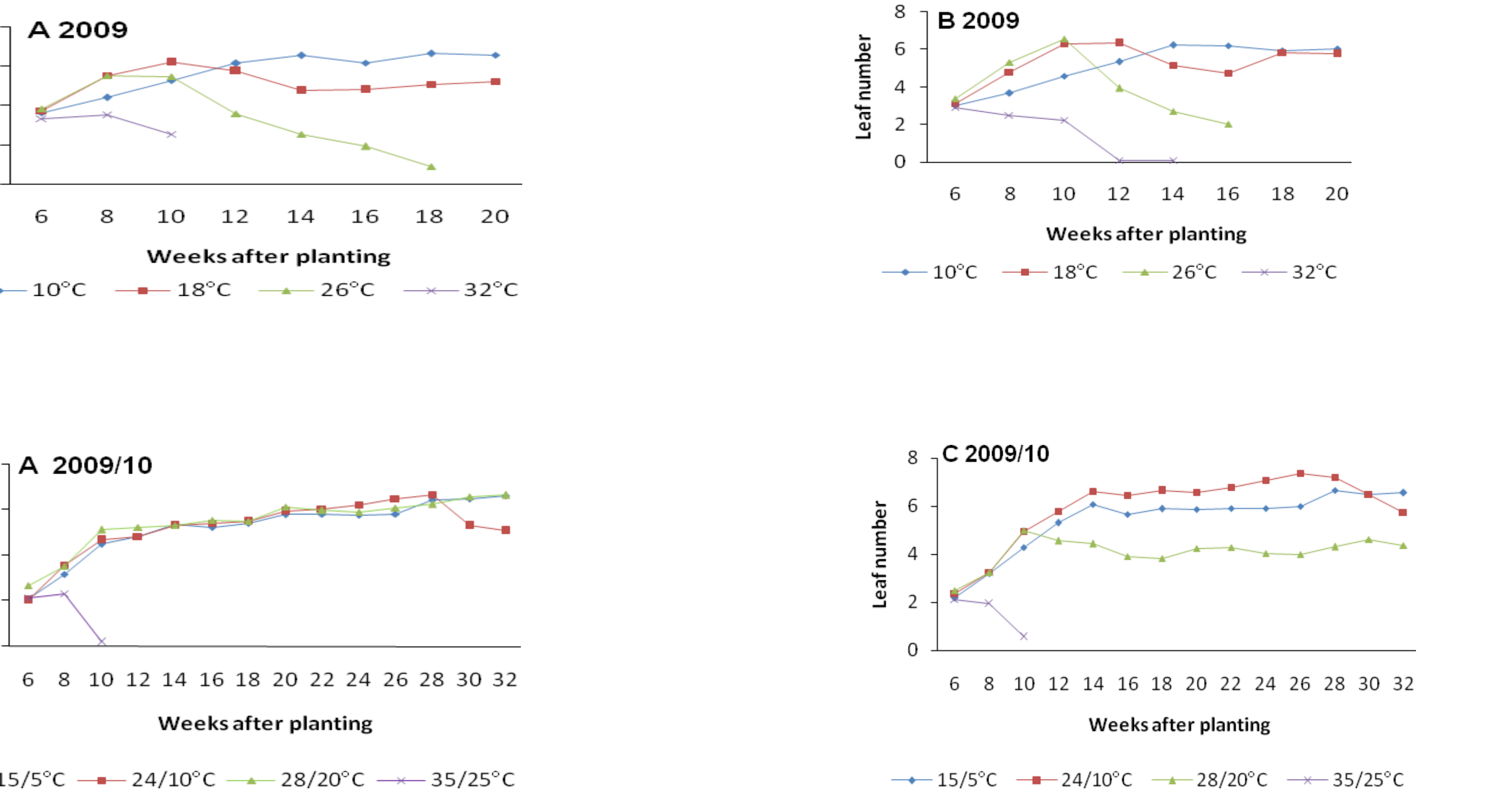
In 2009 plants at the two highest constant temperatures (26 and 32°C) were all dead by weeks 20 and 26 (Figure 4.1 A and B). Although the number of carrot leaves early in the season was the highest at the 26°C treatment, it changed as the season progressed. In the mid-growing season the highest number of leaves was produced at 18°C but from week 14 to 18 more leaves was produced at 10°C. Only plants at 10 and 18°C survived up to week 20 and the number of leaves did not differ significantly between the two temperatures. Quagliotti (1967) planted carrots under constant temperatures of 26, 20 and 14°C, and reported that carrot growth was the best at 14°C, showing that lower temperatures suit growth of carrot plants the best. These results are in line with those found during this study. Hori *et al*. (1970) (cited by Al-Harbi *et al.*, 1997) however, suggested that growth and root development of carrots were best at a constant temperatures of 23 and 28°C, respectively. Rosenfeld *et al*. (1998b) reported that at constant day and night temperatures of 9, 12 and 15°C, growth of carrots increased but as the temperature further increased to 18 and 21°C growth decreased.

The same trends as for constant temperatures were observed when diurnal temperature variation was applied. Plants at the high temperature treatment (35/25°C) died as early as week 12 (Figure 4.1 C and D). However, as indicated in Figure 4.1 C and D plants at the 28/20°C did not die compared to the constant temperature of 26°C in 2009 where plants did die. The fact that cooler night temperatures were used in combination with a high day temperature might be the reason for plants not dying and suggesting that high night temperatures might be the cause of death. The highest number of leaves during the early growth phase was produced under the higher temperature (28/20°C) regime. This, however, changed as the season progressed. In the mid-measuring period temperature did not influence the number of leaves significantly but the highest number were produced at the 24/10°C treatment and from week 24 to 28 the 24/10°C temperature regime produced significantly more leaves than plants at the 28/20°C treatment.

Red spider mite started to attack plants at 32°C and spraying commenced on all plants nine weeks after planting in 2009. In the 2009/10 planting, red spider mite was also noticed on plants in the 28/20 and 24/10°C cabinets from weeks 11 and 12, respectively. A control program was started during week 12 to control this pest. Interestingly no problems with powdery mildew was experienced under high temperature regimes (32 and 35/25°C) in combination with a high relative humidity (86%), or under low temperatures (10 and 15/5°C) in combination with low relative humidity (47%). The most favourable conditions for powdery mildew are night temperatures of 16°C and relative humidity of 90-99%, with temperatures of 27°C and 40-70% relative humidity during the day (Davis *et al*., 2008; Horst, Undated).

Although spider mite attacked the plants in the 32°C cabinet in 2009 and could be suspected of causing, or exacerbating plant death at this temperature, plants at the 35/25°C temperature regime in 2009/10 were not attacked by red spider mite and actually died even earlier in the season. It can, therefore, be accepted that temperature was the primary cause of death in 2009 and not red spider mite. The same logic applies for plants at 26°C in 2009 and those at 28/20°C in 2009/10.

The leaf number data obtained in this trial confirms that carrots are a cool season crop and that although they can tolerate fairly high temperatures (28/20°C), extremely high temperatures (35/25°C) may have a detrimental effect on growth and can ultimately result in death of the plants.



1: Influence of temperature on leaf number of “Nectar” (A), “Star 3002” (B) and “CS 1006” (C) from 6 to 20 weeks after plantinn 6 to 32 weeks after planting in 2009/10

4.2.2 Plant height

The results of the analyses of variance that were carried out to determine the influence of different temperatures on the plant height of “Nectar” and “Star 3002” from 6 to 20 weeks after planting in 2009 and of “Nectar” and “CS 1006” from 6 to 32 weeks after planting in 2009/10 are summarized in Table 4.4.

Table 4.4: Summary of the analyses of variance results indicating the significance of temperature and cultivar on plant height from 6 up to 20 weeks after planting in 2009 and from 6 to 32 weeks after planting in 2009/10

Weeks after planting	Cultivar (C)	Temperature (T)	CxT
	2009		
6	*	*	ns
8	*	*	ns
10	*	*	ns
12	ns	*	ns
14	ns	*	ns
16	ns	*	ns
18	ns	*	ns
20	ns	*	ns
	2009/10		
6	*	*	*
8	*	*	ns
10	ns	*	ns
12	ns	*	ns
14	ns	*	ns
16	ns	*	*
18	ns	*	*
20	ns	*	*
22	ns	*	*
24	ns	*	*
26	ns	*	*
28	ns	*	*
30	ns	*	*
32	*	*	*

$LSD_{T(0.05)}$ *=Significant differences ns= No significant differences

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From Table 4.4 it can be seen that temperature was the major factor affecting plant height, and that cultivar differences were only significant during the early growth stages. The interaction between cultivar and temperature played no significant role in determining the height of carrot plants in 2009. The data for this parameter are presented in Table 4.5.

Table 4.5: Influence of temperature on the plant height (cm) of two carrot cultivars from 6 to 20 weeks after planting in 2009

Cultivar (C)	Temperature (T) 10°C	18°C	26°C	32°C	Mean
		6 weeks after planting			
Nectar	11.41	14.35	14.79	11.36	**12.98**
Star 3002	8.64	10.39	12.34	8.13	**10.08**
Mean	**10.03**	**12.37**	**13.97**	**9.74**	
LSD$_{T(0.05)}$		**T = 5.23**		**C = 2.77**	**CxT = ns**
		8 weeks after planting			
Nectar	23.15	31.58	29.65	13.88	**24.56**
Star 3002	17.66	24.54	28.43	8.09	**19.68**
Mean	**20.40**	**28.06**	**29.04**	**10.99**	
LSD$_{T(0.05)}$		**T = 5.56**		**C = 2.94**	**CxT = ns**
		10 weeks after planting			
Nectar	30.41	37.07	30.62	8.68	**26.69**
Star 3002	24.33	32.78	31.33	6.58	**23.76**
Mean	**27.37**	**34.92**	**30.97**	**7.63**	
LSD$_{T(0.05)}$		**T = 4.99**		**C = 2.64**	**CxT = ns**
		12 weeks after planting			
Nectar	35.69	38.45	27.41	0	**25.39**
Star 3002	31.13	34.60	26.89	0.45	**23.26**
Mean	**33.41**	**36.52**	**27.15**	**0.22**	
LSD$_{T(0.05)}$		**T = 4.89**		**C = ns**	**CxT = ns**
		14 weeks after planting			
Nectar	36.76	38.64	22.07	0	**24.37**
Star 3002	34.77	35.00	19.01	0.47	**22.31**
Mean	**35.76**	**36.82**	**20.54**	**0.24**	
LSD$_{T(0.05)}$		**T = 7.12**		**C = ns**	**CxT = ns**
		16 weeks after planting			
Nectar	37.18	37.00	18.60		**30.93**
Star 3002	36.68	34.34	15.22		**28.75**
Mean	**36.93**	**35.67**	**16.91**		
LSD$_{T(0.05)}$		**T = 9.07**		**C = ns**	**CxT = ns**
		18 weeks after planting			
Nectar	37.77	36.94	4.22		**26.31**
Star 3002	37.78	34.04	1.35		**24.39**
Mean	**37.77**	**35.49**	**2.79**		
LSD$_{T(0.05)}$		**T = 4.37**		**C = ns**	**CxT = ns**
		20 weeks after planting			
Nectar	38.62	34.64			**36.63**
Star 3002	38.52	32.83			**35.68**
Mean	**38.57**	**33.73**			
LSD$_{T(0.05)}$		**T = 4.55**		**C = ns**	**CxT = ns**

From Table 4.5 it can be seen that temperature rather than cultivar had the greatest effect on the plant height of the carrot cultivars used, with plants reacting in a similar way to temperature treatment as was found with leaf number (Section 4.2.1). During the first few weeks of measuring the tallest plants were recorded for the 26°C treatment. Plants at the 18 and 26°C treatments were significantly taller than plants at all the other temperature treatments at week 8 and 10. From week 12 until week 18, the tallest plants were obtained at 10 and 18°C and were significantly taller than those at 26°C. Only plants in the 10 and 18°C treatments survived by week 20 and at this stage the plants in the 10°C treatment were significantly taller than those at 18°C. These results again prove that carrots are a cool season vegetable crop performing best under cooler temperature conditions (Joubert *et al*., 1994; Rubatzky *et al*., 1999). According to Rubatzky *et al*. (1999) growth of carrot plants is slow at 10°C and Quagliotti (1967) also indicated that the final plant size is larger at lower temperature (14ºC) than at higher temperatures (20 and 26ºC). These findings are similar to the findings of this study. It was only during the first 10 weeks after planting that the plant height of “Nectar” was significantly taller than “Star 3002” but this was not true later in the season.

2009/10 Planting

The height of carrot plants was significantly influenced by the interaction between cultivar and temperature during week 6 and again from weeks 16 to 32 in this planting (Table 4.6). Cultivar only influenced plant height significantly at weeks 6, 8 and 32 and temperature significantly influenced plant height over the entire period.

The significant interaction between cultivar and temperature at week 6 showed that the cultivars reacted differently to the temperature treatments. Height of ”Nectar” seedlings was significantly greater at 28/20°C than at 15/5 or 25/28°C, while growth of “CS 1006” seedlings appeared to be unaffected by temperature at this stage with no significant difference in height between temperature treatments.

At week 8 both cultivar and temperature showed significant differences, but the interaction effect was no longer significant, showing that both cultivars reacting to temperature in the same way. “Nectar” seedlings were taller than those of “CS 1006” when taken over all temperatures. Temperature had a major effect on plant height, with plants at both the 24/10 and 28/20°C treatments being significantly taller than those at the 15/5°C treatment, which were in turn taller than those at the highest temperature of 35/25°C.

Cultivar differences were no longer significant at week 10, and the temperature effects were the same as those obtained at week 8. Although plants at the 24/10°C were now taller than those at 28/20°C, this difference was not significant.

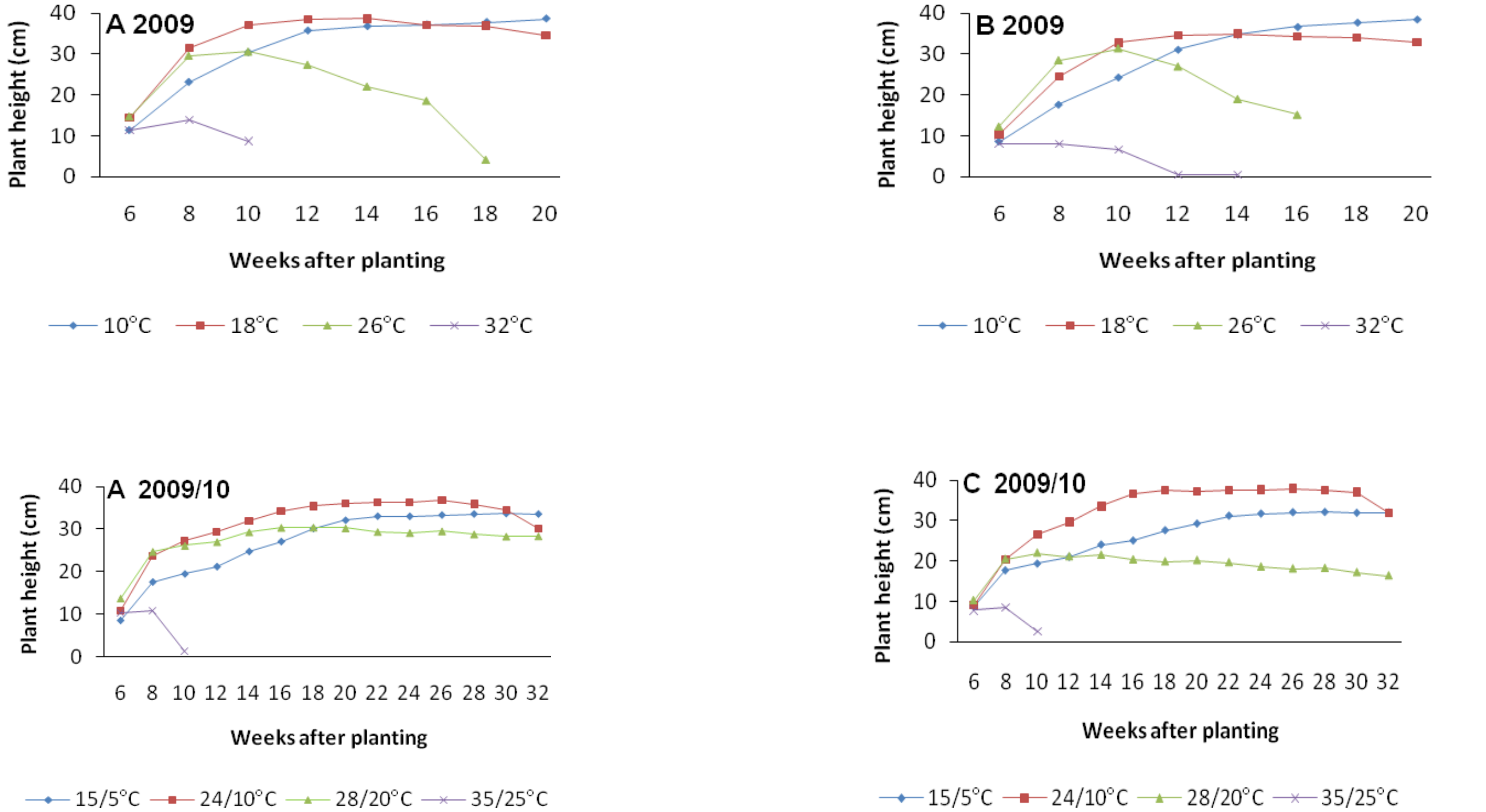
At 12 and 14 weeks plants at the highest temperature treatment (35/25°C) had started dieing back, and those at the 24/10°C were significantly taller than those the other two temperature treatments (15/5 and 28/20°C). From week 16 up to 32 the interaction between cultivar and temperature was significant showing that the two cultivars reacting differently to temperature. In all cases it was found that the height of “Nectar” seedlings was not significantly affected by temperature regime under which the plants were grown, while the height of “CS 1006” seedlings indicated variation due to temperature. During week 16-20, “CS 1006” seedlings grown at 24/10°C were significantly taller than those at either 15/5 or 28/20°C. From week 20 onwards the picture changed somewhat, with seedlings at the 28/20°C treatment being significantly shorter than those at either of the other treatments (24/10 and 15/5°C). This indicated that plants at the lower temperature (15/5°C) were growing faster than those at the higher temperature (28/20°C) from week 18 onwards.

Table 4.6: Influence of temperature on carrot plant height (cm) from 6 to 32 weeks after planting in 2009/10

Cultivar (C)	Temperature (T) 15/5°C	24/10°C	28/20°C	35/25°C	Mean
			6 weeks after planting		
Nectar	8.64	10.87	13.75	10.25	**10.88**
CS 1006	8.90	9.08	10.19	7.81	**8.99**
Mean	**8.77**	**9.98**	**11.97**	**9.03**	
LSD$_{T(0.05)}$		**T = 1.74**	**C = 0.92**		**CxT = 2.56**
			8 weeks after planting		
Nectar	17.63	23.70	24.76	10.75	**19.21**
CS 1006	17.70	20.36	20.42	8.61	**16.78**
Mean	**17.66**	**22.03**	**22.59**	**9.68**	
LSD$_{T(0.05)}$		**T = 2.70**	**C = 1.43**		**CxT = ns**
			10 weeks after planting		
Nectar	19.52	27.19	26.16	1.41	**18.57**
CS 1006	19.37	26.48	21.95	2.55	**17.59**
Mean	**19.45**	**26.84**	**24.05**	**1.98**	
LSD$_{T(0.05)}$		**T = 3.28**	**C = ns**		**CxT = ns**
			12 weeks after planting		
Nectar	21.23	29.45	27.04		**19.43**
CS 1006	21.03	29.65	21.07		**17.94**
Mean	**21.13**	**29.55**	**24.06**		
LSD$_{T(0.05)}$		**T = 3.47**	**C = ns**		**CxT = ns**
			14 weeks after planting		
Nectar	24.77	31.91	29.34		**21.51**
CS 1006	24.04	33.55	21.44		**19.76**
Mean	**24.40**	**32.73**	**25.39**		
LSD$_{T(0.05)}$		**T = 4.95**	**C = ns**		**C xT = ns**
			16 weeks after planting		
Nectar	27.10	34.34	30.40		**22.96**
CS 1006	25.04	36.70	20.31		**20.51**
Mean	**26.07**	**35.52**	**25.35**		
LSD$_{T(0.05)}$		**T = 5.75**	**C = ns**		**CxT = 9.75**
			18 weeks after planting		
Nectar	30.16	35.41	30.43		**24.00**
CS 1006	27.58	37.48	19.84		**21.22**
Mean	**28.87**	**36.45**	**25.13**		
LSD$_{T(0.05)}$		**T = 5.40**	**C = ns**		**CxT = 9.15**
			20 weeks after planting		
Nectar	32.09	35.97	30.26		**24.58**
CS 1006	29.21	37.24	20.16		**21.65**
Mean	**30.65**	**36.60**	**25.21**		
LSD$_{T(0.05)}$		**T = 5.66**	**C = ns**		**CxT = 9.61**
			22 weeks after planting		
Nectar	33.03	36.25	29.40		**24.67**
CS 1006	31.15	37.58	19.60		**22.08**
Mean	**32.09**	**36.92**	**24.50**		
LSD$_{T(0.05)}$		**T = 5.55**	**C = ns**		**CxT = 9.42**
			24 weeks after planting		
Nectar	33.00	36.27	29.17		**24.61**
CS 1006	31.67	37.65	18.53		**21.96**
Mean	**32.34**	**36.96**	**23.85**		
LSD$_{T(0.05)}$		**T = 5.21**	**C = ns**		**CxT = 8.85**
			26 weeks after planting		
Nectar	33.31	36.75	29.56		**24.90**
CS 1006	32.00	37.93	18.07		**22.00**
Mean	**32.66**	**37.34**	**23.81**		
LSD$_{T(0.05)}$		**T = 5.56**	**C = ns**		**CxT = 9.44**
			28 weeks after planting		
Nectar	33.55	35.89	28.84		**24.59**
CS 1006	32.05	37.54	18.19		**21.94**
Mean	**32.80**	**36.71**	**23.52**		
LSD$_{T(0.05)}$		**T = 5.23**	**C = ns**		**CxT = 8.87**
			30 weeks after planting		
Nectar	33.66	34.51	28.32		**24.12**
CS 1006	31.86	37.05	17.17		**21.52**
Mean	**32.76**	**35.78**	**22.74**		
LSD$_{T(0.05)}$		**T = 5.28**	**C = ns**		**CxT = 8.96**
			32 weeks after planting		
Nectar	33.55	30.09	28.38		**23.01**
CS 1006	31.95	31.82	16.34		**20.03**
Mean	**32.75**	**31.00**	**22.36**		
LSD$_{T(0.05)}$		**T = 5.22**	**C = 2.76**		**CxT = 8.85**

Over the 16 week period from week 16 to 32 seedlings of “Nectar” were significantly taller than those of “CS 1006” at the 28/20°C treatment, while no significant difference in plant height between seedlings of the cultivars were noted at either 24/10 or 15/5°C. These results would then appear to indicate that plants of “Nectar” are better adapted to higher temperatures than those of “CS 1006” and this is in agreement with Anon. (2009a) who indicated that the cultivar “Nectar” is recommended for cultivation under hot weather conditions.

The response of carrot plant height to different temperatures in 2009 followed more or less the same trend as that of leaf number. Early in the growing season the tallest plants were produced at 26°C but 32°C influenced plant height negatively as early as from week 8. As the season progressed, carrot plants at 10 and 18°C were the tallest (Figure 4.2 A and B). Quagliotti (1967) reported similar results in that the tallest carrot plants were produced at a constant temperature of 14°C and the shortest plants at 26°C. Libner (1989) also found that plant height of carrots decreased dramatically as temperature rose above 18°C. In the 2009/10 season, diurnal variation in temperature regimes were used, the tallest plants during first few weeks were produced at the 28/20°C treatment (Figure 4.2 C and D) but as the season progressed the tallest plants for both cultivars were produced at 24/10°C. In the same period and in most case carrot plants at the 15/5°C did not differ significantly from the 24/10°C treatment. Numerous researchers also reported on the positive effect of cooler temperatures on plant height for other crops such as radish (Suzuki, 1978) and sugar beet (Ulrich, 1954).



e 4.2: Influence of temperature on plant height of (A) "Nectar", (B) "Star 3002" and (C) "CS 1006" from 6 to 20 weeks after planting and from 6 to 32 weeks after planting in 2009/10

4.2.3 Leaf growth

In order to determine how leaf growth of carrot plants is affected by temperature, the leaf fresh and dry mass were analyzed. The summary on the analyses of variance that was done to determine the influence of cultivar and temperature on the leaf mass at harvesting are shown in Table 4.7.

Table 4.7: Summary on the analyses of variance indicating the significance of cultivar and temperature on leaf mass of carrots

Leaf growth	Cultivar (C)	Temperature (T)	CxT
		2009	
Leaf fresh mass	ns	*	ns
Leaf dry mass	ns	*	ns
		2009/10	
Leaf fresh mass	ns	ns	ns
Leaf dry mass	ns	ns	ns

$LSD_{T(0.05)}$ ***=Significant differences** **ns= No significant differences**

Table 4.7 indicates that neither cultivar nor the interaction between cultivar and temperature had no significant effect on either fresh or dry mass of leaves in 2009 or 2009/10. Temperature on the other hand significantly influenced both fresh and dry mass of the leaves in 2009 but not in 2009/10.

4.2.3.1 Leaf fresh mass

In 2009 the leaf fresh mass was significantly higher (10.56 g) at the 10°C treatment than at the 18°C treatment (3.12 g) (Table 4.8). In 2009/10, where day and night temperatures were used, there was no significant difference in fresh mass between cultivars and between the temperature treatments. However, the highest fresh mass (5.98 g) was obtained at the 24/10°C treatment.

Table 4.8: Influence of temperature on carrot leaf fresh mass (g) at harvesting in 2009

Cultivar (C)	Temperature (°C) (T)		Mean
	10	18	
	2009		
Nectar	10.24	3.41	**6.83**
Star 3002	10.88	2.82	**6.85**
Mean	**10.56**	**3.12**	
$LSD_{T(0.05)}$	**T = 1.88**	**C = ns**	**CxT = ns**

4.2.3.2 Leaf dry mass

Temperature affected the leaf dry mass of carrots at harvesting only in 2009 and the two cultivars did not differ significantly from each other (Table 4.9). The highest leaf dry mass (1.46 g) was obtained at the 10°C treatment, significantly greater than that produced at 18°C treatment (0.63 g) in 2009. In 2009/10 the leaf dry mass was not influenced by any of the treatments. Although there were no significant difference, the greatest leaf dry mass was obtained at 15/5°C.

Table 4.9: Influence of temperature on carrot leaf dry mass (g) at harvesting in 2009

Cultivar (C)	Temperature (°C) (T)			Mean
	10		18	
		2009		
Nectar	1.50		0.63	**1.07**
Star 3002	1.41		0.63	**1.02**
Mean	**1.46**		**0.63**	
$LSD_{T(0.05)}$	**T = 0.26**	**C = ns**	**CxT = ns**	

Temperature only influenced leaf fresh and dry mass in 2009 when a constant temperature was used. The highest fresh and dry mass were produced at 10°C which is in contradiction with results obtained by González *et al*. (2009) who reported a lower leaf fresh mass at 12°C than at 25°C for carrots. Interestingly, the 2009/10 planting's leaf fresh and dry mass were not influenced by either cultivar or temperature. Although not significant, leaf fresh mass was the highest at the 24/10°C treatment and dry mass at 15/5°C. It seems that a cool day and lower night temperature (15/5°C) combination is more beneficial for dry mass production of carrot leaves. Benjamin *et al*. (1997) reported that reducing temperature of an organ should restrict its metabolic activity and its ability to compete for assimilates. Ulrich (1954) grew sugar beet under different night temperatures (23/4, 23/10 and 23/17°C). A low night temperature of 4°C in particular decreased leaf fresh mass of beet and the highest leaf fresh mass was obtained at high night temperature of 17°C, but leaf dry mass was not influenced by any of the different night temperatures. Suzuki (1978) planted radish plants under different night and day temperatures of 20/25°C (high temperatures), 13/18°C (medium temperatures) and 8/12°C (low temperatures). Leaf dry mass of radish was increased at the higher temperatures (20/25°C) and reduced at the lower temperatures (8/12°C).

Carrot leaf mass was increased at lower temperatures in both plantings, although not significantly while leaf number and plant height were increased at higher temperatures from as early as eight weeks after planting. However, as the season progressed leaf number and plant height were significantly increased at lower temperatures in both plantings. This appears to indicate that carrots are a cool season crop.

4.3 CONCLUSION

From this study it is clear that temperature had a considerable influence on the growth parameters irrespective of cultivar, although "CS 1006" plants had more leaves than "Nectar" but shorter plant height. Carrots produced better vegetative growth at lower temperatures and plants under high temperature treatments (35/25°C) died. From this experiment, it can be concluded that the optimum temperatures for vegetative growth range between 15-24°C during the day and 5-15°C at night. This shows that this specie is adapted for production during the cooler seasons, or in the cooler areas of the country.

CHAPTER 5

INFLUENCE OF TEMPERATURE ON YIELD AND QUALITY OF CARROTS

5.1 INTRODUCTION

Quality and yield are both very important components of crop production, including that of carrots. The yield of any crop as stated by Brewster (1994) is determined by the following: the quantity of light absorbed by its leaves while harvestable dry matter is being produced; the efficiency with which the absorbed light is converted by photosynthesis into sucrose; the proportion of photosynthetic output transferred to the harvested part of the plant; the conversion coefficient between photosynthetic sucrose and the biochemical constituents of the harvested material; the weight losses due to respiration and decay after the above photosynthetic and biosynthetic processes have taken place.

Carrot yields can vary depending on the production methods followed by the producers and growing conditions. Yields of 25 to 30 tons ha^{-1} may be considered good for the small-rooted early market**,** but for processing more than 100 tons ha^{-1} is often achieved. Fresh market bunched or topped pre-packed carrot yields range from 30 to 60 tons ha^{-1} (Rubatzky *et al*., 1999). Carrot root growth depends on assimilate supplied from the leaves, the photosynthetic plant parts, and storage root growth can be estimated from the total plant growth (Benjamin *et al*., 1997; Suojala, 2000a). Cooper (1973) stated that the influence of temperature on root fresh and dry mass varies for different crops. As carrot is a cool season crop, cooler temperatures will increase the fresh and dry mass of the roots (Joubert *et al*., 1994: Rubatzky *et al*., 1999). The fresh and dry mass of carrot storage roots increased when exposed to 23°C compared to lower temperatures (Anon., 2008b). González *et al*. (2009) however, reported a significantly higher dry mass at 12°C than at 25°C. High yields can be achieved by choosing cultivars with a high net assimilation rate that are able to maintain growth even under unfavourable conditions at the end of the season (Suojala, 2000b).

Carrot root quality is characterized by both external and internal quality parameters. The quality of carrots as defined by Simon *et al.* (2008), is a collective of attributes such as root length, diameter, colour, flavour, and texture. The external quality parameters include root length, diameter and absence of defects and it is these parameters consumers use to choice as to whether they will consume it or not. It is recommended that carrots for pre-packing should have a length of 18 to 22 cm, a shoulder diameter of 25 to 30 mm and free from defects (Anon., 2009a). The Nantes carrot types preferred for pre-pack market perform the best in autumn and winter production (Simon *et al*., 2008). High soil temperatures encourage the production of shorter and thicker roots (Tindall, 1968; Petzoldt, 2008; Anon., Undated a) and temperatures below 10°C causes longer and more slender roots. However, too much soil moisture causes short and thick carrots (Joubert *et al*., 1994; Anon., Undated a).

Important attributes contributing to internal quality include sweetness, harshness and bitterness, texture and carotene content. Carrots are not a major staple food in any part of the world, but they are commonly accepted as a primary vegetable in many countries because of their nutritional value. The provitamin A carotenoids (mainly β-carotene) are the most important nutrients found in carrots (Simon & Wolff, 1987; Joubert *et al*., 1994; Kjeldsen *et al*., 2003; Bhale, 2004). β-carotene contributes to the orange colour of carrots. Cultivar choice and planting date can be managed by producers in such a way to obtain a high internal quality. When planting is done in the warmer times of the year the producer needs to choose a cultivar that can adapt to the warmer temperatures. Planting date should be in the cooler times of the year when conditions are favourable for carrot production (Northolt *et al*., 2004).

The eating quality of carrots can be measured directly by sensory methods or indirectly through chemical, mechanical or optical measurements. Important quality properties are sugar content, dry matter, non-volatile bitter compounds and volatile compounds (Kreutzmann *et al*., 2008a). The sensory quality of carrots is, amongst others, influenced by location, being a composite factor of precipitation, temperature, growth system and length of growing period (Hogstad *et al*., 1997). Firmness, sweet taste and absence of bitter or harsh taste are used as the main sensory quality criteria of carrots (Suslow *et al*. 1998). According to Kreutzmann *et al*. (2007), flavour is one of the important factors in assessing carrot quality. The volatile terpenes are mainly responsible for the typical aroma and flavour of carrots (Hampel *et al*., 2005; Anon., 2008b). Terpenes are commonly found in roots grown under higher temperatures (Rosenfeld *et al*., 2004) and are responsible for the bitter taste of carrots (Simon *et al*., 1980). Extended periods of hot weather can cause strong flavour and coarse roots. A harsh and oily flavour of carrots is associated with elevated levels of terpenes and reduced sugar content, whereas sweetness and overall preference seem to be related to a high concentration of sugars and a reduced level of terpenes (Seljåsen *et al*., 2001). The common terpenes in carrots are α-pinene, β-pinene, limonene, caryophyllene, myrcene, terpinene and terpinolene. However, differences in flavour components have been found to be attributable more to genetics than to climatic conditions (Anon., 2008b).

The influence of temperature on the sensory aspects of carrots has been studied by several authors (Rosenfeld *et al*., 1998a; Rosenfeld *et al*., 1998b; Seljåsen *et al.*, 2001; Rosenfeld *et al*., 2004; Varming *et al.*, 2004; Kreutzmann *et al.,* 2007; Szymczak *et al*., 2007; Kreutzmann *et al*., 2008a; Kreutzmann *et al*., 2008b). Various descriptive studies have been done, including quantitative descriptive analysis (QDA) (Rosenfeld *et al*., 2004; Varming *et al.*, 2004; Kreutzmann *et al*., 2007; Szymczak *et al*., 2007; Kreutzmann *et al*., 2008a) and flavour profiling (Rosenfeld *et al*., 1998a; Rosenfeld *et al*., 1998b). Both these techniques require extensive training of panel members and are time intensive.

Free choice profiling (FCP) (Langron, 1983; Arnold & Williams, 1986) is a sensory technique developed to reduce the need for extensive panel training. It also eliminates the pre-established measure of agreement among the panellists on their interpretation and meaning of the terms they will employ (Deliza *et al*., 2005). The technique has shown results compatible to those obtained by more conventional procedures, and has many practical advantages (Williams & Arnold, 1985). Free choice profiling assumes that assessors do not differ in how they perceive sensory characteristics, just in the way they describe them. Assessors develop idiosyncratic vocabularies (Williams & Arnold, 1985), which will inevitably vary from assessor to assessor, as they are grounded in individual experience and familiarity with the product. These procedures require little training; assessors must be objective, capable of using line scales, and use their vocabularies consistently (Williams & Langron, 1984). Any sensory characteristics can be examined using FCP. The range of characteristics can be restricted by the researcher, but the number of descriptors produced is limited only by the perceptual and descriptive skills of the assessor (Oreskovich *et al*., 1991). Problems, however, arise in FCP when assessors, particularly those with a lack of sensory experience, find it difficult to generate an adequate vocabulary to fully describe the samples (Piggott *et al.,* 1990). It is evident that a low level of training increases specificity of descriptors generated and reproducibility of results (Gains & Thomson, 1990). The gathering of information about cognitive perception directly from the consumers, (Moskowitz, 1996; Russel & Cox, 2003) has been shown as an invaluable tool in determining which attributes are beneficial both in product development and marketing terms when attempting to create the consumers' "ideal" product (Jack, 1994).

The objective of this study was to determine the effect of temperature on the yield and quality (external and internal) parameters of two pre-pack carrot cultivars.

5.2. RESULTS AND DISCUSSION

5.2.1 Yield parameters

Root fresh and dry mass were determined in order to establish the effect of temperature on the yield of carrots. A summary of the analyses of variance that were carried out on these parameters to determine the influence of cultivar and temperature are shown in Table 5.1.

Table 5.1: Summary of the analyses of variance showing the significant effect of cultivar and temperature on carrot yield

Yield parameters	Cultivar (C)	Temperature (T)	CxT
		2009	
Root fresh mass	ns	*	ns
Root dry mass	ns	*	ns
		2009/10	
Root fresh mass	ns	*	ns
Root dry mass	ns	*	ns

$LSD_{(T\leq0.05)}$ *=Significant differences ns= No significant difference

From Table 5.1 it can be seen that yield parameters were only significantly affected by temperature and that cultivar, or the interaction between cultivar and temperature, had no significant effect.

5.2.1.1 Root fresh mass

Where a constant temperature was used only temperature affected root fresh mass in 2009 (Table 5.1). The highest root fresh mass (36.69 g) was obtained at 10°C, significantly higher than at 18°C (10.38 g) (Table 5.2). González *et al*. (2009) also grew carrots at constant temperatures of 12 and 25°C and found that fresh mass of roots at 12°C was significantly higher than at 25°C. Similarly, Rosenfeld *et al*. (1998a) also grew carrots at constant temperatures and reported that root fresh mass at 9 and 12°C was significantly higher than those at 15, 18 and 21°C. Where variation (day and night) in temperatures were used in 2009/10 the highest root fresh mass of 27.69 g was also obtained at the lower temperature (15/5°C) treatment, significantly higher than the 7.74 g and 12.12 g obtained at the 28/20 and 24/10°C temperature treatment, respectively. Ulrich (1954) however, reported that root fresh mass of beet was higher at a day/night temperature of 23/17°C than at lower night temperatures of 10 and 4°C but at the same day temperature (23°C). Difference in results may be due to the fact that the same day temperature was used compared to the different day temperatures (24 and 15°C) used in this study. During both 2009 and 2009/10 root fresh mass increased as temperatures decreased. Although not significant, both “Star 3002” and “CS 1006” exhibited a greater root fresh mass than “Nectar”.

Table 5.2: Influence of cultivar and temperature on carrot root fresh mass (g) in 2009 and 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	10		18	
		2009		
Nectar	34.26		11.62	**22.94**
Star 3002	39.12		9.11	**24.11**
Mean(T)	**36.69**		**10.38**	
LSD$_{(T\leq0.05)}$	**T=4.14**	**C=ns**	**CxT=ns**	
		2009/10		
	15/5	**24/10**	**28/20**	
Nectar	25.44	12.05	5.65	**14.38**
CS 1006	29.94	12.18	9.82	**17.31**
Mean (T)	**27.69**	**12.12**	**7.74**	
LSD$_{(T\leq0.05)}$	**T=5.21**	**C=ns**	**CxT=ns**	

5.2.1.2 Root dry mass

Root dry mass showed the same trend as root fresh mass in both seasons, and was also only significantly influenced by temperature (Table 5.3). The highest root dry mass (4.01 g) was obtained from plants at 10°C, significantly higher than the 1.12 g produced at 18°C in 2009. González *et al*. (2009) also reported a significantly higher dry mass at 12°C than at 25°C. However, Rosenfeld *et al*. (1998a) and Rosenfeld *et al*. (1999) reported that carrot root dry mass was significantly higher at 18 and 21°C than at 9, 12 and 15°C.

During 2009/10 planting where diurnal day and night temperatures were used the highest root dry mass was obtained from plants at 15/5°C (4.11 g), significantly higher than that from plants at the 24/10 (1.16 g) and 28/20°C (1.01 g) treatments. It was also noted that the root dry mass of “CS 1006” plants was higher than that of “Nectar”, irrespective of temperature, although this result was not statistically significant. What was interesting about this result is that it was opposite to that obtained for fresh mass, thus indicating that roots of “Nectar” had a greater water content than those of “CS 1006”.

Table 5.3: Influence of cultivar and temperature on carrot root dry mass (g) in 2009 and 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	10		18	
		2009		
Nectar	3.87		1.29	**2.58**
Star 3002	4.15		0.96	**2.55**
Mean (T)	**4.01**		**1.12**	
LSD$_{(T\leq0.05)}$	**T=0.52**	**C=ns**	**CxT=ns**	
		2009/10		
	15/5	**24/10**	**28/20**	
Nectar	3.40	1.03	0.80	**1.74**
CS 1006	4.82	1.29	1.23	**2.45**
Mean (T)	**4.11**	**1.16**	**1.01**	
LSD$_{(T\leq0.05)}$	**T=0.85**	**C=ns**	**CxT=ns**	

The water content of the carrot root at harvest is 85 to 90% (Odebode & Unachukwu, 1997) and the total soluble solids make up 30 to 70% of the dry matter content (Kjellenberg, 2007). Sucrose is the main form in which carbohydrates are transported to the roots where it is stored in the form of sucrose, glucose or fructose. The ratio of sucrose to reducing sugars varies between cultivars (Daie, 1984; Anon., 2003; Northolt *et al*., 2004). These results again confirm that carrots produced better under cool conditions, confirming findings by Joubert *et al*. (1994) and Rubatzky *et al*. (1999). It can also be seen that lower growth temperatures favour the accumulation of dry matter in the storage roots. This is in agreement with Reddy (2010) who found that the production and transport of sugars, as well as the accumulation of dry matter in carrot roots was better under low temperature conditions.

5.2.2 External quality parameters

Root length, diameter and presence of defects were used to determine the effect of temperature on the external quality of carrot roots. A summary of the analyses of variance that was carried out to determine the influence of different temperatures on root length and diameter of two carrot cultivars in 2009 and 2009/10 are shown in Table 5.4.

Table 5.4: Summary of the analyses of variance showing the significant effect of cultivar and temperature on carrot root length and diameter in 2009 and in 2009/10

External quality parameters	Cultivar (C)	Temperature (T)	CxT
		2009	
Root length	ns	*	*
Root diameter	*	*	ns
		2009/10	
Root length	ns	*	ns
Root diameter	ns	*	ns

LSD$_{(T \leq 0.05)}$ ***=Significant differences** **ns= No significant differences**

5.2.2.1 Root length

During 2009 carrot root length was significantly affected by the interaction between cultivar and temperature (Table 5.4), showing that the two cultivars reacted differently to temperature. Plants of both “Nectar” and “Star 3002” produced significantly longer roots at the lower temperature treatment (10°C) than at 18°C (Figure 5.1). From Figure 5.1 it can be seen that “Nectar” is better adapted to the higher temperature as root length of this cultivar was only reduced by 47.3% as temperature increased from 10 to 18°C, whereas that of “Star 3002” declined by 59.33%. However, root length of cultivars did not differ from each other at a specific temperature treatment.

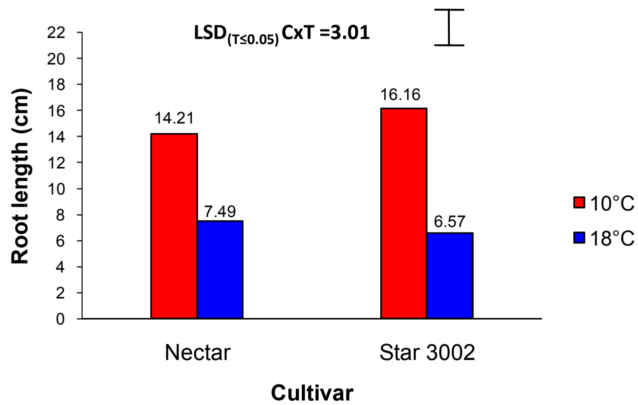


Figure 5.1: Influence of cultivar and temperature on carrot root length in 2009

During the second planting (2009/10) it was again found that the plants grown at the lowest temperature (15/5°C) produced the longest roots (16.6 cm). The roots were significantly longer than those produced at 24/10°C (10.82 cm) which in turn were significantly longer than those produced at 28/20°C (7.35 cm), irrespective of the cultivar (Table 5.5). The results from both plantings are in agreement with those obtained by Rosenfeld *et al*. (1998a; 1999; 2000). The studies conducted by Rosenfeld *et al*. (1998a) and Rosenfeld *et al*. (1999) indicated that the longest roots were obtained at 9 and 12°C where carrots were grown at constant temperatures of 9, 12, 15, 18 or 21°C. Rosenfeld *et al*., (2000) also showed that temperatures of 10 to 15°C increased carrot root length. Carrots harvested from the 2009/10 planting at the low diurnal temperature treatment of 15/5°C were closest to the recommended length (18-22 cm) for pre-pack carrots at 16.60 cm. In 2009, carrots at the 10°C treatment (15.19 cm) were closest to the recommended length.

Table 5.5: Influence of cultivar and temperature on root length (cm) of carrots in 2009 and in 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	10		18	
		2009		
Nectar	14.21		7.49	**10.85**
Star 3002	16.16		6.57	**11.36**
Mean (T)	**15.19**		**7.03**	
LSD$_{(T \leq 0.05)}$	**T=1.10**	**C=ns**	**CxT=3.01**	
		2009/10		
	15/5	**24/10**	**28/20**	
Nectar	16.69	11.48	7.34	**11.84**
CS 1006	16.50	10.15	7.35	**11.33**
Mean (T)	**16.60**	**10.82**	**7.35**	
LSD$_{(T \leq 0.05)}$	**T=1.34**	**C=ns**	**CxT=ns**	

5.2.2.2 Root diameter

Temperature and cultivar significantly affected carrot root diameter in the first planting (Table 5.6). The thickest storage roots (21.75 mm) were obtained from plants cultivated at 10°C, significantly thicker than those from plants at 18°C (15.75 mm). "Nectar" exhibited a root diameter (19.74 mm) significantly thicker than "Star 3002" (17.76 mm). During the second planting root diameter was only significantly affected by temperature with the thickest roots being obtained at 15/5°C. These did not differ significantly in diameter from those at 24/10°C, but were both significantly thicker than carrots at 28/20°C. These results were similar to these obtained in radish, as Suzuki (1978) reported that the thickening of radish root was significantly higher at lower day/night temperatures (12/8°C) than at higher day/night temperatures (25/20°C). These results show that roots were thicker at lower temperatures than at higher temperatures although Tindall (1968), Petzoldt (2008) and Anon. (Undated a) indicated that carrot roots tend to be thicker at warmer temperatures.

Table 5.6: Influence of cultivar and temperature on root diameter (mm) of carrots in 2009 and in 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	10		18	
		2009		
Nectar	22.63		16.86	**19.74**
Star 3002	20.87		14.65	**17.76**
Mean (T)	**21.75**		**15.75**	
LSD$_{(T \leq 0.05)}$	**T=1.56**	**C=1.56**	**CxT=ns**	
		2009/10		
	15/5	**24/10**	**28/20**	
Nectar	18.55	18.62	18.22	**18.46**
CS 1006	18.49	18.35	18.27	**18.37**
Mean (T)	**18.52**	**18.48**	**18.24**	
LSD$_{(T \leq 0.05)}$	**T=0.18**	**C=ns**	**CxT=ns**	

5.2.2.3 Defects

The only defects observed in 2009 were green shoulders and misshapen carrots. Green shoulder of carrots was again a problem in the 2009/10 planting, but hairiness of roots also occurred. The summary of the analyses of variance that was done to determine the influence of different temperatures on the presence of root defects in various cultivars indicated that no factors caused significant defects in the 2009 planting, and only temperature played a significant role in the 2009/10 planting (Table 5.7).

Table 5.7: Summary of the analyses of variance showing the significant effect of cultivar and temperature on defects of carrots in 2009 and in 2009/10

Defects	Cultivar (C)	Temperature (T)	CxT
		2009	
Green shoulder	ns	ns	ns
Misshapen	ns	ns	ns
		2009/10	
Green shoulder	ns	*	ns
Hairiness	ns	*	ns

$LSD_{(T\leq0.05)}$ *=Significant differences ns= No significant differences

Green shoulder in carrots is caused by the formation of chlorophyll in the shoulder of the storage root (Petzoldt, 2008). During the first planting green shoulder of carrot roots was not significantly influenced by any of the treatments (Table 5.8). Although temperature did not significantly influence the presence of green shoulder on the roots it was more pronounced at 18°C (91%) than at 10°C (85%), indicating that the prevalence of the defect could be greater at higher temperatures. During 2009/10 the percentage of green shoulder was significantly greater at 28/20°C (77.5%), than at 15/5 (32.5%) and 24/10°C (12.5%). Interestingly, the lowest percentage of green shoulders was observed at 24/10°C, although this was not significantly lower than at 15/5°. This would appear to indicate that, although temperature did play a role, some other factor/s were also important in the occurrence of this defect. Carrot cultivars of the Nantes type are particularly susceptible for the formation of green colouration on the shoulders and within the core area of the root (Petzoldt, 2008). Green shoulder of carrot roots are caused by genetic and climatic factors such as light and temperature. When roots are exposed to high light intensities and temperatures, chlorophyll synthesis is stimulated in the shoulder area (Ravishakar *et al*., 2009). Greening in carrot roots not only affects appearance but also makes them unsuitable for consumption due to the presence of some as yet unknown bitter compounds present in the affected areas (Ravishakar *et al*., 2007).

Table 5.8: Influence of cultivar and temperature on the percentage (%) green shoulders in 2009 and 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	10		18	
		2009		
Nectar	82.5		92.5	**87.5**
Star 3002	87.5		90.0	**88.8**
Mean (T)	**85.0**		**91.0**	
LSD$_{(T\leq0.05)}$	**T=ns**	**C=ns**	**CxT=ns**	
		2009/10		
	15/5	**24/10**	**28/20**	
Nectar	30.0	12.5	85.0	**42.5**
CS 1006	35.0	12.5	70.0	**39.2**
Mean (T)	**32.5**	**12.5**	**77.5**	
LSD$_{(T\leq0.05)}$	**T=29.0**	**C=ns**	**CxT=ns**	

Few misshapen roots were noticed during the 2009 planting, and this parameter was not significantly influenced by either temperature or cultivar (Table 5.9). Although 27% of "Nectar" roots were misshapen at 18°C, this was not significantly more than all the other treatments. These findings are in agreement with those of Taber & Jauron (1998), Anon. (1993) and Anon. (2009c) who reported that misshapen (skewed/ twisted) carrots were caused by overcrowding, soil debris, fresh manure, heavy soils and nematodes and not temperature.

Table 5.9: Influence of cultivar and temperature on the percentage (%) of misshapen roots in 2009 and of hairy roots in 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	10		18	
		2009		
Nectar	17.5		27.5	**22.5**
Star 3002	12.5		10.0	**11.3**
Mean (T)	**15.0**		**18.8**	
LSD$_{(T\leq0.05)}$	**T=ns**	**C=ns**	**CxT=ns**	
		2009/10		
	15/5	**24/10**	**28/20**	
Nectar	65.0	25.0	77.5	**55.8**
CS 1006	62.5	50.0	100.0	**70.8**
Mean (T)	**63.8**	**37.5**	**88.8**	
LSD$_{(T\leq0.05)}$	**T=48.0**	**C=ns**	**CxT=ns**	

During 2009/10 it was found that temperature had a significant effect on the occurrence of hairy roots. Carrots grown at 28/20°C had significantly more hairy roots (88.8%) than those at 24/10°C (37.5%), while the occurrence of hairy roots on plants grown at 15/5°C (63.8%) was not significantly different from that at the other temperatures. The percentage hairy carrots were higher for "CS 1006" (70.8%) than for "Nectar" (55.8%), but not significantly more. According to Joubert *et al*. (1994) carrots develop a hairy/rough appearance when the temperature is fairly high in the summer. This is in agreement with the findings of this study.

However, the high percentage of hairy roots found at the lowest temperature (15/5°C) would appear to indicate that some other factor, not only temperature, was playing a role. Christey & Braun (2004) indicated that hairy root development in carrots is related to soil moisture levels, with tap root developing many small feeder roots under low moisture conditions. Excessive soil moisture can, however, also lead to increased lateral root formation so that the root surfaces appear hairy (Drost & Bitner, 2010; Anon., 2008b). According to Becard & Fortin (1988), cultivars also differ in their susceptibility to hairy root. In this study the cultivars were found to respond differently, although this difference was not significant. It is however also possible, that the high percentage of hairiness in 2009/10 was caused by the long growing season, and the fact that the soil was kept fairly wet.

5.2.3 Internal quality parameters of carrots

Internal parameters such as firmness and total soluble solids (TSS) were measured during both the 2009 and 2009/10 plantings. Carotene, α-pinene, β-pinene, caryophyllene, limonene, myrcene, terpinolene, terpinene were only analysed in 2009/10 something that was not done in 2009 due to of a lack in funding. A summary of the analyses of variance that was carried out to determine the effect of cultivar and temperature on the internal quality parameters are shown in Table 5.10.

Table 5.10: Summary of the analyses of variance showing the significance of cultivar and temperature a on the internal quality parameters of carrots in 2009 and 2009/10

Internal quality parameters	Cultivar (C)	Temperature (T)	CxT
2009			
Firmness	ns	*	*
Total soluble solids	ns	*	ns
2009/10			
Firmness	ns	*	ns
Total soluble solids	ns	*	ns
Carotene	ns	*	ns
α-Pinene	ns	ns	ns
β-Pinene	ns	*	ns
Caryophyllene	ns	*	ns
Limonene	ns	ns	ns
Myrcene	ns	ns	ns
Terpinolene	ns	ns	ns
Terpinene	ns	ns	ns

$LSD_{(T\leq 0.05)}$ *=Significant differences ns= Not significant

As shown in Table 5.10 the firmness of carrots was significantly affected by the interaction between cultivar and temperature during 2009, but in 2009/10 only temperature had an effect on the parameter. The total soluble solids of carrots were significantly influenced by temperature in both 2009 and 2009/10. Carotene, β-pinene and caryophyllene content of carrots were the only chemical components influenced by temperature. None of the internal quality parameters showed significant differences due to cultivar.

5.2.3.1 Root firmness

During 2009 the interaction between cultivar and temperature had significant effect on the firmness of carrot roots (Table 5.10). Both "Nectar" and "Star 3002" was firmer at the low temperature (10°C) treatment than at 18°C, although not significantly so (Figure 5.2). At a specific temperature the firmness of the two cultivars also did not significantly differ from each other. In 2009/10 significantly firmer roots (15.03 mm) were produced at 15/5°C, than at 24/10 and 28/20°C (Table 5.11). If a less strict significant test were to be used it would probably indicate a significant difference in "Star 3002" between the two temperatures.

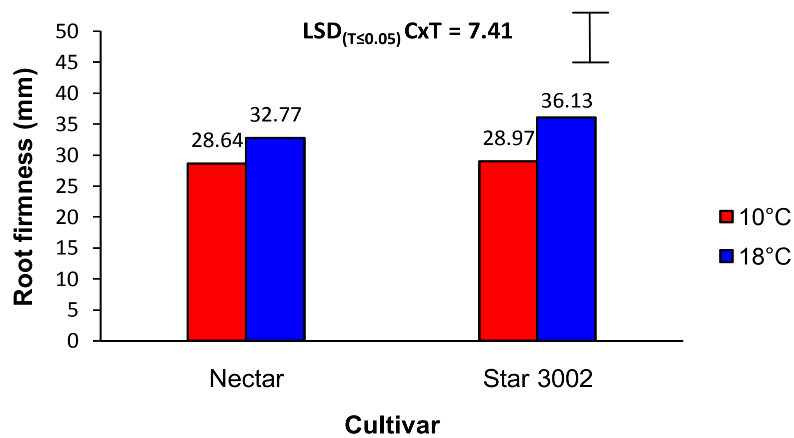


Figure 5.2: Influence of temperature on the firmness (mm) of "Nectar" and "Star 3002" in 2009

Herppich *et al*. (2005) also reported that firmer carrots were obtained when grown at 10°C than at 20°C but Rosenfeld *et al*. (1998a) on the other hand reported that carrots grown at 15, 18 and 21°C were firmer than those grown at 9 and 12°C.

Table 5.11: Influence of cultivar and temperature on firmness (mm) of carrots in 2009 and in 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	10		**18**	
		2009		
Nectar	28.64		32.77	**30.70**
Star 3002	28.97		36.13	**32.55**
Mean (T)	**28.80**		**34.45**	
LSD$_{(T \leq 0.05)}$	**T=2.72**	**C=ns**	**CxT=7.41**	
		2009/10		
	15/5	**24/10**	**28/20**	
Nectar	17.25	42.00	31.00	**30.08**
CS 1006	12.81	43.56	30.38	**28.92**
Mean (T)	**15.03**	**42.78**	**30.69**	
LSD$_{(T \leq 0.05)}$	**T=10.90**	**C=ns**	**CxT=ns**	

5.2.3.2 Total soluble solids

Temperature had a significant effect on the total soluble solids of carrots in both seasons (Table 5.10). The total soluble solids in roots from the 18°C treatment (6.78 °Brix) was significantly greater than of roots from 10°C (6.02 °Brix) in 2009. During 2009/10 the total soluble solids of carrots was the highest (10.67 °Brix) at 15/5°C, significantly higher than at 24/10 or 28/20°C. Rosenfeld *et al.* (1998a) grew carrots at different temperatures (9, 12, 15, 18 and 21°C) and also obtained the highest total soluble solids at 18°C, significantly higher than what was obtained at 9 and 12°C. Similarly, Simon *et al*. (1982) found that carrots grown in California winter climate have a higher sugar content and sweeter taste than carrots grown in Florida and Wisconsin summer climate. On the other hand, Ulrich (1954) reported that the sucrose concentration in the roots of beet was greater at day/ night temperatures of 23/4 and 23/10°C than at 23/17°C. At low night temperatures, respiration rate is low and the carbohydrates stored as sucrose, glucose and fructose in the root are not been used in the same extend as under higher night temperatures (Sutcliffe, 1977; Benjamin *et al*., 1997). This could elucidate the 2009/10 results, but not those obtained in 2009, where higher TSS values were obtained at the higher temperature. However, the values from both temperatures were very close to those obtained at the higher temperature in 2009/10. It therefore appears as though the night temperature play a very important role here.

Table 5.12: Influence of cultivar and temperature on the total soluble solids (°Brix) of carrot roots in 2009 and in 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	10		18	
		2009		
Nectar	5.94		7.38	**6.66**
Star 3002	6.09		6.19	**6.14**
Mean (T)	**6.02**		**6.78**	
LSD$_{(T\leq0.05)}$	**T=0.74**	**C=ns**	**CxT=ns**	
		2009/10		
	15/5	**24/10**	**28/20**	
Nectar	10.84	6.72	6.91	**8.16**
CS 1006	10.50	5.84	6.34	**7.56**
Mean (T)	**10.67**	**6.28**	**6.63**	
LSD$_{(T\leq0.05)}$	**T=1.10**	**C=ns**	**CxT=ns**	

5.2.3.3 Carotene

The carotene content of carrots were significantly higher at 15/5°C (4.67 mg kg^{-1}), than at 24/10 (1.92 mg kg^{-1}) but not at 28/20°C (3.55 mg kg^{-1}) (Table 5.13). The findings of this study correspond well to those of Banga *et al*. (1955); Rosenfeld *et al*. (1999); Rosenfeld *et al*. (1998a) and Rosenfeld *et al*. (1998b) who reported a significant higher carotene content in carrots at 18°C than at 9 and 12°C, but not significantly higher than at 15 and 21°C. Joubert *et al*. (1994) and Anon. (2003) also state that the best carrot colour, which is associated with a high carotene content develops at temperatures of between 15 and 20°C.

Age of the roots (Rubatzky *et al*., 1999), high temperature and genetic variation (Seljåsen *et al*., 2001) influence the carotene production in carrots. According to Rosenfeld (1998) the carotene content in carrot storage roots is high at temperatures between 10 and 12°C giving roots their deep orange colour, but as the temperature rises from 21 to 27°C and above, the carotene content decreases causing the roots to become paler/lighter. Tindall (1968) stated that extreme high soil temperatures also result in pale yellow carrots. A temperature below 10°C causes roots of carrots to become paler/lighter (Joubert *et al*., 1994; Petzoldt, 2008; Anon., Undated a). Studies have shown that carrots grown under cool night and warm day temperatures produce more carotene than carrots grown under constant day and night temperatures (Anon., 2008a).

Table 5.13: Influence of temperature on the carotene content (mg kg^{-1}) of carrot roots in 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	15/5	24/10	28/20	
Nectar	5.28	1.65	3.53	**3.49**
CS 1006	4.06	2.18	3.57	**3.27**
Mean (T)	**4.67**	**1.92**	**3.55**	
LSD$_{(T\leq 0.05)}$	**T=2.44**	**C=ns**	**CxT=ns**	

5.2.3.4 Terpenes

Although seven different terpenes were analysed after harvesting the carrots, only two were significantly influenced by temperature (Table 5.10). Only data of these two will be shown and discussed. Cultivar and the interaction between cultivar and temperature had no effect on the terpene content of the roots.

β-Pinene

β-pinene (1.39 mg kg^{-1}) was significantly higher in the roots of plants grown at 24/10 (1.29 mg kg^{-1}) and 28/20°C (1.39 mg kg^{-1}) than those at 15/5°C (0.31 mg kg^{-1}) (Table 5.14). From Table 5.14 it can be seen that the β-pinene content of carrot roots increased with increasing temperatures. Rosenfeld *et al*. (2002) found that the highest β-pinene content was found at a constant temperature of 21°C with the lowest at 9°C. This would appear to be consistent with the findings of this study, as 21°C was the highest temperature used by Rosenfeld *et al*. (2002).

Table 5.14: Influence of cultivar and temperature on the β-pinene content (mg kg^{-1}) in roots of carrots in 2009/10

Cultivar (C)	Temperature (°C) (T)			Mean (C)
	15/5	24/10	28/20	
Nectar	0.33	1.21	1.37	**0.97**
CS 1006	0.29	1.37	1.42	**1.03**
Mean (T)	**0.31**	**1.29**	**1.39**	
LSD$_{(T\leq 0.05)}$	**T = 0.38**	**C = ns**	**CxT = ns**	

Caryophyllene

Caryophyllene followed the same trend as β-pinene (Table 5.15). Caryophyllene concentration was significantly lower (0.31 mg kg^{-1}) at 15/5°C than at both 24/10 (1.29 mg kg^{-1}) and 28/20°C (1.39 mg kg^{-1}) treatments. Rosenfeld *et al*. (2002) also reported that the highest caryophyllene concentration was obtained in carrots grown at 21°C, significantly higher than that obtained from plants grown at 9 and 12°C. However, this was not significantly greater than that obtained at 15 and 18°C, indicating that higher temperatures favour high caryophyllene content in carrots. This is the compound that is also responsible for the bitter taste in carrots (Rosenfeld *et al*., 2002). Kjeldsen *et al*. (2003) also suggested that β-caryophyllene may be responsible for terpene-like, spicy, woody aroma in carrots.

Table 5.15: Influence of cultivar and temperature on the caryophyllene content (mg kg^{-1}) of carrot roots in 2009/10

Cultivar (C)	Temperature (°C) (T) 15/5	24/10	28/20	Mean
Nectar	0.63	2.30	2.36	**1.76**
CS 1006	0.68	1.41	1.47	**1.19**
Mean	**0.66**	**1.85**	**1.92**	
LSD$_{(T\leq0.05)}$	**T = 0.79**	**C = ns**	**CxT = ns**	

Although not significant, the concentration of all the other terpenes analysed showed the same tendency, being lowest in plants cultivated at 15/5°C and increasing as growing temperature increased (Data not shown). From this study it is clear that as temperature increased the terpene content also increased, although this was not always significant. Rosenfeld *et al*. (2002) also reported that elevated growing temperature increased the terpene content of carrots, and that volatile terpenes such as α-terpinene and β-caryophyllene are responsible for the bitter taste. However, Czepa & Hofmann (2003) recently showed that polyacetylenes such as falcarinol and falcarindiol-3-acetate are the most important indicators of the bitter taste in carrots. These were unfortunately, not determined in this study.

5.2.4 Sensory analysis

The free choice profiling (FCP) technique generated seven taste attributes amongst the ten panellists. The descriptors included three of the four basic tastes, excluding salty. Other descriptors included ‘carrot’, ‘chemical’ and ‘bland’. The presence of an aftertaste was also noted. In a study by Szymczak *et al*. (2007), a trained panel, using quantitative descriptive analysis (QDA), generated 13 descriptors, including 3 taste and 5 odour attributes: carrot odour; sweet odour; off odour; carrot flavour, sweet taste, sour taste, bitter taste and off flavour. Kreutzmann *et al*. (2007) used a set of 13 attributes, including terpene aroma, carrot aroma, silage aroma, green aroma, hay aroma, terpene flavour, carrot flavour, sweetness, bitterness, green flavour, soapiness, nutty flavour and a burning aftertaste. According to Kreutzmann *et al*. (2008a), the characteristics of carrot flavour, which is a rather complex attribute, include terpene aroma, green flavour, sweetness and bitterness.

It should be noted that, because an untrained panel was used to conduct a descriptive test, the word ‘taste’ was used liberally, e.g. ‘carrot’ is not a taste, but rather a flavour. However, Kjellenberg (2007) named ‘carrot’ as a taste quality perceived in the oral pit as an experience of the liquid created in the mouth when chewing. Furthermore, the term ‘bitter’ has been supplemented with the term ‘harsh’, which is used to describe a burning turpentine-like flavour occurring most clearly at the back of the throat. There was no guarantee that all assessors used these attributes in the same way, or indeed attached the same importance to them in discriminating amongst the samples. The assessors used elementary words to describe their perceptions of the samples, which reflected their lack of training, as well as naiveness. Training of assessors would merely improve reproducibility of results and lead to the use of more specific sensory terms. According to Deliza *et al*. (2005), precisely defined vocabularies are not needed for describing products in order to reveal relationships and differences between samples.

Table 5.16 is the PANOVA summary of the efficiency of each generalized procustes analysis (GPA) transformation in terms of reduction of the total variability. The scaling (p-value = 0.0001) and translation (p-value < 0.0001) transformations were the most efficient, having the lowest p-values, and were therefore significant. The rotation transformation (p-value > 0.0001) was not significant, meaning that the terms (descriptors) could not be corrected. The other two significant transformations, performed by the GPA, corrected the differences between the individual assessors' judgements (Arnold & Williams, 1986): the translation step corrected the level effect and the isotropic scaling step corrected the range effect.

Table 5.16: PANOVA-table for free choice profiling of six carrot samples

Source	DF	Sum of squares	Mean squares	F	Pr > F
Scaling	9	54.282	6.031	4.174	0.000
Rotation	189	221.594	1.172	0.811	0.899
Translation	63	1016.444	16.134	11.166	< 0.0001

According to the eigenvalues i.e. percentage by which variation is explained in a plot (Table 5.17), 90.94% of the variation is explained by dimension 1, and 5.48% of the variation is explained by dimension 2. The first two factors allowed a representation of 96.42% of the initial variability of the data. Figure 5.3 shows the importance of the all the factors on their own, as well as their accumulating values.

Table 5.17: Eigenvalues showing the variability corresponding to all dimensions

	F1	F2	F3	F4	F5
Eigenvalue	12.455	0.750	0.331	0.136	0.023
Variability (%)	90.942	5.479	2.419	0.992	0.167
Cumulative (%)	90.942	96.422	98.841	99.833	100.000

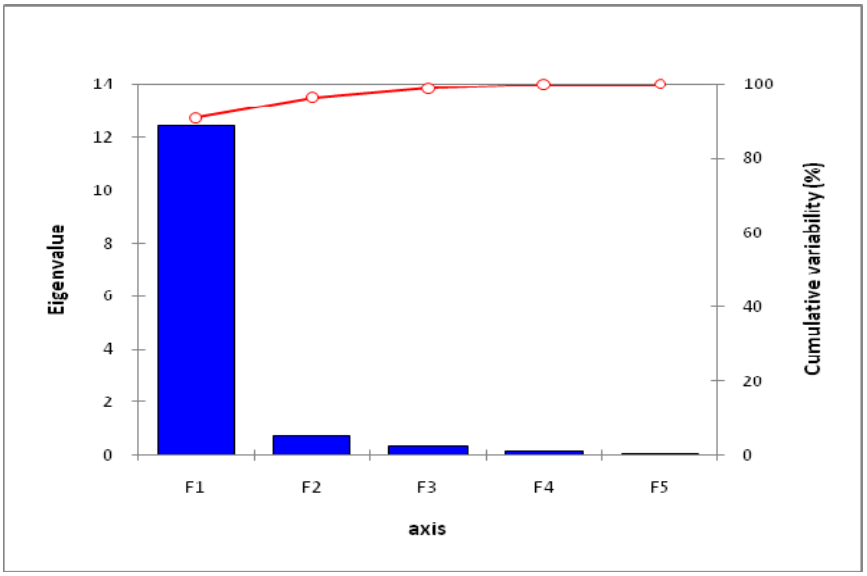


Figure 5.3: Screen plot of eigenvalues and cumulative variability

The FCP (F1 + F2) for the taste attribute of the two carrot cultivars and their three growth temperatures is shown in (Figure 5.4). From this graph it is clear that the panel was capable to distinguish the growth temperature of 15/5°C, from the other two temperatures, 24/10°C and 28/20°C. The first component was positively correlated (values > 0.5) with bitter, sour, chemical, bland and aftertaste – thereby describing the taste of the two carrot cultivars, "Nectar" and "CS1006" at the growth temperatures 24/10°C and 28/20°C. This was in agreement with the findings of Rosenfeld (1998a) and Rosenfeld *et al*. (2004) that the highest bitter taste in carrots grown at 21°C, the highest temperature in their trials.

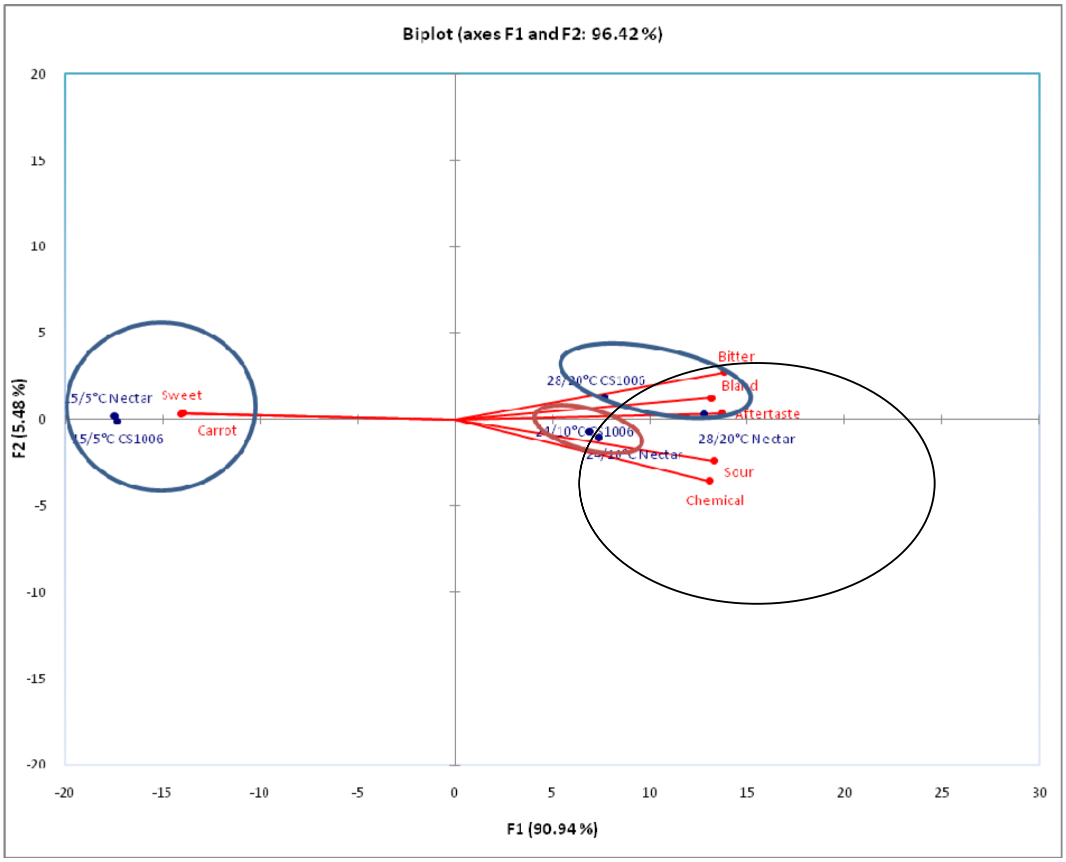


Figure 5.4: Generalized Procustes Analysis (GPA) biplot of free choice profiling for taste attributes of carrot cultivars grown under different temperatures.

Descriptors that were negatively correlated (values > -0.5) with the first dimension were sweet and carrot. These two descriptors described the taste of the two carrot cultivars at the growth temperature of 15/5°C. Carrots grown at 9°C were also found to have the highest scores for sweet taste (Rosenfeld, 1998a; Rosenfeld *et al.*, 2004). Varming *et al*. (2004) found that sugar and dry matter were correlated to a sweet taste, and that a low growing temperature favoured sweet taste (Rosenfeld *et al.*, 1998a). As it can be seen on Figure 5.3, the 'positive' and 'negative' attributes lay in total opposite direction from one another.

The low value of 5.48%, by which dimension 2 explained the variation, made it difficult for the panel to distinguish between the two temperature treatments of 24/10°C and 28/20°C, confirming the insignificance of the rotation transformation. There was, however, a clear indication that the two heat treatments could be separated, as indicated on the biplot. The chemical and sour attributes may very well be descriptive of the growth temperature 24/10°C, while bitter, bland and aftertaste could be indicative of the effect of the growth temperature 28/20°C, for both cultivars. It was previously observed that there is a relationship between bitter tasting flavour compounds and dry matter in carrots grown at high temperatures (Rosenfeld *et al*., 1998a). Furthermore, harsh flavour attributes (terpene flavour, green flavour, bitterness and burning aftertaste) were found to increase in intensity with increasing terpene content (Kreutzmann *et al*., 2008a). According to Nakamura & Okai (1993), certain substances, among others terpenes, block up the taste receptors on the tongue. The high levels of certain taste and flavour variables at the highest temperatures might thus be responsible for such a blockage or masking effect, which may result in lower perception of sweetness.

The ten semi-naive assessors, using FCP, successfully described the carrot cultivars in this study. The sensory analysis showed profound differences in the sensory profile comparing two carrot cultivars grown at high temperatures (24/10 and 25/20°C) and low temperature (15/5°C). The low temperature sensory profile was characterized by the descriptors sweet and carrot. Carrots with the high temperature sensory profile had bitter, sour, chemical and bland taste, with a definite aftertaste.

From the chemical analysis and sensory data it is clear that the two carrot cultivars did not differ from each other concerning the internal quality parameters measured. Only temperature had a significant influence on the internal quality of carrots. The chemical analysis data corresponded well with the sensory data and it is clear that the best quality carrots were obtained at the lower temperature treatment (15/5°C). The sensory panel referred to carrots grown at 24/10°C as carrots with a sour and chemical taste while those at 28/20°C with bitter, bland taste and an aftertaste. The chemical data supported the sensory data where The terpenes responsible for bitter taste as indicated by various researchers (Simon *et al*., 1980; Nakamura & Okai, 1993; Seljåsen *et al*., 2001; Rosenfeld *et al*., 2002; Rosenfeld *et al*., 2004) was at the highest concentration in carrots grown under high temperatures. The TSS was also the highest in carrots grown under low temperatures and therefore the sweet taste. The sweet and carrot taste at 15/5°C can be explained by the higher TSS content at the 15/5°C treatment. According to Seljåsen *et al*. (2001) a harsh and oily flavour of carrots is associated with elevated levels of terpenes and reduced sugar content, whereas sweetness and overall preference seem to be related to a high concentration of sugars and a reduced level of terpenes. The findings of Simon *et al.* (1980) suggested that the sweetness and overall preference were enhanced by sugars and reduced by volatile compounds which confirm the results of this study. Rosenfeld *et al*., (1998b) indicated that carrots for sensory profile (sweet with low terpene content) be grown at low temperatures. Rosenfeld *et al*., (1999) also reported the sweetest carrots at lower temperature 12°C; this corresponded well with the results obtained in this study. Similarly, carrots grown at 9 and 12°C had higher contents of sugars and were sweeter than those grown at 18 and 21°C (Rosenfeld *et al*., 1998a).

According to (Nakamura & Okai, 1993; Rosenfeld *et al*., 2002; Rosenfeld *et al*., 2004) substances such as terpenes have a blocking effect on the sweetness in carrots. The higher temperatures might therefore be responsible for such a blockage or masking effect, which may result in lower perception of sweetness. This is confirmed by the results of this study where most terpenes were highest at higher temperatures 24/10 and 28/20°C and according to Rosenfeld *et al*. (2002) terpenes are responsible for the bitterness in carrots. Bitter and aftertaste were at their maximum at higher temperature 28/20°C. In the study done by (Rosenfeld *et al*., 1998a; Rosenfeld *et al*., 1999) the highest bitter and aftertaste were greater at the 18 and 21°C treatments than at 9 and 12°C. Only one terpene; terpinolene, was highest at lower temperature 10°C when a constant temperature was used. The same results were found by Rosenfeld *et al*. (2002). Unfortunately the sensory analysis for 2009 planting could not be done because carrot plants at the two highest temperature treatments died.

5.3 CONCLUSIONS

It can be concluded that temperature had a marked effect on both the yield and quality parameters of carrot roots from the cultivars Nectar, Star 3002 and CS 1006. Yields, determined by root fresh and dry mass were greater at the lowest temperatures (10°C in 2009 and 15/5°C in 2009/10). Better external quality (root length and diameter) was also obtained at the lowest temperatures, although differences were not always significant. The presence of defects such as green shoulder and misshapen roots, as well as hairy roots was more pronounced as temperature increased. It can, therefore, be seen that yield and external quality parameters of carrots were the best at lower temperatures.

The results obtained in this study showed that temperature had a significant effect on most of the internal quality parameters of carrots. Temperature was found to have a significant influence on root firmness, total soluble solids, carotene, β-pinene and caryophyllene. The internal quality parameters such as root firmness, total soluble solids and carotene were the best at the lower temperature treatments, whereas the terpene content were always higher at the higher temperature treatments, although not always significant. These results were supported by the sensory panel’s results who also reported the best sweet carrot taste from carrots grown at the lower temperature treatment.

As a result it can be concluded that the highest yields of the best quality carrots are obtained during the cooler growing periods.

CHAPTER 6

SUMMARY AND RECOMMENDATIONS

6.1 SUMMARY

Carrot is a root vegetable crop known for its high nutritional value and is one of the vegetables grown on a small scale, particularly in under developed countries. Carrots react more or less the same to varying climatic conditions, particularly temperature, which plays a significant role in the production (growth, yield and quality). For this reason carrots should be cultivated at optimum temperatures (15 to 25°C) to obtain high yields. Extremely high and low temperatures have a negative effect on carrot growth, yield and quality because at both extremes the growth ceases, yield is decreased and the quality (both internal and external) is affected. When temperatures rise too high above the optimum, growth and yield are drastically reduced, and the quality is also eventually affected negatively. Carrot roots tend to be shorter and thicker at very high temperatures and when temperatures are too low the roots become longer and thinner. The internal quality of carrots is also affected negatively when the temperatures are high as the production of terpenoids, responsible for the bitter taste, is increased, thereby masking the sweet taste of carrot roots. The reaction of different cultivars to different temperatures should also be taken into account when growing carrots for the pre-pack market.

The main objective of this study was thus to determine the effect of different temperatures on growth, yield and quality of pre-pack carrot cultivars. In order to achieve this, two pot trials were conducted in controlled environment chambers.

Trial one

This trial was conducted to determine the response of two carrot pre-pack cultivars, “Nectar” and “Star 3002”, at four temperatures (10, 18, 26 and 32°C).

Temperature significantly influenced number of leaves, plant height and leaf growth of carrot plants. At the high temperatures (26 and 32°C) carrot plants died, while the growth, yield and quality of roots were positively influenced by lower temperatures (10 and 18°C). The growth of the two carrot cultivars did not differ significantly in their response to temperature at the end of the growth season.

“Nectar” plants produced significantly more leaves than “Star 3002” plants at only week 6 and 8. Temperature also influenced carrot leaf number significantly from 6 to 18weeks after planting. Plant height of “Nectar” was also significantly greater than that of “Star 3002” during the first 6, 8 and 10 weeks after planting. Plant height was significantly influenced by temperature 20 weeks after planting. Growth (leaf number, plant height and leaf growth), yield (fresh and dry mass), some external qualities (root length, diameter and defects) and most of the internal quality parameters were also influenced significantly by temperature. Root mass (both fresh and dry), root length and diameter, as well as firmness was higher in plants grown at 10°C than those grown at 18°C. The presence of root defects and total soluble solids were more pronounced in plants at the 18°C treatment than those at the lower 10°C treatment.

Trial two

This trial was conducted to establish the response of the two carrot pre-pack cultivars “Nectar” and “CS 1006” to four different day/night temperature regimes (15/5, 24/10, 28/20 and 35/25°C).

Data from this trial indicated that temperature only had a significant influence on carrot leaf at 6, 8, 10, 24, 26 and 28 weeks after planting. During week 6, 8 and 10 after planting leaf number under temperature 28/20°C was significantly greater than that under 15/5 and 35/25°C. Leaf number under temperature 24/10°C during week 24, 26 and 28 was significantly more than that at 35/25°C but not significantly greater than those at 15/5°C. Temperature significantly influenced carrot plant height throughout the growth season. At temperature 28/20°C plant height was significantly higher than that at 15/5, 24/10 and 35/25°C only at 6 weeks after planting. From 10-30 weeks after planting carrot plants under temperature 24/10°C were higher than the other carrot plants under 15/5 and 35/25°C although not always significant.

Root fresh and dry mass reacted positively to lower temperatures and ‘Nectar” plants’ roots were heavier than those of “CS 1006” plants. Similarly, root length and diameter were also greater at lower temperatures and on average plants of the cultivar “CS 1006” had better external quality than plants of “Nectar”. Higher temperatures increased the presence of defects such as green shoulder, misshapen and hairiness on carrot roots, and cultivar differences were also noticed, with “Nectar” having a greater percentage of defects than “CS 1006”.

Firmness and some of the terpenes such as β-pinene and caryophyllene were significantly influenced by temperature. The total soluble solids and carotene content of roots was found to increase at low temperatures, being highest at the lowest temperature (15/5°C). Sensory analysis also showed that sweetness of carrot roots was greatest at the lowest temperature regime (15/5°C), while the highest temperature regime of 28/20°C promoted bitterness.

6.2 RECOMMENDATIONS

Based on the results from these two pot trials the following recommendations can be made:

- Characteristics of carrot cultivars and climatic conditions must be taken into account when growing carrots

- By considering the response of the different parameters under different temperatures, it seems that the optimum results for growth, yield and quality were obtained at lower temperatures between 10 and 18°C when a single temperature was applied and at 15/5 and 24/10°C when day and night temperature variation was applied. As constant temperature does not exist in nature, it is recommended that carrot be planted under warmer day temperatures between 15 and 24°C and cooler night temperatures between 5 and 10°C.

- From this it can be seen that planting season plays an important role in determining the growth, yield and quality of carrots. The influence of temperature combination of high day/low night temperature was significantly better than that of high day/high night temperature where plants died. Carrots should be cultivated during cooler periods in order to improve growth, yield and quality.

In retrospect, a few aspects of temperature on carrots were addressed in this study and the following warrants further investigations:

- Response of carrot root to a long growing season.

- The effect of the interaction between temperature and light intensity, as well as temperature and photoperiod on carrot growth.

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Annexure 1

Semi naïve panelist **Code of sample: 718**

TASTE:

1. Sweet

1	2	3	4	5	6	7	8	9	10

None **Very high**

2. Carrot

1	2	3	4	5	6	7	8	9	10

None **Very high**

3. Bitter

1	2	3	4	5	6	7	8	9	10

None **Very high**

4. Salty

1	2	3	4	5	6	7	8	9	10

None **Very high**

5. Chemical

1	2	3	4	5	6	7	8	9	10

None Very high

6. **Earthy/mouldy**

1	2	3	4	5	6	7	8	9	10

None **Very high**

7. **Cardboard-like**

1	2	3	4	5	6	7	8	9	10

None **Very high**

8. **Woody**

1	2	3	4	5	6	7	8	9	10

None **Very high**