Cultivation aspects of hydroponic cut tulip (*Tulipa gesneriana*) production in South Africa

By

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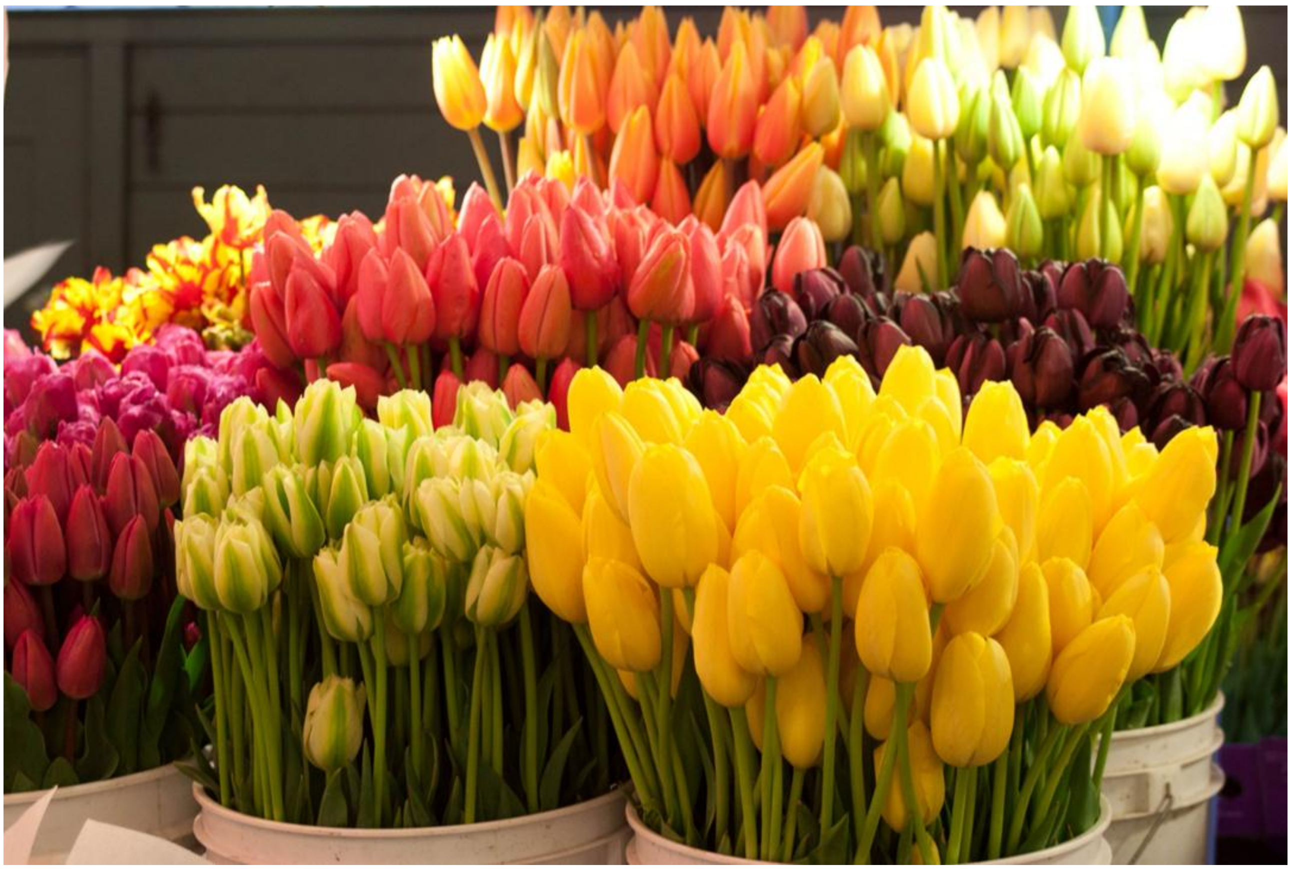
"The earth laughs in flowers" – E.E Cummings



Abstract

Tulip cut flowers are considered speciality flowers, but are cultivated on a limited scale in South Africa. Published research done on the cultivation aspects of *Tulipa* spp. in warm climates is sparse and insufficient. The production potential of this valued floriculture crop under South African conditions however prompts a need for research as profitable returns can only be realised when cut tulip producers deliver high quality tulips, both for the local and potentially the export market. Understanding how cut tulips react to different cultivation aspects under local conditions is key in developing successful and profitable forcing programs for cut tulip production in South Africa. In order to produce quality tulips it is vital that producers minimize the occurrence of physiological disorders by optimizing cultivation aspects such as nutrition, bulb quality and age, cultivar selection as well as postharvest treatments.

To study the nutritional requirements of cut tulips produced in a hydroponic system under South African conditions two similar experiments were conducted, using early-forcing and late-forcing tulip bulbs respectively. In each experiment the effect of four different nutrient solution formulations ("Current SA", "Standard Steiner", "Europe", "Europe+NH_4") and four different cut tulips cultivars ('Leen van der Mark', 'Jan van Nes', 'Ill de France', 'Royal Virgin') on growth, quality and vase life was evaluated. Results showed that although nutrient solutions did not significantly affect the scape growth of cut tulips, vase life was significantly affected by nutrient solution formulation for both early- and late-forcing bulbs. For early-forcing bulbs nutrient solution "Europe" produced tulips with a significantly longer vase life than other nutrient solutions and for late-forcing bulbs nutrient solution "Standard Steiner" produced tulips with a significantly longer vase life than other nutrient solutions. Cultivars differed significantly in terms of growth, quality and vase life for both early- and late-forcing bulbs. It was found that the cultivar 'Leen van der Mark' presented the longest stem length, greatest fresh weight and longest vase life of all cultivars evaluated for both early- and late-forcing bulbs and it seems to be a cultivar with a low risk in terms of quality and vase life for forcing hydroponically in warm climates.

As stem topple, a physiological disorder which can be prevalent in hydroponically produced tulips, has been shown to be reduced by the application of calcium fertilizers, the next experiment was conducted to investigate the role of foliar sprays to reduce or eliminate this common disorder. Various foliar spray treatments, including calcium nitrate ($CaNO_3$), CalTrain, NonTox Silica® and an untreated control, were evaluated for their effect on the occurrence of postharvest stem topple and the vase life of the two tulip cultivars 'Jumbo Pink' and 'Strong Gold' respectively. Trends indicated that foliar sprays containing calcium, "$CaNO_3$" and "CalTrain", reduced the incidence of postharvest stem topple. The vase life of hydroponically forced cut tulips was significantly increased by the use of foliar fertilizer sprays as compared to the control.

The vase life of cut tulips is an important parameter directly affecting quality. In a final experiment, the efficacy of three postharvest treatments to extend the vase life and minimize postharvest stem elongation of the four cut tulip cultivars 'Deshima', 'Synaeda Orange', 'White Marvel' and 'Margarita' was evaluated. Treatments consisted of an untreated control, an overnight stem pulse of Chrysal BVBPlus, a four hour fumigation of Chrysal Ethylene Buster® (1-MCP) and a combination of the latter treatments. Vase life, postharvest stem elongation and vase-solution used were parameters measured. No statistically significant effects on any parameters measured could be identified between the various treatments. Trends observed suggest that treatments containing BVBPlus may prolong the vase life, minimize postharvest stem elongation and improve the usage of vase life solution of hydroponically produced cut

tulips. BVBPlus thus shows potential for use as an essential postharvest treatment for cut tulips produced hydroponically under warm climate conditions, but further research is needed for conformation.

This research is a first report on key agronomical aspects of the hydroponic cultivation of cut tulips in South Africa and aims to serve as a basis for future research, ultimately to support successful commercial cultivation of tulips on a larger scale in South Africa as well as internationally.

Uittreksel

Tulp snyblomme word beskou as spesialiteitsblomme, maar word op 'n beperkte skaal in Suid-Afrika verbou. Gepubliseerde navorsing gedoen oor die verbouingsaspekte van *Tulipa* spp. in warm klimate is skraps en onvoldoende. Die potensiële belangrikheid van kennis aangaande verbouingsaspekte van hierdie gewas in warm klimate toon 'n behoefte aan navorsing onder plaaslike Suid-Afrikaanse toestande, aangesien winsgewende opbrengste slegs verwesenlik kan word wanneer sny tulp produsente ‘n hoë kwaliteit produk lewer aan beide die plaaslike en moontlik ook die uitvoermark. Die begrip van hoe hierdie gewas reageer op verskillende aspekte van verbouing onder plaaslike toestande is noodsaaklik vir suksesvolle en winsgewende sny-tulp produksie in Suid-Afrika. Om hoë kwaliteit tulpe te produseer, is dit van kritiese belang dat produsente die voorkoms van fisiologiese afwykings minimaliseer deur die optimalisering van verbouingsaspekte soos voeding, bolgehalte en ouderdom, kultivar keuse, sowel as na-oes behandelings.

Om die voedingsbehoeftes te bestudeer van sny tulpe wat in hidroponiese stelsels onder Suid-Afrikaanse toestande gekweek word, was twee soortgelyke eksperimente uitgevoer, met behulp van vroeë-geforseerde en laat-geforseerde tulp bolle onderskeidelik. In elke eksperiment was die effek van vier voedingsopslossings (“Current SA”, “Standard Steiner”, “Europe”, “Europe+NH4”) en vier sny tulp kultivars (‘Leen van der Mark’, ‘Jan van Nes’, ‘Ill de France’, ‘Royal Virgin’) op groei, gehalte en vaaslewe geëvalueer. Resultate bevind het getoon dat hoewel voedingsoplossing formulasie geen beduidende effek op steel groei gehad het nie, was vaaslewe beduidend geaffekteer deur voedingsoplossing formulasie vir beide vroeë- en laat-geforseerde bolle. Vir vroeë-geforseerde bolle het die voedingsoplossing “Europe” tulpe produseer met ‘n beduidende langer vaaslewe as die ander voedingsoplossings en vir laat-geforseerde bolle het die voedingsoplossing “Standard Steiner” tulpe produseer met ‘n beduidende langer vaaslewe as die ander voedingsoplossings. Kultivars het beduidend verskil in terme van groei, kwaliteit en vaaslewe vir beide vroeë- en laat-geforseerde bolle. Daar was bevind dat die kultivar ‘Leen van der Mark’ die langste steel lengte, hoogste vars massa en die langste vaas lewe van al die kultivars vir beide vroeë- en laat-geforseerde bolle getoon het. ‘Leen van der Mark’ blyk ‘n kultivar te wees met ‘n lae risiko in terme van kwaliteit en vaas lewe asook geskik vir hidroponiese forsering onder warm klimaatstoestande.

Aangesien die vermindering van steelkantel, ‘n fisiologiese afwyking wat heersend kan voorkom in hidroponiese gekweekte tulpe, bewys is deur die aanwending van kalsium bemesting, is ‘n volgende eksperiment onderneem om die rol van verskeie blaarbespuitings te evalueer om hierdie fisiologiese afwyking te verminder of te voorkom. Verskeie blaarbespuiting behandelings, insluitend kalsium nitraat ($CaNO_3$), CalTrain, NonTox Silica® en 'n onbehandelde kontrole, is geëvalueer vir hul effek op die voorkoms van na-oes steelkantel en die vaas lewe van die twee tulp kultivars 'Jumbo Pink’ en ‘Strong Gold' onderskeidelik. Tendense het aangedui dat die kalsium-bevatttende blaarbespuitings , "CaNO3" en "CalTrain" wel die voorkoms van die na-oes steel kantel kon verminder. Die vaas lewe van hidroponies geforseerde sny tulpe is betekenisvol verhoog deur die gebruik van blaarbespuitings kunsmis soos in vergelyking met die kontrole.

Die vaas lewe van sny tulpe is 'n belangrike parameter wat direk gehalte affekteer. In 'n laaste eksperiment, is die doeltreffendheid van drie na-oes behandelings geëvalueer om die vaas lewe van die vier sny tulp kultivars ‘Deshima', ‘Synaeda Orange', 'White Marvel' en 'Margarita' te verleng. Behandelings het bestaan uit 'n onbehandelde kontrole, 'n oornag steel puls van Chrysal BVBPlus, 'n vier uur beroking met Chrysal Ethylene Buster ® (1-MCP) en 'n kombinasie van die laaste behandelings. Vaas lewe, na-oes stamverlenging en vaas-oplossing verbruik, was parameters wat gemeet was. Geen statisties beduidende uitwerkings op enige parameters gemeet was geïdentifiseer tussen die onderskeie behandelings nie. Tendense waargeneem dui egter daarop aan dat behandelings wat BVBPlus bevat die vaas lewe kan verleng, na-oes stamverlenging verminder en die gebruik van vaas oplossing verbeter in sny tulpe wat hidroponies geproduseer is in ‘n warm klimaat. BVBPlus toon dus potensiaal as 'n noodsaaklike na-oes behandeling vir sny tulpe wat hidroponies gekweek is onder warm klimaatstoestande, maar verdere navorsing is nodig om dit te bevestig.

Hierdie navorsing is 'n eerste verslaggewing oor belangrike agronomiese aspekte van die hidroponiese verbouing van sny tulpe in Suid-Afrika en het ten doel om te dien as 'n basis vir toekomstige navorsing, met die uiteindelike doel om die kommersiële suksesvolle verbouing van tulpe te ondersteun op 'n groter skaal in Suid-Afrika sowel as internasionaal.

Contents

The referencing style in this thesis for all papers was written according to the requirements of the South African Journal of Plant and Soil. This thesis represents a compilation of manuscripts where each chapter stands as an individual unit. Repetition between chapters that may occur was thus unavoidable.

1. General Introduction

Of all the bulbous cut flowers the tulip is without a doubt the most popular. Tulips (genus *Tulipa*) are spring-flowering plants of the lily (*Liliaceae*) family, with boldly coloured cup-shaped flowers. Tulips are grown on a large scale, especially in the Netherlands where their history goes back to the end of the sixteenth century. Today billions of tulips are being cultivated, the vast majority of them being exported from Holland. This goes not only for dry bulb sales, but also for the cut flowers produced from the bulbs. These cut flowers, available year-round, are in highest demand from November to May in the Northern Hemisphere. Currently there are more than 3000 cultivated varieties registered, with new additions each year to replace older varieties and to keep up with consumer trends. According to FloraHolland (2012) the value of cut tulips sold annually is in the region of €227 million, ranking it the third highest demanded cut flower in the world, only to be surpassed by roses and chrysanthemum (FloraHolland 2012). In South Africa cut tulip production is limited due to supra-optimal summer temperatures, generally high light intensities and the high cost of climate control required to produce quality cut tulips under these climatic conditions.

Tulip bulbs for commercial cut flower production in South Africa are imported from the Netherlands and Chile to allow year round production (Personal communication, A van Wyk, 2013[1]). For bulbs to meet export requirements which are essential to ensure successful cut-flower forcing in the greenhouse, bulbs are cultivated for several annual cycles in the field to accumulate sufficient reserves and achieve a predetermined size. The cycle starts where bulbs are planted in prepared fields at the end of autumn and are then grown throughout the winter into early spring. Bulbs are lifted at the end of spring and towards the beginning of summer. The tulip bulb requires a warm-cool-warm annual temperature sequence for growth and development to continue through to flowering. At harvest time the apical meristem is contained within vegetative bulbs which require temperatures of 17-34°C to complete leaf initiation, whilst lower temperature ranges of 17-23°C is required to allow floral initiation and organogenesis to proceed (De Hertogh and Shoub 1974). Thereafter, the bulbs require low temperatures (1-9°C) for mobilization of reserves in the bulb to ensure sufficient floral stalk elongation and floral maturation. After being lifted, bulbs grown for flower production are stored at the recommended warm temperatures (17-34°C) until leaf initiation and flower differentiation have taken place, and stage G is achieved, when the gynoecium is clearly visible on dissection of bulbs (Barrett et al. 1978). Under controlled conditions this generally takes one to three weeks, depending on the cultivar and the production system used.

To force the tulip into production two techniques have been developed based on controlling the temperature cycle. The one system is referred to as “Standard Forcing” whereas the other system is known as “Special Precooling”. Both techniques rely on the completion of floral initiation and organogenesis (stage G) before moving the bulbs from warm temperatures to cool temperatures. The bulbs’ vernalization (low temperature) requirement can then be satisfied by “Standard Forcing”. In

[1] Prominent Tulips, Rawsonville, South Africa.

"Standard Forcing", bulbs are transplanted under low temperatures to only allow rooting and vernalization, and are then transferred to the greenhouse where scape growth and flowering occurs. Alternatively, in "Special Precooling", vernalization is provided through precooling the bulbs. Bulbs are dry stored for 9-12 weeks at 2-5°C and are then planted directly in the greenhouse where rooting, scape growth and flowering all take place (De Hertogh and Le Nard 1993).

The value of the South African cut tulip industry is estimated at approximately R1.5-2 million. According to Multiflora, tulips are responsible for a mere 0.8% of the total cut flower market in South Africa (Personal communication, H Boshoff, 2013[2]). In the Netherlands, cut tulips make up more than 10% of total cut flowers sold by FloraHolland. Woolworths, a reputable South African retailer, which holds the largest domestic market share for cut flower products, has indicated that the domestic market is always looking for niche and specialty type floral products of good quality (Personal communication, C Coetzee, 2012[3]). However, very little is known about specific requirements for cut tulip production under warm climate conditions, both in South Africa and internationally. Experience from cut tulip production in South Africa has shown that a number of physiological disorders (stem topple, short stems and blasting) may be especially prevalent under local climatic conditions. A lack of knowledge of plant physiology, plant protection and production technology have been identified to be some of the major disadvantages in the flower industry (Kamenetsky 2005). Research is required to study and evaluate current tulip production practices and systems as well as that of recommended postharvest procedures under local conditions, to ensure high quality flower production. This approach is essential as programmed forcing of flower bulbs is a "high tech" activity demanding extensive knowledge of the interactions between environmental conditions, plant protection and crops.

The hydroponic production of cut tulips is favoured for its close control of the root zone environment, elimination of soil borne disease and cleanliness (Gomez-Merino et al. 2008). Research is necessary to identify cultivation methods to overcome the high occurrence of physiological disorders that occur in South African (especially in the Western Cape) cut tulip production (Personal communication, A van Wyk, 2013), and to determine the appropriate postharvest treatment to increase the longevity of cut tulips (Personal communication, C Coetzee, 2012).

This study was aimed at obtaining a better understanding of the requirements for cut tulip production under South African conditions. Although cultivation was done in a climate controlled glass house, in South Africa there are many aspects of the production chain which differ vastly to conditions of the Northern Hemisphere countries. For this purpose, tulips produced here will be referred to as cut tulips produced under warm climate conditions. To achieve this goal, all existing and traceable literature were reviewed as pertaining to tulip physiology and cultivation, especially under warmer climates, with special emphasis on factors that influence physiological disorders and postharvest quality. The literature review was followed by a range of experimental trials, with the main objective to study the relationship between

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[2] Futures Trust, Potchefstroom, South Africa.
[3] Woolworths, Cape Town, South Africa.

cultivation aspects and physiological disorders as well as postharvest quality and longevity of cut tulips grown in a hydroponic system in the Western Cape (Rawsonville). Research that was undertaken included studies concerning nutrition of hydroponically forced tulips using four Triumph tulip cultivars. Furthermore, the efficacy of postharvest treatments, either as a liquid overnight pulse on cut stems, or as a gas fumigant to extend vase life, were studied. Lastly, the effect of various foliar sprays including calcium nitrate, CalTrain and NonTox - Silica® were evaluated for their efficacy to improve specifically postharvest toppling of two tulip cultivars.

This research is a first report on key agronomical aspects of the hydroponic cultivation of cut tulips in South Africa and aims to serve as a basis for future research, ultimately to support successful commercial cultivation of tulips on a larger scale in South Africa and internationally.

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2. Nutrition and Physiological Disorders of Cut Tulips – A Literature Review

I. Current global trends in bulb production

The global demand for ornamental geophytes can only be realized when the quality of the products are consistently high and meet consumer expectations. To achieve marketable flower quality and thus customer satisfaction in cut tulip flowers, forcing should be done with high quality bulbs that are produced free from diseases, insects and physiological disorders, and that will flower within a desirable marketing window (Benschop et al*.* 2010).

Globalisation of the floricultural trade and marketing system, transfer of knowledge and the shift to floricultural production to assist economic progress in developing countries has led to the expansion of bulb production beyond countries with a temperate climate (Kamenetsky 2005). The benefit of cultivating bulbs in warm-climate regions is primarily linked to the relatively higher light intensities and winter temperatures which are appropriate to allow flower development. Growth in bulb production under these climates is also stimulated by relatively inexpensive land, labour costs and the expansion of international trade (Benschop et al. 2010). Production of geophytes from warmer regions can supply the local market, but can also be destined for the export market as these cut flowers and potted plants are often produced in an alternate season to that of cooler production regions. Geophyte species without chilling requirements, which originate from subtropical and arid regions, may be considered more suitable for commercial bulb-production in warmer climate regions. However, the cultivation of thermo-periodic bulbs can be equally successful, provided that research is focused on selecting appropriate flower crops and cultivars suitable for cultivation under warmer conditions. Successful production of flower bulbs is practised in southern France and Italy, where a special group of Single Late tulip cultivars is produced under the common name of ‘French Tulips’. These cultivars are well-suited for the Mediterranean climate – they have high light intensity requirements and relatively modest chilling requirements (Kamenetsky 2005). An investment into new technologies for crop cultivation, storage and transportation is required. These technologies should be based on a clear understanding of the interactions between the environment and the flower crop during the various phenological stages (Kamenetsky 2005).

To accurately program flower bulbs for forcing, controlled temperature facilities are necessary. For the forcing of spring flower bulbs, rooting rooms have been developed (De Hertogh and Le Nard 1993). These facilities are used in conjunction with the cold weeks required by these bulbs and often utilize moving benches to reduce labour inputs. For the hydroponic forcing of tulips, which has increased significantly in recent times, rooting rooms and benches have been modified to accommodate this medium. The climatic control of the greenhouse environment is very important for the forcing of flower bulbs. Proper climate control assists in eliminating or minimizing the incidence of diseases, insects, and physiological disorders (Benschop et al. 2010). While techniques to control flowering are available for many species (De Hertogh and Le Nard 1993), the mechanisms directly affecting the processes of scape elongation and flowering have not been clarified. This is true even in a species like the tulip which has been subjected to extensive research (Kamenetsky and Okubo 2013). Basic research is still required on these processes, especially when produced in regions outside the Northern Hemisphere temperate production regions (Le Nard and De Hertogh 2002).

II. Hydroponic forcing of cut tulips

Hydroponic forcing of cut flowers is a relatively new technique. The earliest reports on hydroponic tulip production showed a requirement for nitrogen and calcium, with calcium nitrate being the best calcium source to use (De Hertogh et al. 1978; Nelson and Niedziela 1998a). Commercial progress in hydroponic forcing has been very rapid. Currently 70-80% of Dutch cut flowers are forced hydroponically, compared to 30-35% in 2002 (Kamenetsky and Okubo 2013). A key factor to successful hydroponic production of cut tulips was the realization that a “water-forced” tulip does not require the massive root system that was traditionally seen on pot or soil grown crops. Hydroponic forcing has evolved whereby bulbs receive 80% of their cold treatment as dry bulbs (12-13 weeks) and are then planted into hydroponic trays (Figure 1) filled with a dilute solution of calcium nitrate or calcium chloride. Bulbs are returned to cold temperatures, where rooting proceeds for another 2-4 weeks, where after the bulbs are forced in the greenhouse. Some advantages of hydroponically produced tulips are: A reduced requirement for cold storage facilities, as most of the cooling is done to dry bulbs that occupy less volume, forcing per se is a few days faster per crop, and harvesting is much cleaner, faster, and easier compared to soil culture. There are also several disadvantages of hydroponic tulip forcing. To mention a few: Not all cultivars are suited to hydroponic forcing, very high quality and disease free bulbs are required, a need for specialized equipment, exceptional cleanliness is a prerequisite, whilst the norm is that a slightly lower quality of hydroponic tulips is produced compared to soil-grown tulips.

Figure 1: A simple hydroponic tulip forcing system where a pin tray is used to keep bulbs upright (Picture taken by Geline Derbyshire 2013).

III. Nutrition

Correct fertilization for tulips used as cut flowers is important (De Hertogh and Le Nard 1993; Jhon et al. 2006). Tulips are considered light feeders, and the bulbs themselves store many nutrients for the plants' initial growth (Ho and Rees 1977). Excessive fertilization can lead to reduced plant height, which may affect the flower quality (De Hertogh 1974). Fertilization of the bulbs during the previous growing season could influence flower quality of forced tulips (De Hertogh et al. 1978).

Up until a few years ago, most forcing of cut tulips was accomplished in a soil-containing system. The use of hydroponics for the production of cut tulips has been driven by difficulties in soil nutrient management and the need to consider pathogenic diseases that occur in soil. Soilless cultivation has the benefit of being clean, allowing precision control of plant nutrition and facilitating a close control of the root zone environment (Olympios 1999). However soilless production systems have increased risks associated with a generally smaller root system and a low buffering capacity of water and nutrients (Silber and Bar-Tal 2008).

Nutrients and water are not necessarily taken up from a nutrient solution in the same proportions in which they are present. The rate at which absorption takes place depends on the plant, the climate and environment as well as the type of culture and stage of development of the crop (Ae-Kyung et al. 2005). It is important in soilless agriculture to synchronise plant demands for water and nutrients, otherwise deficiency or salinization may rapidly occur (Klaring 2001). In work done by Osorio et al. (2009) the root application of a full strength Steiner solution is recommended in the production of hydroponically produced cut tulips, as this offered the highest quality plants with greater basal diameter and bud length, the highest concentration of nutrients and the longest period of vase or potted life.

Nitrogen (N)

Nitrogen can be supplied either in the form of ammonia (NH_4) or nitrates (NO_3) (Hinsinger et al. 2003). The major form of N supply is NO_3 based fertilizers. NO_3 is non-toxic and readily translocated from the root apoplast through the xylem to plant roots and shoots, where it is sequestered at high concentrations in plant cell vacuoles (Rice 2007). High concentrations of NH_4 are toxic to plants. Plant tolerance to NH_4 toxicity varies, depending on crop type, cultivar and growing conditions (Sonneveld and Voogt 2009). NH_4 competes with calcium, magnesium and potassium for uptake, and should therefore be used carefully on crops sensitive to Ca deficiency (Hohjo et al. 1995; Sonneveld and Voogt 2009). In work done by Cheal and Hewitt (1964), nitrogen deficiency had the greatest effect of all the nutrients on both 'Golden Harvest' and 'Elmus' tulips and the impact was visible before the time of flowering.

During bulb production basic fertilizers are applied before planting. The availability of mineral nutrients during tulip production depends on the type of soil, its acidity and mineral content, the specific tulip cultivar together with the size and weight of the planted bulbs. Nutrient requirements per hectare for bulb production are approximately 140-150 kg nitrogen, 40-50 kg phosphate, 140-150 kg potassium and 110-120 kg calcium (Kamenetsky and Okubo 2013). Under field conditions, tulip roots accumulate a large amount of N during the winter. It was reported that the accumulated N in the roots originated mainly from absorbed N from the medium rather than from the bulb stored N (Ikarashi et al. 2003). Under winter conditions, the accumulated N in some roots was found not to be readily translocated to other roots, suggesting that the nitrogen is accumulated independently in each root. The accumulated N remained in a soluble form and glutamine was found to be the major N constituent. After sprouting, accumulated N in the roots is rapidly consumed for growth of leaves and stems. A part of this N is then redistributed also to daughter bulbs as the new plants mature. The behaviour of accumulated N in the roots during winter is similar to the bulb stored N. It may thus be concluded that the physiological role of the N accumulation in roots is to provide a sufficient amount of N required for a rapid growth of leaves immediately after sprouting. Available N in the mother bulb is translocated primarily to the shoot and roots (Ohyama et al. 1988).

Nitrogen application during forcing is as important as during bulb production. According to Lee and Suh (2005), flowering was accelerated by application of high concentrations of nitrogen (17.9 $meq.L^{-1}$ compared to 10.7 $meq.L^{-1}$), whereas the length of the last internode together with the total stem length were decreased. These results are in agreement with those of Choi et al. (1997), who worked on *Iris* and *Lilium*. For the cultivar 'Ile de France', irrespective of plant growth retardant injections, time to flowering was reduced by the highest (17.9 $meq.L^{-1}$) N treatment (Lee and Suh 2005). When the N concentration of the planting bulb was less than 0.6-0.7%, floral differentiation was markedly delayed and the quality of the bulb deteriorated especially in forcing culture (Ohyama et al. 1988).

Phosphorus (P)

Phosphorus (P) plays a pivotal role in the nutrition of all plants as an essential element participating in a wide array of physiological and biochemical processes (Kirkby and Johnston 2008). P plays a key role in plant biochemical energy storage and transfer as a linkage binding site in ADP/ ATP. P is taken up as either HPO_4^{2-} or $H_2PO_4^-$ depending on the pH. P is only required in small quantities for normal plant growth and high application levels can cause P toxicity. P is important for root growth, vegetative growth, flowering and fruit set (De Hertogh and Le Nard 1993; Fulton 2010). In a study by Cheal and Winsor (1966) phosphorus deficiency in tulips was characterized by small leaves and daughter bulbs that were lighter than normal in weight. P deficiency symptoms were more evident in cultivar ‘Golden Harvest’ than ‘Elmus’ when a higher rate of nitrogen was given (Cheal and Hewitt 1964). Flower size was not significantly affected by the use of different sources of P-fertilizers, but flowering could be delayed (De Hertogh and Le Nard 1993). The provisional results of Ehlert et al. (2000) pointed out that tulips and lilies have low P requirements.

Potassium (K)

Potassium is involved in numerous metabolic processes including osmotic control, enzyme activation, carbohydrate production and partitioning, and anion/cation balance. Plants deficient in K exhibit retarded growth, leaf edges become flaccid, with chlorotic stripes which start at the leaf tips and develop on the margins of older leaves (Fulton, 2010). K is the most abundant element in the cell, with concentrations of 100 mmol or higher. High potassium concentrations are necessary for the neutralization of soluble anions and macromolecules in cytoplasm, as the cytoplasm has few organic cations.

Potassium and calcium have been shown to largely determine the quality[4] of cut tulip flowers (Gomez-Merino et al. 2009). Cultivar ‘Elmus’ was more responsive than ‘Golden Harvest’ to potassium deficiency, showing distinct yellow patches most evident on the upper surface at the base of the leaves along with pronounced interveinal chlorosis, but without scorching (Cheal and Hewitt 1964). Interestingly, the tulip bulb responds only slightly or sometimes not at all to the application of potassium. At times the inclusion of potassium in fertilizers is reduced to avoid inducing a magnesium deficiency (De Hertogh and Le Nard 1993). Cheal and Hewitt (1964) also observed an interaction between potassium and nitrogen. The two elements had an antagonistic effect on the uptake of one another when applied at high levels.

Magnesium (Mg)

Magnesium is a major constituent of the porphyrin ring of chlorophyll, and also serves as an enzyme activator and cofactor in plants. Approximately 70-85% of plant Mg is utilised in enzymatic processes and 15-30% is used in chlorophyll synthesis (Merhaut 2007). Deficiencies result in a distinct interveinal chlorosis of older leaves giving a herringbone appearance (Rice 2007). Following general interveinal chlorosis, deficiency symptoms, such as necrosis associated with magnesium deficiency, first appeared on the oldest leaf of ‘Golden Harvest’ tulips, while no necrosis was found in ‘Elmus’ tulips (Cheal and

[4] Quality was determined by stem length, appearance and days in the flower pot

Hewitt 1964). Magnesium can have a beneficial effect on the yield of tulips (Cheal and Winsor 1969). A positive increase in the yield of tulips was observed either with a spray of $MgSO_4$ or with a bulb dip prior to planting. Magnesium should be used only if the soil concentration is less than 30 $mg.L^{-1}$ at pH exceeding 5.8 (De Hertogh and Le Nard 1993).

Calcium (Ca)

Calcium is a key element in the primary cell wall of plant cells, improving the load bearing strength and cell to cell adhesion. A third of all Ca exists in the plant as the compound Ca-pectate, which stabilises the cellulitic matrix and cements adjacent cells together (Rice 2007). Calcium is also an important factor in membrane integrity, ion transport regulation and also functions as a secondary messenger controlling enzyme activity (Merhaut 2007). In tulips Ca is necessary for good cell development (Klougart 1980). Similarly to other crops, Ca has low mobility in the tulip. Ca deficiency is therefore often a problem, especially during hydroponic forcing of tulips. Symptoms include smaller foliage of light green colour, flower abortion (Klougart 1980), and scape topple (Klougart 1980; Nelson and Niedziela 1998b) (Figure 2).

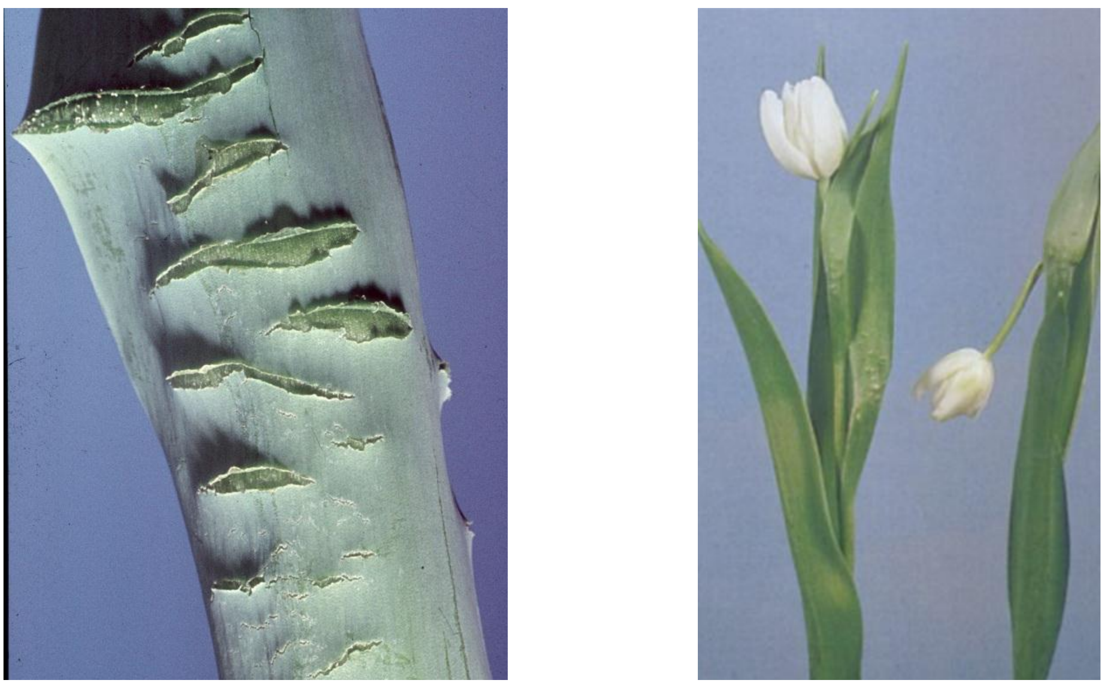

Figure 2: Calcium deficiencies can cause leaf topple “bladkiepen” (left) and stem topple “kiepen” (right) in tulips (Picture by Dr Henk Gude, Wageningen University and Research Centre, The Netherlands).

Ca is largely restricted from the cytoplasm of plants with only low concentrations in the order of 10^{-3}–10^{-5} M occurring therein. This precludes any sizeable transport of Ca in the symplasm, thus necessitating Ca translocation in the xylem. Tulip roots will absorb available Ca, but only a portion is transported to the daughter bulbs. The shoot is the major sink of Ca. Unlike what is observed with most other nutrients, there is negligible translocation of Ca from foliage to daughter bulbs during senescence of the foliage (Nelson et al. 2003). Relative humidity (RH), through its influence on transpirational flow, directly affects xylem transport of Ca (Nelson et al. 2003). With the addition of Ca nitrate fertilizer, either applied as aqueous solutions beginning 14 days after planting, or as Osmocote[5] applied as a surface application immediately after planting tulips, cultivars 'Apeldoorn', 'Golden Melody' and 'Orient Express' experienced decreased flower abortions and increased flower size and fresh weight (De Hertogh et al. 1978). In work done by Rasool (2012) where three different levels of Ca were tested, it was found that Ca applied at the highest level, 10.00 $kg.ha^{-1}$, recorded the maximum bulb sprouting per cent (99.89%), plant height (37.10 cm), wrapper leaf area (232.35 cm^2), leaf boron (27.52 $mg.kg^{-1}$), calcium (5.52%) and zinc content (26.77 $mg.g^{-1}$), whilst the percentage of malformed leaves (0.11%) was minimized. In addition the maximum number of bulbs, weight of bulbs and highest bulb production ratio was achieved when applying 10.00 $kg.ha^{-1}$ Ca. With Ca applications of 10 $kg.ha^{-1}$ maximum vase life (7.85 days) was recorded. Ca clearly plays a critical role in the development of tulips and high quality cut tulips simply cannot be produced without the addition of Ca fertilizers.

Copper (Cu)

Copper is an essential metal for normal plant growth and development, although it is also potentially toxic. Copper participates in numerous physiological processes and is an essential cofactor for many metallo-proteins; however, problems arise when excess copper is present in cells (Yruela 2005). The tulip appears to be efficient in accumulating copper (De Hertogh and Le Nard 1993). It was recorded that applying 1 mM $CuCl_2$ stimulated ethylene production in tulip pistils and in the fourth (upper) internodes, thereby inducing flower bud blasting, almost totally inhibiting stem growth, and inducing gum formation in the upper part of the fourth internode (Wegrzynowicz and Saniewski, 1992).

Boron (B)

The importance of boron (B) as a nutrient is probably underestimated. The main functions of boron relate to cell wall strength and development, cell division, fruit and seed development, sugar transport, and hormone development. Some functions of boron interrelate with those of N, P, K and Ca in plants (Blevins and Lukaszewski 1998). An application of slow-release B produced remarkable increases in yield (De Hertogh and Le Nard 1993). B deficiency may induce abortion of tomato flowers owing to insufficient pollination (Combrink and Smit 2004). Ikarashi and Baba (1977) found that B deficiencies caused decreased bulb yields as well as caused a reduction in root growth and lead to short scapes, transverse cracks (Figure 3) in the upper portion of the scape (“Kubicore”) and the disappearance of flower anthocyanin pigments (“Ironuke”). B deficiency causes symptoms that result from plant cells that are not properly adhered by the middle lamellae. In higher plants, B deficiency may cause a number of symptoms. Cracks often appear in stems. These cracks are horizontal, and show across the width of the stem. The basal part of young leaves and internal tissues of organs may become necrotic (Miller 2008). B

[5] Osmocote is a granular fertilizer (14: 6.2: 11.6 NPK)

deficiency symptoms were evident at 4 $g.kg^{-1}$ in roots, stem and flower, and at 2 $g.kg^{-1}$ in the main bulb. Kirkham (1977) reported that necrotic tips of tulip leaves might have been caused by boron toxicity and that high applications of boron to tulips may result in leaf tip scorch. Some symptoms of B deficiency in tulip are similar to those of Ca deficiency. Both Ca and B deficiency can result in topple; however, B deficiency causes transverse cracks on the upper part of flower scapes (Nelson and Niedziela 1998a).

Figure 3: Boron deficiencies cause stem cracking in tulips (Picture by Dr Henk Gude, Wageningen University and Research Centre, The Netherlands).

IV. Physiological disorders in tulips

Tulips in general, although usually cultivar specific, are highly susceptible to a range of physiological disorders. Most physiological disorders are produced by low and/or high temperature stresses and/or nutrient deficiencies and are especially evident during forcing. Economically, the most critical of these physiological disorders are flower abortion, stem topple and short stems. However there are several other factors that can contribute to reduced quality of cut tulips (De Hertogh and Le Nard 1993).

1. Flower abortion

Tulips are susceptible to flower abortion, in which the flower is initiated, but fails to complete its development and thus aborts (Hanks and Rees 1977). This complex and economically costly physiological disorder, also known as 'blasting', seems to be cultivar dependent (De Hertogh et al. 1983). Blasting manifests itself by a dry necrosis of the floral organs whose colour changes to a pale yellowish-brown (Figure 4) and is easily differentiated from bud necrosis, which is usually a wet necrosis, the colour turning to brownish-black (De Munk and Kamerbeek 1976).

Figure 4: Varying degrees of blasting are shown with an increase in severity from left to right (De Munk and Kamerbeek 1976).

While symptoms of this disorder are most observed in the greenhouse phase, the induction thereof can occur during many developmental phases of the shoots and to varying degrees (De Hertogh et al. 1983). Buds can even abort within the bulbs before planting. Development is progressive, from mild cases in which white tipping of the anthers and ragged tepal margins occur, to the loss of the whole flower (blasting) or the flower and the top internode or even of the whole shoot (Hanks and Rees 1977).

The time of abortion of a flower-bud can be determined by measuring the length of the papery desiccated remnants of the flower-bud, which can be found between the foliar leaves. When these papery-desiccated-remnants-of-the-flower-buds do not exceed 1 cm in length the bud usually aborts before planting and the disorder is often called “heating in transit” (De Munk and Kamerbeek 1976).

According to De Hertogh and Le Nard (1993) tulips are most susceptible to blasting if one or more of the following conditions listed below occur: Either bulbs have not reached a sufficient state of physiological maturity before being placed at low temperatures or bulbs are placed at low temperatures when their flower buds and/or roots have not sufficiently differentiated. In addition, the risk of subsequent flower blasting is increased when the temperature is lowered too early and/or is applied for a long duration; when bulb roots are damaged or prevented from normal activity such as bruising or breaking at planting, diseases, high soil salinity, excessive water and soil compaction; or when bulb roots do not emerge rapidly after planting. This can be due to insufficient root development, especially when soil temperature, or in the case of hydroponics, water temperature, is higher, or with delayed planting, extended transport, the presence of a very hard tunic, and in the absence of sufficient soil moisture. Blasting is also induced when daughter bulbs develop before rooting at the expense of flower scape elongation; or during plant growth when the water supply is not adequate and /or the temperature is not maintained at a level compatible with normal stem elongation. It has been observed that forcing temperatures of 26/22°C (day/night) led to a lower flowering percentage; Furthermore, high percentages of blasting occur when bulbs are stored or transported at too high temperatures (25-30°C) or when bulbs are exposed to ethylene concentrations as low as 0.1 $mg.L^{-1}$ either in storage or in the soil or when bulbs do not receive optimal ventilation conditions for extended periods.

1.1 Physiological maturity

The minimum bulb weight for flower induction and initiation is generally believed to be 8 g, although the critical bulb weight for floral induction varies with the genotype. De Munk and Hoogeterp (1974) found that plants from small bulbs (10-11 cm) are more sensitive to blasting than plants form larger bulbs (12-13 cm). However, later results indicated that this relationship is more complicated, as they found that the minimum weight of bulbs able to differentiate a flower bud can vary from 3 to 8 g for the same genotype depending on the conditions under which the bulbs were produced (Le Nard and De Hertogh 2002).

The duration of the period necessary for flower bud differentiation and the size of the flower bud appear to be the main criteria which can be used to predict the bulb behaviour and would thus give some indication on the physiological maturity of a bulb. The use of these criteria seems particularly relevant in the case of bulbs forced very early at rather high temperatures. Conditions which favour root activity and delay plant maturity, was found to negatively affect floral induction and earliness of flower differentiation. Le Nard (1986) suggests that the roots affect floral induction through their cytokinin synthesis. Classical physiological understanding indicates that flowering and root initiation and/or elongation are usually antagonistic processes. In several species, root removal promotes flowering. High or low temperatures applied to the root system also influence flower initiation in some plants. These observations clearly implicate the root system as exerting at least partial control of flowering (Kinet et al. 1993).

1.2 Water status of bulbs

Desiccation of the tepals and stamens and a deficient stem elongation are expected to be the final result of a change in water status (Kamenetsky and Okubo 2013). The physical transition of water from a state where they are bound to larger molecules to free cellular water has been linked to dormancy release in tulips (Kamenetsky et al. 2003). Bulb storage time can have an effect on the water status of bulbs (Van der Toorn et al. 2000). Franssen et al. (2002) found that a decrease in the water content of the scales, resulting in an increase in the osmolality of the tissue sap after 24 weeks of storage could be indicative for the emergence of flower-bud blasting in tulips. It was suggested that the increase in osmolality was a result of starch degradation and sugars transported from the scales to the shoot. Despite the availability of sufficient external water to sustain growth after planting, aborted flowers also have lower water contents than normal flowers (Franssen et al. 2002).

1.3 Hormonal activity of bulbs

A water deficit imposes stress on the young shoot located inside the bulb and is the cause of increased abscisic acid (ABA) levels which in turn results in a weakened sink of the flower bud. The sink of the flower bud can also be weakened by ethylene, but strengthened by gibberellic acid (GA) or cytokinin such as kinetin. Therefore, it was suggested that the natural balance between growth substances controls the flower bud development. Disrupted hormonal activity, especially with regards to GA_3 and IAA, might cause bud abortion in tulips (Xu et al. 2007). De Munk and Gijzenberg (1977) reported that a combination of ABA and ethephon have a comparable effect on bulbs to ethylene.

1.4 Storage conditions

1.4.1 Temperature treatments

Appropriate bulb post-harvest temperature treatments will assist in the prevention of flower blasting (De Hertogh and Le Nard 1993). Blasting often follows as a delayed effect of excessively low temperatures, inadequate duration of the cooling period, or premature commencement of the cold treatment during storage (Rees 1966). It is important that bulbs should have reached Stage G[6] before low temperature treatments are applied. It is well known that many external factors, including climate conditions, the time of bulb lifting and specifically the temperature during postharvest bulb storage could influence flower bud differentiation and the date on which Stage G is reached (Sochacki and Chojnowska 2004). When blasting is caused by high temperatures during transporting the bulbs, this disorder has been called “heating in transit” (De Munk and Hoogeterp 1974).

1.4.2 Storage period

According to Franssen et al. (2002), after 26 weeks of storage, bud abortion after planting increased significantly and blasting was evident in all the bulbs stored for 28 weeks and/or longer. This indicates that there is a critical storage period affecting the flowering potential of tulip bulbs. It was found that during long cold storage, daughter bulbs may grow at the expense of the shoot. De Hertogh and Le Nard (1993) also found that bud abortion emerged already after six months of cold storage. During long-term storage, when bulbs were treated with ethylene at a late stage of floral development, both the extent and the percentage of flower abortion increased during growth in the greenhouse (Kawa et al. 1993).

1.4.3 Ethylene

Ethylene is known to be a very important factor related to flower blasting, especially if exposure takes place during the storage period, before or after precooling, or just after transferring the planted bulbs into the greenhouse (De Hertogh 1974). The developmental stage of the bulb is extremely important and so is the timing of ethylene stress as sensitivity to ethylene changes with different physiological stages. When ethylene exposure takes place shortly after lifting, exogenous ethylene is actually beneficial for flower development (De Hertogh and Le Nard 1993), but can also cause gummosis[7]. Once the flower is fully developed, ethylene induces flower abortion (De Munk 1973). Disorders like gummosis, bud necrosis, and flower-bud blasting, as well as growth inhibition of root and shoot initials, can be induced if bulbs are exposed to ethylene-polluted air for more than a week and sensitivity to ethylene increases with time in storage (De Munk and Kamerbeek 1976).

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[6] The last stage at which flower is fully developed in a bulb is called Stage G, but there is considerable variation in date from year to year.

[7] Gummosis is the formation of gums and gum-like substances in bulb scales, stem tissue and perianth leaves (De Munk and Saniewski 1989).

The main technology for reducing ethylene injury is ventilation, where the objective is to reduce atmospheric ethylene in the storage rooms to 0.1 $\mu L.L^{-1}$ or less (De Munk and Kamerbeek 1976). By sea freight, it takes approximately three weeks to ship bulbs from The Netherlands to South Africa. Transport in shipping containers is of special concern because at shipping temperatures of 17 - 21°C the recommended ventilation rates, even those exceeding 100 $m^3.m^{-3}.h^{-1}$, are insufficient for complete ethylene removal (Liou and Miller 2011). Ethylene levels above 0.3 $mg.L^{-1}$ towards the end of the storage period has been reported to cause flower blasting in tulips (De Munk 1975). When bulbs are injured, either mechanically or through pathogen infection, ethylene production can increase. Wounding of bulbs may lead to increased respiration of bulbs and cause evolution of ethylene (Franssen and Voskens 1997). The most important sources of exogenous ethylene in stocks of tulips are bulbs infected with *Fusarium oxysporum* f. tulipae (De Munk 1973).

All *Fusarium* infected bulbs should be eradicated during storage and before planting as these bulbs produce ethylene. A positive interaction between storage temperature and ethylene injury with regard to flower blasting has been observed by De Munk and Kamerbeek (1976). At temperatures below 13°C ethylene exposure caused almost no damage except at 100 $mg.L^{-1}$. It has been shown that precooled (5°C) tulip bulbs transferred to high temperatures rapidly produce endogenous ethylene and that higher post-cooling temperatures also stimulated ethylene evolution and flower blasting. When bulbs were stored at 17, 20 and 23°C the amount of injury caused progressively increased with temperature. In addition, it was reported that injury scores were higher the longer the bulbs were exposed to ethylene, also when the concentration of ethylene was raised from 0.5 to 1.0 and 10 $mg.L^{-1}$ (De Munk and Kamerbeek 1976).

Furthermore, Moe (1979) found that the import of ^{14}C-sucrose into the flower bud and other plant organs was inhibited by ethylene while treatment with $GA_{4/7}$ seemed to maintain the ^{14}C-sucrose import to the flower bud during storage. Several morphological effects observed in bulbs or bulbous plants may reflect an earlier exposure of the bulbs, or the plants developing from them, to ethylene. When, for instance, removal of the outer brown tunic during storage of tulip bulbs reveals a faint yellow colour in the normally white-coloured scales, this may be an indication that ethylene was present in the storeroom (De Munk and Kamerbeek 1976).

1.5 Greenhouse forcing conditions

1.5.1 Bulb root development and functioning

Certain factors causing flower blasting are related to poor rooting. De Hertogh and Le Nard (1993) also recommended that the tunic be removed in some instances[8] before planting to improve root development. When developing roots show abundant protrusions, probably root hairs, this is an indication of the presence of ethylene, since root hairs do not normally develop (De Munk and Kamerbeek 1976). The inhibition of root development can be observed before bulbs are planted by a reduced swelling of the root

[8] Tunics of some cultivars may inhibit root growth.

zone (Rees 1966). When bulbs exposed to ethylene have been planted and are removed from ethylene exposure, root growth resumes. The delay in development takes so much time that non-exposed bulbs could have already a considerable root system when the exposed bulbs only start rooting. This delay in rooting may have an influence on the occurrence of blasting of the flower buds (De Munk 1975).

1.5.2 Ethylene in the greenhouse

Although ethylene can cause flower-bud blasting during dry storage before planting, by exposure of planted tulip bulbs to ethylene gas, or when bulbs are grown in *Fusarium* infected soils, ethylene can also result in flower abortion after planting (De Munk 1973). Blasting as a direct effect is observed when tulips are exposed to ethylene in the greenhouse (De Munk and Hoogeterp 1974). When tulips of cultivar 'Apeldoorn' were exposed to 0.5 $mg.L^{-1}$ ethylene for 3.5 days, beginning at the transfer to greenhouse, 64% of flowers was blasted. When ethylene exposure was introduced later during the greenhouse period, damage due to blasting was considerably lower (De Munk and Kamerbeek 1973). The effect of ethylene can be countered by injecting flower buds with a solution of kinetin or GA_3 prior to ethylene exposure (De Munk and Kamerbeek 1976). In work by Cerveny and Miller (2010) ethylene exposure at concentrations as low as 1 $mL.L^{-1}$ during the first week of growth reduced shoot and root elongation and subsequently increased flower bud abortion. At 10 $mL.L^{-1}$, all root growth was essentially eliminated. It is presumed that ethylene concentrations arising from *Fusarium*-infected bulbs increase as the gas becomes ''trapped'' due to low air movement around soil or substrate particles, thick canopy density, or other factors limiting diffusion surrounding individual plants. These influences could therefore contribute to high ethylene concentrations in isolated locations throughout a commercial greenhouse (Cerveny and Miller 2010).

1.5.3 Nutrition

Nutrition is an important factor during bulb enlargement and can affect behaviour during forcing. The nitrogen (N) and calcium (Ca) contents of bulbs can affect flowering (Cheal and Hewitt 1964). De Hertogh et al. (1978) showed a decrease in flower abortions for cultivars 'Apeldoorn', 'Golden Melody' and 'Orient Express' through applying either $Ca(NO_3)_2$, a 20:8.8:16.6 (NPK) or Osmocote fertilizer during forcing. Flower abortion, as a result of Ca deficiency was also observed by Nelson and Niedziela (1998b) when tulips were forced in distilled water. Ca uptake during forcing plays a major part in the occurrence of "blindness" of forced tulip flowers. The Ca content of the flower primordia will decrease during the flower development if no Ca uptake takes place (Klougart 1980). An increase in bulb N content brought about by N applications during cultivation produced tulip bulbs which when exposed to ethylene were more susceptible to flower bud blasting (De Munk et al. 1980). However, in the absence of exposure to ethylene there was no relationship between N and flower bud blasting. Nitrate application to tulips during forcing reduced flower-bud blasting in susceptible plants. When blasting is to be expected, however, the application of additional fertilizer is suggested (De Munk et al. 1980).

1.5.4 Plant growth regulators

According to Nelson and Niedziela (1998b) the plant growth retardant, ancymidol, can be toxic at higher amounts and this supports the hypothesis of Hanks and Rees (1977) that ancymidol induces flower bud abortion. Ancymidol inhibits gibberellin biosynthesis and, since gibberellin promotes growth, treatment with ancymidol induces a more compact growth form by suppressing growth between nodes. Hanks and Rees (1977) reported that flower blasting was reduced by injecting GA or kinetin. From the results of De Munk and Gijzenberg (1977) it was found that the application of gibberellins, GA_{4+7} and GA_3, as well as the cytokinins, benzyladenine and kinetin, antagonizes ethylene-induced flower-bud blasting. Moe (1979) reported that tulip flower blasting may be controlled by the growth-regulation status of the plant. Studies by the author, confirmed that injection of gibberellin and/or cytokinin into bulb scales or flower buds prevented ethylene induced flower blasting and promoted extension growth of the shoots, flower organs and roots. $GA_{4/7}$ may improve the sucrose supply to the flower bud by influencing the starch degrading enzymes (Moe 1979).

1.5.5 Source-sink relationships

The quantity and nature of the reserves in the bulb determines the capacity to initiate a flower (Le Nard and De Hertogh 2002). Flower-bud blasting can be seen as based on a lack of substrate supply to the flower. Initially the mother bulb is the source, while the flower, leaves and daughter bulbs are the sinks. After some growth and development of the plants in the greenhouse, the leaves become a second source when photosynthesis commences. At the beginning of the greenhouse period, during the expansion of the leaves, the flower may compete with daughter bulbs, and probably with the leaves too, for substrate from the mother bulb. Tulips are most susceptible to flower-bud blasting in that period (De Munk and Gijzenberg 1977). A certain minimum rate for the synthesis and transfer of sucrose from the bulb scales to the shoot is needed for normal development of the flower to proceed (Moe 1979).

It is of critical importance to prevent flower abortion in order to produce quality tulips. By following a few rudimentary rules, flower abortion can be prevented: use high quality bulbs that received proper postharvest temperature treatments; ensure proper ventilation during transportation of bulbs to prevent the accumulation of ethylene; eradicate all *Fusarium* infected bulbs during storage and planting, as these bulbs produce ethylene; if necessary and feasible, remove the tunic before planting; force under optimal greenhouse conditions and use large bulbs (12 cm +) where possible, especially for early forcing.

2. Stem topple

An important factor in the quality of cut tulips is the firmness of the stem as, irrespective of the thickness of the stem and the weight of the flower, the stem may topple (De Munk and Kamerbeek 1973). A lack of stem firmness leads to the disorder known as “Stem Topple” and is also known as “Sugar Stem”, “Leatherneck” and “Wet Stem” (De Hertogh et al. 1983). This condition affects mainly the flower scape, but can also affect the leaves where epidermal cells may burst (De Hertogh and Le Nard 1993). Topple is characterized by the appearance of glassy, water-soaked areas on the flower stem usually just before or during flowering (Figure 5). This is normally followed by shrinkage and furrowing at the site of the disorder and then the portion above the lesion topples over.

Figure 5: Collapsing flower stems caused by shrinkage and furrowing of glassy, water-soaked areas on the flower stem causing the disorder "Stem Topple" (Picture by Dr Henk Gude, Wageningen University and Research Centre, The Netherlands).

Stem topple is usually observed 5-7 days before flowering and 2-3 days after harvest (De Hertogh and Le Nard 1993). Cultivars vary in their susceptibility to this disorder (De Hertogh and Le Nard 1993). Toppling is always found in those parts of the stem in which the most rapid elongation growth took place and which show tissue infiltration and sap exudation. The earlier the aberration occurs the lower the internode will be where toppling will occur. Postharvest topple (during the vase life of tulips) occurs most frequently in the uppermost internode (De Munk and Kamerbeek 1976). Similarly to '"blossom end rot" (BER) found in tomatoes, Stem Topple can be caused by a host of different factors.

2.1 Nutrition

The collapse (topple) of flower stalks is described as a symptom of calcium deficiency, and it is characterized by the curvature of peduncles at the top of the neck of the plant, when forming the flower (Gomez-Merino et al. 2009). The calcium content in toppling internodes shows a marked decrease when compared to healthy internodes (De Munk and Kamerbeek 1976). To explain this deficiency, Algera (1968) has evidence that Ca ions are taken up, mobilized or transported more slowly than other mineral components. When the stem elongates rapidly, calcium is not supplied in the region of most rapid growth at a sufficient rate. A relative deficiency will increase upwards in the stem to such an extent in this particular zone that the cells can no longer develop normally and become dysfunctional (Algera 1968). It is suggested that this disorder can be suppressed by irrigating tulips with Ca^{2+} enriched water (De Munk and Kamerbeek 1976). Interestingly, topple was found in both large and small bulbs of cultivar 'Elmus' despite a continuous supply of calcium, challenging the common belief that this disorder is caused by a deficient uptake of calcium during forcing (Cheal and Hewitt 1964). Calcium is transported in the xylem sap to the exposed leaves where it is deposited. As calcium is mostly phloem immobile, almost no translocation of Ca occurs. It has been reported that tulips of the cultivar 'Elmus' developed topple when receiving fertilizers containing adequate calcium, but lacking nitrogen, although high in potassium (Cheal and Hewitt 1964). An interaction between nitrogen and potassium was observed. Topple did not occur when nitrogen was supplied at the standard rate, but when nitrogen was deficient increasing the amount of potassium was detrimental (De Hertogh et al. 1983).

In trials done by Klougart (1980) the effect of different calcium fertilizers were evaluated and results showed that calcium nitrate was the best calcium source to ensure high levels of calcium uptake. Topple is caused not only by a calcium deficiency, but by circumstances that accentuate calcium requirements similar to conditions that are conducive to the development of "blossom-end rot" in tomatoes. Such conditions which would accentuate calcium requirements include a high potassium supply and water stress associated with a high salt content of the rooting medium (Cheal and Hewitt 1964). The use of sulphate and potassium in combination might also be regarded as related factors in the cause of topple. The excess of sulphate over calcium, especially in the presence of potassium, is considered causal factor of the incidence of this disorder (Cheal and Hewitt 1964). Some symptoms of boron (B) deficiency are similar to those of calcium deficiency. Ca and B deficiency can result in topple, although B deficiency causes transverse cracks on the upper part of flower scapes (Figures 2 and 3). Application of a complete nutrient fertilizer was detrimental by decreasing the Ca^{2+} uptake. This may be due to NH^{4+} and K^{+} competing with Ca^{2+} for uptake in the complete fertilizer (Nelson and Niedziela 1998a).

2.2 Relative humidity (RH)

The relative humidity in the greenhouse influences transpirational flow, and xylem transport of Ca and therefore the incidence of topple may be increased by high RH during greenhouse forcing. However, it would appear that a range of RH does not impact the manifestation of Ca deficiency symptoms at a normal temperature (19°C). Plants accumulate more Ca at a lower humidity than at higher humidity, yet it is interesting to find that in trials done with four different cultivars, the cultivar with the highest transpiration rate did not have the highest rate of Ca uptake (Nelson et al. 2003).

2.3 Temperature

Stem topple is often associated with a very rapid elongation caused by high forcing temperatures (De Hertogh and Le Nard 1993). This disorder appears lower in the stem the higher the temperature in the greenhouse is (Nelson and Niedziela 1998a). At high temperatures stem elongation is accelerated and the calcium content shows more lag during growth than at lower temperatures. According to Klougart (1980) the optimum temperature for nutrient solution to grow cut tulips is 18°C. Nelson and Niedziela

(1998a) confirm that the prevention of Ca deficiency was very difficult when bulbs were forced under high temperature regimes (22°C day/18°C night). The enhanced deficiency at high temperatures is probably due in part to the shorter period in which calcium uptake must occur and weaker plants which topple easier due to lower dry weight, while maintaining a similar height. Stem topple can also be observed at low forcing temperatures (<14°C), under conditions when the relative humidity is too high (De Hertogh and Le Nard 1993). De Munk and Kamerbeek (1976) found a negative correlation between the storage temperature applied to bulbs and the occurrence of stem topple. Lower storage temperatures (<13°C, compared to >17°C) showed a higher incidence of toppling (51.25% and 20% respectively). It is not clear whether the storage temperature itself has a “delayed” effect on this disorder or whether it is the temperature-induced rapid elongation growth that is responsible.

2.4 Plant growth regulators

A chemical height retardant, ancymidol, reduces the incidence of stem topple in tulips. The cells of ancymidol-treated plants were reduced in length and exhibited greater radial expansion (De Hertogh and Shoub 1974). Such cells that are shorter and have greater width would appear to be stronger and should thus be more resistant to topple. It is reported that ancymidol reduced height and eliminated topple in all cultivars (Nelson and Niedziela 1998b). Different rates of ancymidol should be applied depending on the time of forcing as well as the cultivar. Ancymidol functions through two mechanisms. First it affects cell division by reducing the number of cell divisions which occurred in the intercalary meristem of the tulip. Secondly, ancymidol reduced cell elongation of the tulip internodes with a concomitant radial enlargement (De Hertogh and Shoub 1974).

2.5 Postharvest toppling

Toppling is promoted by administering glucose to cut stems, as this causes more rapid elongation of the stem (Algera 1968). Excessive elongation of the uppermost internode of cut tulips can be prevented by adding 25 $mg.L^{-1}$ ancymidol to the vase solution. By preventing this excessive elongation, toppling may be prevented too. Vase solutions that contain 20-40 $mg.L^{-1}$ ancymidol can significantly reduce elongation of the last internode of cut tulips without having a negative effect on vase life or flower quality (Einert 1975).

3. Short stems

When buying cut flowers of a particular cultivar much attention is given to a number of qualitative characters such as flower size, leaf quantity, stem firmness and stem length (Pasterkamp 1996). The ability to regulate tulip growth and development is of interest to both the applied plant physiologist and the flower-bulb industry. It is particularly important to control the growth of the scape. The cut flower industry prefers to have a long-stemmed tulip flower while the pot plant industry requires a more compact plant. The most effective means of regulating scape length has been through control of environmental factors and cultivar selection (De Hertogh and Shoub 1974). Tulip stem and leaf extension are almost entirely due to cell elongation. Different internodes of the scape successively initiate their growth period.

Internode one (lowest internode) is followed by internodes two, three and four and then the uppermost internode which is just below the flower. The growth of the uppermost internode continues after anthesis and contributes greatly to overall plant height. For bulbs subjected to the same storage and growing conditions the growth pattern is cultivar dependent (De Hertogh and Le Nard 1993).

3.1 Temperature

Cold affects the elongation of the stalk, and thereby influences the quality of the cut flower. How the elongation of the stalk is promoted by cold temperatures and which physiological and bio-chemical mechanisms are involved, has however remained obscure (Balk and De Boer 1999). Under normal growing conditions, the elongation of the scape of a given cultivar is primarily controlled by temperature (De Hertogh and Le Nard 1993). Increasing durations of low temperature increased stem length, with both the top and lowest internodes being affected (Charles-Edwards and Rees 1975). Growth curves illustrating the effects of bulb storage temperatures show that the total shoot growth pattern is sigmoidal. The first phase with a slow growth rate is followed by a phase of rapid growth that ceases shortly after anthesis. For a specific planting temperature regime, the duration and magnitude of the rapid growth stage is determined by the previous storage temperatures. It has been shown that cell division stops before the rapid growth stage and thus that this elongation is due entirely to cell elongation (De Hertogh and Le Nard 1993).

It is known that cooling of tulip bulbs is very important for optimal stem elongation and insufficient cooling may result in short stems. Under the same growing conditions, the total growth of internodes is markedly affected by previous bulb storage temperature. It appears that extended low temperature storage leads to an increase of the total plant height and mainly affects the growth of the lowermost and uppermost internodes (De Hertogh and Le Nard 1993). The low temperature storage of tulip bulbs is often referred to as “preparation for elongation”, although the actual elongation takes place in the greenhouse sometime after. Two aspects of cooling are relevant: The temperature level and the duration of the cooling (De Munk and Kamerbeek 1973). In work done by Hoogeterp (1973) a positive correlation was found between stem length and duration of cooling (Table 1), whilst a negative correlation was reported between stem length and the degree of cooling (temperature).

Table 1: Stem length (cm) of various tulip cultivars as influenced by duration and degree of cooling (Hoogeterp 1973).

		Temperature (°C)		
Cultivar	**Duration of Cooling**	5	9	13
Paul Richter	6 weeks	32	27	19
	15 weeks	41	39	18
Mirjoran	6 weeks	32	27	13
	15 weeks	40	32	16
Lustigw Witwe	6 weeks	36	32	19
	15 weeks	45	36	29

It was reported that when ethephon as an ethylene source was applied to bulbs, shoot elongation was more retarded in bulbs that were precooled for eight weeks than bulbs precooled for 12 weeks. The shoots of non-cooled bulbs elongated slowly and if anthesis occurred, severe flowering disorders prevailed (Lambrechts et al. 1994). Low temperature treatment of tulip bulbs triggers a sequence of events that results in a rapid growth of shoot and daughter bulbs. In a study by Balk and de Boer (1999) it was clear that low temperature treatment of tulip bulbs had an effect on the expression of various genes involved in the subsequent process of elongation of the stalk. They found that the expression of three gene encoding sucrose-hydrolysing enzymes and one gene encoding a tonoplast intrinsic protein in the flower stalk of tulips was influenced by a preceding low-temperature treatment of the bulbs. A possible relationship between these changes and the stalk-elongation was found.

During the early development of the flower the optimum temperature for rapid development is near 20°C, but after the gynoecium is formed (Stage G), lower temperatures are known to be essential for the rapid extension growth which occurs shortly before anthesis (Gilford and Rees 1973). It was reported that when bulbs, previously stored at low temperatures (< 2°C), were planted at different greenhouse temperatures, scape elongation was more rapid in bulbs grown at higher planting temperatures. Plant height at anthesis was increased with increasing day temperature, but decreased with increasing night temperature (De Hertogh and Le Nard 1993).

3.2 Ethylene

Short stems may result from ethylene present in the atmosphere of greenhouses. In addition, ethylene may also be produced by *Fusarium* infected bulbs. Even when such bulbs are adequately cooled, the stem will not elongate fully. It is unknown whether the ethylene manifests itself in the same way as the effects of temperature on bulbs that are sub-optimally cooled (De Munk and Kamerbeek 1976). In work done by Koller Hagness and Moe (1975) treatment of bulbs with ethephon before planting reduced shoot growth and promoted bud blast. The direct and delayed effects of exogenous ethylene depends on the ethylene concentration, the stage of bulb development, duration of the exposure, storage temperature and the conditions after exposure to ethylene (De Hertogh and Le Nard 1993). Silver thiosulphate (STS), an inhibitor of ethylene action, completely reversed the inhibitory effect of ethephon on stem elongation induced by IAA (Kawa-Miszczak and Sanlewski 1992). One of the effects of ethylene in plant tissues is partial inhibition of stem elongation. It was found that ethylene or ethephon at appropriate concentrations would inhibit elongation of the flower stem which occurs when the cut stem is placed in water. Tulip flower senescence however was not, or was only slightly, affected by ethylene. This differs with the effects of ethylene on other cut flowers in which petal senescence is normally accelerated (Kofranek and Nichols 1982).

3.3 Bulb carbohydrate reserves

Low temperatures may be vital for the mobilization of reserves, mainly starch, and for the accumulation of soluble constituents in the bulb scales (Lambrechts et al. 1994), which when transported to the shoot, can be used for elongation. Starch breakdown in the scales and glucose accumulation in the shoot is known to occur during shoot elongation, but the present knowledge of carbohydrate partitioning in tulip bulbs and other bulbous crops during shoot elongation has been little studied and is rather incomplete. Physiological investigations have shown that at the onset of stalk elongation, endogenous starch and sucrose contents decline concomitantly with an increase in the glucose content. Invertase, a sucrose cleaving enzyme, is clearly involved here. Rapid elongation of the tulip flower stalk is probably comparable to situations in other species where high invertase activity correlates with rapid elongation, especially in etiolated tissue (Balk and De Boer 1999).

3.4 Nutrition

Cheal and Hewitt (1964) reported that increased nitrogen fertilization decreased the length of the first internode of tulips of the cultivar ‘Elmus’. Stems from large bulbs of the cultivar ‘Golden Harvest’ were shortened and became stouter by increasing the nitrogen level fivefold. Magnesium deficiency of ‘Elmus’ bulbs showed a slight decrease in total stem length (Cheal and Hewitt 1964). In work done by Lee and Suh (2005) on ‘Golden Apeldoorn’ and ‘Ill de France’, the lengths of the first, second and third internodes were not affected by nutrient solution composition, but the length of the last internode, total stem length and flower size (tepal length) were all decreased by the highest N level used (17.9 $meq.L^{-1}$).

3.5 Plant growth regulators and retardants

Results of trials by Hanks and Rees (1977) indicate that two mechanisms are responsible for extension growth of the tulip stem. Firstly, there is an auxin-mediated system that depends on auxins produced in the gynoecium which regulates mainly the growth of the top internode and secondly a gibberellin-mediated system, inhibited by ancymidol, which regulates especially the growth of the lower internodes.

It was shown that a viable flower and leaves are essential for normal scape elongation (Hanks and Rees 1977; De Munk 1979). The gynoecium produces endogenous growth substances, which diffuse basipetally to stimulate the growth of the internodes. De Munk (1979) reported that elongation of the stem depends on auxins that are produced in the complete flower, the gynoecium, the leaves and the stem. NAA or IAA can completely replace the stimulus produced by the flower and the leaves are also essential for scape growth to take place (Saniewski and De Munk 1981). The growth and development of many ornamental plants can be influenced by growth regulating chemicals although the tulip has not been one of the most responsive plants (De Hertogh and Shoub 1974). It appears likely that a complex interaction of growth substances and inhibitors controls tulip stem elongation (Nowak et al. 1976). Ancymidol reduced height and eliminated topple in all cultivars in work done by Nelson and Niedziela (1998a). It has been suggested that ancymidol acts partly as an antagonist in growing plant systems (De Hertogh and Shoub 1974). The rapid flower stalk elongation of low temperature pre-treated tulip bulbs, grown subsequently under high temperatures, was attributed to the accumulation of gibberellins in the bulbs during cold storage (Nowak et al. 1976). De Munk and Gijzenberg (1977) found that when cytokinins, such as benzyladenine (BA), was injected into the buds of growing tulips, some additional growth of the flower and upper internode occurred. Kawa-Miszczak and Sanlewski (1992) found that BA stimulated the thickening of stem and partially countered the gibberellin effect on stem elongation. The inhibitory effect of ABA on the pistil and stem growth of tulips can be regarded as the result of the decrease of substrate (carbohydrates) supplied from the bulb to the sink (flower bud and stem).

V. Conclusions

The South African floriculture market is always looking for niche type floral products of good quality (Personal communication, C Coetzee, 2012[9]). Tulips are considered such a type of speciality cut flower (Yue and Hall 2010) and show significant potential for commercial hydroponic cultivation. Commercial hydroponic cut tulip production is currently done on a limited scale in South Africa; mainly due to challenging cultivation aspects and lack of knowledge with regards to postharvest management for extended vase life. However, a greater understanding of the cultivation aspects of producing this crop hydroponically under warm climate conditions will enable producers to further access domestic and international markets. It is evident that correct fertilization of cut tulips is necessary in order to minimize physiological disorders and produce quality cut tulips. When deficient, certain nutrients may have a negative impact on growth and quality of cut tulips and may induce physiological disorders. It is thus imperative that the appropriate nutrient solutions are used when hydroponically producing cut tulips to produce a product of high quality. Most research available on aspects of cultivation and nutrition of cut tulips is focused on temperate climates and thus prompts a need for research under local conditions. Scientific experimentation based on the experience of growers will give a better understanding of cut tulips and assist to develop this crop to its full horticultural economic potential.

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3. Paper 1: The role of nutrient solution composition on the uptake of nutrients, growth and vase life of hydroponically grown cut tulips under South African conditions

Abstract

The tulip is considered by most to be one of the premier ornamental flowering bulb crops. The nutrient reserves in the bulb are however apparently not sufficient to ensure quality flowers with an extended vase life. This research was carried out to study the effect of nutrient solution composition, cultivar and physiological bulb age on the growth, postharvest parameters and vase life of hydroponically forced cut tulips in the Western Cape Province of South Africa. Two comparable nutrition trials were performed. The first trial which was executed in October 2012 using early-forced bulbs ("physiologically younger") was followed by a similar trial in March 2013, though using late-forced ("physiologically older") bulbs. Each trial included the four tulip cultivars, 'Leen van der Mark', 'Jan Van Nes', 'Ill de France' and 'Royal Virgin' which were grown according to a split-plot design in four different nutrient solutions: A nutrient solution used by tulip producers in South Africa (Current SA), a standard Steiner solution (Standard Steiner), a nutrient solution used by tulip producers in Belgium (Europe) and the latter nutrient solution amended so that 20% of the nitrogen was provided in the form of ammonium (Europe+NH_4^+). Each nutrient solution had an electrical conductivity (EC) of 1.6-1.8 $mS.cm^{-1}$. Nutrient solutions did not significantly affect the mean growth recorded per measurement (88.59 mm) of cut tulips, but significant differences were found between the leaf areas produced by plants forced in the various nutrient solutions. "Standard Steiner" (251.92 cm^2) and "Europe" (237.71 cm^2) produced plants with the largest leaf areas. Flowers with the longest vase life were produced when forced in nutrient solution "Europe" (5.37 days) using early-forced bulbs and nutrient solution "Standard Steiner" (8.54 days) using late-forced bulbs. Significant cultivar differences were observed for all parameters evaluated. 'Leen van der Mark' was found to be the cultivar that displayed the best quality and longest vase life for both early- and late-forced bulbs. Early- and late-forced bulbs differed significantly in terms of growth, for all postharvest parameters evaluated as well as vase life. Late-forced bulbs presented a significantly longer vase life than early-forced bulbs, but discrimination between these bulbs is extraneous in terms of year-round production.

Keywords: forcing, fertilization regime, nitrogen, calcium, bulb age, vase life.

Introduction

Major shifts in the world economy, societies and technology are responsible for dramatic changes in the international floricultural industry such as a continued increase in floriculture production in Latin America, Africa and Asia. The globalization of the horticultural trade has led to advances in the transfer of knowledge and economic progress in these developing countries. Therefore, in addition to the traditional flower bulb-producing and –consuming countries, globalization and increased competition has resulted in the development of new production centres globally. Thus, bulb production is no longer limited to countries with temperate climates as the production of bulbs and bulbous cut flowers of high quality has become much more significant during the last few decades in regions with warm climates. This has been promoted further by relatively inexpensive land, low labour costs and the expansion of international trade (Kamenetsky and Okubo 2013).

The value of the South African cut tulip industry is estimated at approximately R1.5-2 million. According to Multiflora, tulips are responsible for a mere 0.8% of the total cut flower market in South Africa (Personal communication, H Boshoff, 2013[10]). In the Netherlands, cut tulips make up more than 10% of total cut flowers sold by FloraHolland. Woolworths, a reputable South African retailer, which holds the largest domestic market share for cut flower products, has indicated that the local market is always looking for niche and specialty type floral products of premium quality (Personal communication, C Coetzee, 2012[11]). However, very little is known about specific requirements for cut tulip production under warm climatic conditions, both in South Africa and internationally. Year round cut tulip production is fairly limited in South Africa, primarily due to supra-optimal climatic conditions and the expensive climate control required for the production of quality cut tulips. In addition, to deliver high quality cut tulips, South African cut tulip producers are almost exclusively reliant on imported bulbs. In order for local cut tulip producers to produce year round, bulbs are alternatively imported from both the Northern- (Netherlands) and Southern Hemispheres (Chile). Each batch of bulbs, irrespective of the country of origin, will serve both as early- and late-forcing bulbs, as early-forcing bulbs refer to those bulbs that would be planted early in the season, whilst late-forcing bulbs would be stored dry and planted later in the season. Since each batch of bulbs imported are all harvested at approximately the same time, the bulbs that are used for late-forcing, are physiologically "older" when forcing takes place (Personal communication, A van Wyk, 2012[12]). Insufficient research is available on how the physiological bulb age or forcing season of bulbs will affect product quality, especially when produced in non-temperate regions.

Until about the 1980's, most forcing of cut tulips was accomplished in a soil-containing system. The increased use of hydroponics for the production of cut tulips has been driven by problems of soil nutrient management and the need to overcome soil-borne pathogenic diseases. Soilless culture is clean, soil-free, and allows close control of the root zone environment (Lee and Suh 2005). Soilless cultivation has the added benefit of precise control of plant nutrition and root environment, but it also has increased risks owing to the smaller root system and low buffering capacity of water and nutrients (Olympios 1999; Silber and Bar-Tal 2008). In soilless agriculture, it is important to synchronise plant demands for water and nutrients, if not, deficiency or salinization may rapidly occur, which will negatively affect the

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[10] Futures Trust, Potchefstroom, South Africa.
[11] Woolworths, Cape Town, South Africa.
[12] Prominent Tulips, Rawsonville, South Africa.

postharvest quality of the cut stems. Despite some distinct challenges associated with tulip production in hydroponics, this technique has great potential in determining and delivering the exact requirements of minerals during forcing (Klougart 1980).

Proper fertilization for tulips used as cut flowers is essential (De Hertogh and Le Nard 1993; Khan et al. 2006), yet information on this aspect of cut tulip production is, surprisingly, very limited (Khan et al. 2006). In general, a perception exists that tulips are light feeders, as the bulbs themselves store all the nutrients required for the initial growth phase (Ho and Rees 1975). In fact, is it well-known that excess fertilization can lead to reduced plant height, which will affect the marketability of the product. Also, the use of slow or controlled release fertilizers is not recommended as the plants are likely to be harvested before most of the nutrients are released. However, several research reports clearly indicate that the nutrient reserves in the tulip bulbs are not sufficient to obtain quality flowers and that fertilization of the bulbs during the previous growing season could influence product quality of forced tulips (De Hertogh et al. 1978). Khan et al. (2006) reported an increase in vase life of tulips due to nutrient treatment, as compared to forcing in distilled water. This increase in vase life may be attributed to healthy scape and leaves, which may have more food reserves, to be utilized during the vase period when the bulb is removed. A healthy scape may also facilitate better water uptake, essential for maintaining turgor, and therefore the freshness of the cut flowers. In addition, the promotion of flowering was recognized to be correlated to a combination of the bulb's fertility level, the composition of the growing medium, and the use of supplementary nutrients (De Hertogh et al. 1978). Still, general fertilization recommendations in literature appear fairly non-specific and inconsistent with regard to the use of a balanced nutrient solution and focussed primarily on the primary nutrients and the ratios between them.

According to Dole and Wilkins (2004) low nutrition and a medium EC are acceptable for tulip forcing. It is recommended that once bulbs are removed from the cooler, 2.4 $g.L^{-1}$ calcium nitrate ($CaNO_3$) can be applied at each watering to reduce the potential for stem topple. Earlier literature recommended additional nitrogen and calcium to be essential for the production of tulip cultivars 'Apeldoorn', 'Golden Melody', and 'Orient Express' for cut-flowers in gravel culture (De Hertogh et al. 1978). The tulip cultivar 'Apeldoorn' specifically required only calcium during hydroponic production of flowers as calcium uptake was suppressed when the nutrient solution contained a complete fertilizer 13:1.7:15.8 (NPK) (Klougart 1980). This was attributed to the possible competition of ammonium (NH_4^+) and potassium (K^+) with calcium for uptake. Fertilization of tulips in green houses and tunnels is only recommended after shoot emergence (Gill et al. 2009). Weekly application of fertilizer with a 2:1 ratio of $CaNO_3$ to KNO_3 is recommended or a supply of 200-250 ppm ($mg.L^{-1}$) of N on a constant basis using a well-balanced fertilizer either 2:1:1 or 3:1:1 is suggested. Acceptable conductivity readings are considered to be between 1-1.5 $mS.cm^{-1}$ (De Hertogh and Le Nard 1993). Similarly, Lee and Suh (2005) referred to a study of De Marco and Phan (2003) that reported the necessity of optimizing levels of nutrients such as PO_3^{-4}, NO_3^- and K^+ during hydroponic production of tulips to ensure a high quality crop, delivering maximum productivity. It is surprising therefore that in a most recent literature review Kamenetsky and

Okubo (2013) maintained a view that satisfactory forcing can be achieved using only a dilute solution of $CaNO_3$ or calcium chloride ($CaCl_2$) with an EC of 1.2-1.5 $mS.cm^{-1}$. This recommendation was most likely based on the assumption that production is limited to cooler climatic regions.

In work done in Mexico by Osorio et al. (2009) the root application of Steiner solution was recommended as it offered the highest quality plants with greatest basal diameter and bud length, the highest concentration of nutrients and the longest vase life. Research in Korea by Lee and Suh (2005) reported days to flowering to be accelerated by nitrogen levels above 14.3 $meq.L^{-1}$, as compared to lower levels, whilst the length of the first internode was slightly increased by nitrogen levels above 12.1 $meq.L^{-1}$.

Hydroponic forcing systems are becoming increasingly important for production of high quality cut tulips, therefore further studies to optimize nutrient sources and concentrations for hydroponically produced tulips are essential (Lee and Suh 2005). As no information is available concerning the benefits of using a full nutrient solution for cut tulip production under South African conditions, this research was conducted with the aim to adapt and optimize hydroponic nutrition of tulip production systems under local conditions to assist South African producers to deliver the high quality products that are required by both the domestic and export market to meet customer demands. The objectives of the study were thus to evaluate growth and product quality of four cut tulip cultivars, produced by bulbs of two different physiological ages, against various nutrient solutions in a hydroponic system as employed by Prominent Tulips in Rawsonville, Western Cape Province (Personal communication, A van Wyk, 2012).

Material and methods

Plant material

Top quality[13] tulip bulbs >10-12 cm in circumference were imported dry from the Netherlands from B&B Bulbs (De Gouw 41-E 1602 DN Enkhuizen, Netherlands) at the end of October 2012. According to results previously obtained by South African cut tulip producers (Personal communication, A van Wyk, 2012), two strong and two poor[14] performing cultivars were selected. The generally strong performing cultivars chosen were 'Leen van der Mark' and 'Jan van Nes', whilst cultivars with more variable performance in terms of blasting, toppling and insufficient stem length were represented by 'Royal Virgin' and 'Ill de France' (Figure 1).

[13] All bulbs must meet phytosanitary requirements set by Government in order to be imported (see Appendix A).

[14] A cultivar was considered poor due to a high percentage (>70%) of bulbs previously displaying physiological disorders such as blasting, topple and insufficient stem length, rendering flowers unmarketable.

Figure 1: Four cultivars from the Triumph tulip group selected for hydroponic production under warm climate conditions in the Western Cape, South Africa. From left to right: ‘Leen van der Mark’, ‘Jan van Nes’, ‘Royal Virgin’ and ‘Ill de France’ (www.bulbsonline.com).

Bulbs of the respective cultivars were allocated and planted according to a split-plot design. In each of 12 trays 48 bulbs were planted randomly per tray to represent 12 bulbs of each cultivar. Standard forcing trays were used (60 x 40 x 10 cm), as designed by the Bulbfust Company (Bulbfust B.V. Hoekvaartweg 14, 1771 RP, Wieringerwerf, The Netherlands). These trays are characterized by a grid of plastic “pins” into which the bulbs are pressed for upright support (Figure 2).

Figure 2: Tulip bulbs are planted in plastic trays with pins on to which bulbs are pressed to keep plants upright, whilst the tray has a plug with two drainage holes to maintain the proper solution depth when the tray is level (Miller 2002).

Three bulbs per cultivar per tray were randomly selected and labelled (Figure 2). These plants were selected to use for growth measurements, postharvest evaluations as well as nutrient analysis prior to harvest so as to eliminate bias. The remaining unlabelled, marketable plants were to be used in vase life studies.

Treatments

Two comparable trials were carried out in a climate controlled glass house at Welgevallen Experimental Farm, Stellenbosch University, Stellenbosch. One trial was conducted in October 2012, immediately after the arrival of the bulbs in South Africa to represent bulbs that were forced after a limited storage period (to be referred to as early-forcing bulbs), whilst a follow-up trial was done in March 2013, using bulbs that were in dry storage[15] for more than a six month period (to be referred to as late-forcing bulbs). These bulbs thus differed in their physiological age prior to rooting and forcing.

Four different nutrient solutions, all with an EC of ±1.6-1.8 $mS.cm^{-1}$ and pH of ±5.5-6.5, were used in a continuous recirculating closed system in both these trials (Table 1). The nutrient solutions, which were made up by dissolving nutrients in Stellenbosch municipal water (Table 2), were replaced with fresh nutrient solution weekly, with the EC and pH adjusted to fall within the required margins. No toxic amounts of any nutrients were detected in the water analysis and thus no water treatment was required (Combrink and Kempen 2011).

Table 1: The macro-nutrient composition ($meq.L^{-1}$) of the various nutrients added to municipal tap water to formulate nutrient solutions for evaluation in a cut tulip hydroponic production system in South Africa.

Treatment	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	Cl^-
Current SA[16]	0	4.5	7.5	4.5	13.5	0	0	3
Standard Steiner[17]	0	5.8	7.4	3.3	9.9	0.8	5.8	0
Europe[18]	0	10.2	5.3	1	13.6	2.2	0.7	0
Europe + NH_4^+[19]	3	7.5	4.5	1.5	11.0	2.5	3	0

[15] Dry storage is done in the dark at approximately 2°C.
[16] A nutrient solution currently used by cut tulip forcers in South Africa was chosen as a control (Personal communication, A van Wyk, 2012).
[17] A standard Steiner solution (Steiner 1961).
[18] A nutrient solution used by tulip forcers in Belgium (Personal communication, S Deckers, 2010[20]).
[19] A nutrient solution used by tulip forcers in Belgium with 20% of the nitrogen provided in the form of ammonium (Personal communication, S Deckers, 2010).

Table 2: Mineral content of municipal water (meq.L^{-1}) from the Welgevallen Experimental Farm, Stellenbosch University, as was used in the hydroponic systems to evaluate four nutrient solutions for cut tulip production. Analysis done by Bemlab [16 Van den Berg Crescent, Gant's Centre, Strand] immediately prior to the start of the first trial.

Na	K	Ca	Mg	Fe	Cl	CO_3	HCO_3
0.109	0.005	0.170	0.029	0.004	0.350	0.055	0.054
SO_4	**B**	**Mn**	**Cu**	**Zn**	**P**	**NH_4-N**	**NO_3-N**
0.039	0.000	0.000	0.000	0.000	0.004	0.046	0.007

The treatment "Current SA" represented the nutrient solution formulation routinely used by cut tulip producers in South Africa (Table 3). $CaCl_2$ was specifically included by producers to control slimy roots (Personal communication, A van Wyk, 2012). The second treatment formulation represented that of a Standard Steiner solution (Steiner 1961), whilst the third treatment which is referred to as "Europe" represented a nutrient solution made up within predetermined minimum and maximum limitations for each macro and micro nutrient, as used and recommended by a Belgium agronomist (Personal communication, S Deckers, 2010[20]). The fourth treatment which was labelled as "Europe+NH_4^+" was different only from the third nutrient solution ("Europe") in that it contained approximately 20% of its N in the form of ammonium. Micronutrients, as Hidrospoor (Omnia, Epsom Downs Business Park, 13 Sloane Street, Bryanston), were applied at a dosage of 20g per 1000L for the various nutrient solutions, except "Current SA" which contained no micronutrients in its formulation. The composition of micronutrients (mg.L^{-1}) added using Hidrospoor was: 1.68 Fe, 0.4 Mn, 0.2 Zn, 0.03 Cu, 0.5 B and 0.05 Mo respectively. Each nutrient solution was replicated three times where each repetition comprised of a closed recirculating system consisting of a nutrient solution tank, a pump and a forcing tray.

Table 3: The final macro-nutrient compositions (meq.L^{-1}) of the four different nutrient solutions used for evaluating hydroponic production of four cut tulip cultivars in South Africa.

Treatment	Na^+	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	Cl^-	HCO_3^-
Current SA	0.109	0.046	4.505	7.670	4.529	13.507	0.004	0.039	3.35	0.054
Standard Steiner	0.109	0.046	5.805	7.570	3.329	9.907	0.804	5.839	0.35	0.054
Europe	0.109	0.046	10.205	5.470	1.029	13.607	2.204	0.739	0.35	0.054
Europe + NH_4^+	0.109	3.046	7.505	4.670	1.529	11.007	2.504	3.039	0.35	0.054

[20] Soil Service of Belgium, Belgium.

Rooting

Immediately after removal from storage, bulbs were rooted in sterilized standard forcing trays in a dark rooting room at 3-4°C where roots were bathed with nutrient solution which continuously circulated from the stock tank to the forcing trays. Rooting was completed when roots were approximately 3-5 cm in length. This process took 3 weeks for early-forcing bulbs and 1 week for late-forcing bulbs. EC and pH of the nutrient solutions were stabilized between ±1.6-1.8 $mS.cm^{-1}$ and ±5.5-6.5 respectively, and were monitored throughout the rooting period (Milwaukee models EC60 and pH56, Milwaukee Electric Tools, 13135 West Lisbon Road, Brookfield, USA). During the rooting period, nutrient solution was replaced weekly to prevent salinization or depletion of nutrients.

Vegetative growth phase

Once bulbs were sufficiently rooted, trays were moved into the glasshouse for the active production phase to commence. The glasshouse climate was controlled for an average temperature at 20±2°C and relative humidity measured at approximately 55-65%. The growth and development (expressed as plant height in mm) of 3 plants per cultivar per nutrient treatment was recorded twice a week.

Harvest

Flowers were harvested at a harvest-ready stage, which implicated a minimum stem length[21] of 300 mm and a well-developed flower with a noteworthy colour change. For labelled flowering stems, the stem length (mm), leaf area[22] (cm^2) and plant fresh weight (g) were recorded at harvest. Plants were subsequently dried in an oven at 70°C for five days; where after the dry weight of each plant (g) was recorded. Dried plant samples were then milled and sent to the Western Cape Institute for Plant Production (Department of Agriculture: Western Cape Private Bag X1, Elsenburg 7607) for analysis of micro and macro nutrients.

The unlabelled harvest-ready, marketable flowers were removed with the attached bulb and placed vertically[23] in dry trays in a cold room at 2°C for 2-3 days, as is commercial practice (Personal communication, A van Wyk, 2012). Bulking up with flowers was allowed for no longer than five consecutive days, in order to construct ten bunches of eight flowers each per nutrient solution. As soon as enough flowers were bulked up for the vase life tests, bulbs were removed from the base of the flower stems such that maximum stem length was achieved. Ten bunches of mixed/available cultivars were constructed per nutrient solution. Stems were wrapped in commercial plastic sleeves before pulsing within a solution of Chrysal BVBPlus[24] overnight[25] in a cold room at 2±0.5°C. A retail period was simulated, where flowers were placed in clean, round 5 L plastic buckets, which contained 2 L of tap water and a Chrysal Clear Professional 2 T-bag (new generation)

[21] The stem length was measured from the base of the flower to the bottom of the stem.
[22] Leaf area was determined using a portable area meter (Li-3000A, Li-COR, Lincoln, Nebraska, USA).
[23] Flowers were placed upright to prevent skewed growth of the stem (positive geotropism), because tulip stems elongate postharvest at 2°C.
[24] Stems were placed in a 0.2% Chrysal BVBPlus solution to prevent postharvest stem elongation and to maximize vase life.
[25] Overnight pulsing was done for about 12±2 hours.

(http://www.chrysal.com/int/Home/Products/Transport-ampamp-Display-Solutions/Chrysal-Clear-Professional-2-T-Bag.html) for two days and three nights as is commercial practice.

Vase life

After the retail simulation, the vase life tests could commence. The plastic wrapping was removed from flowers and each bunch transferred to a 1 L cylindrical glass vase containing 0.5 L of standard vase life solution. Vase solution was made up of 10 ml Chrysal Universal Flower Food added to 490 ml of tap water. The vase life duration of each stem was evaluated daily based on the degree of wilting, colour loss of the tepals, toppling of the stem and yellowing of the foliage. The day on which the first flower was removed as well as the day on which 50% of the flowers were removed was recorded.

Statistical analysis

Data was analysed using ANOVA and RANOVA (Repeated Measures Analysis of Variance). Where appropriate and applicable, 3^{rd} and 4^{th} order interactions were calculated. Mean comparisons were achieved using Fischer's LSD ($P<0.05$) using Statistica 12 statistical software (Statsoft (SA) Inc., Tulsa, Oklahoma, USA).

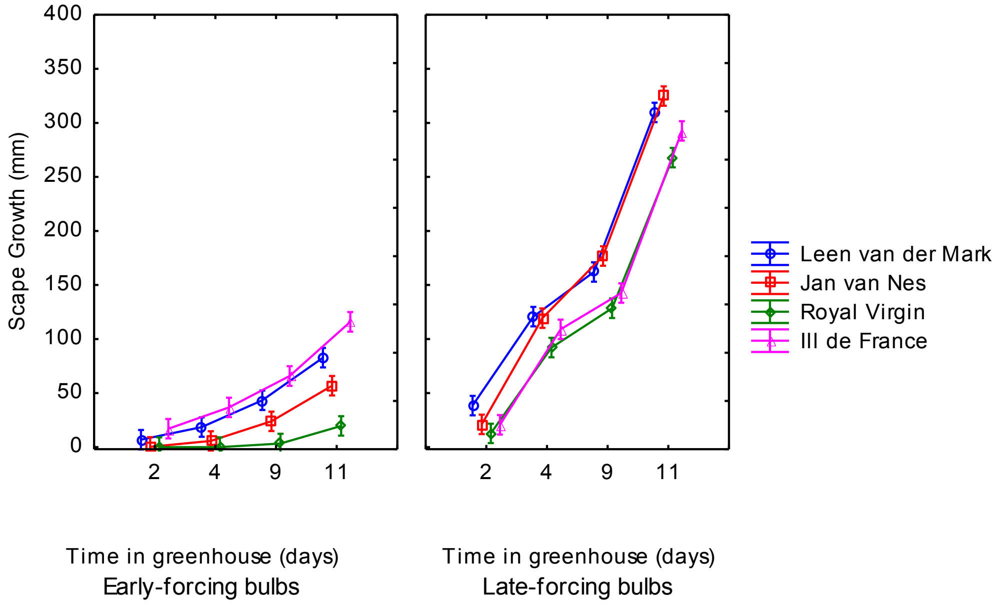
Results and discussion

Scape Growth

Gilford and Rees (1973) in agreement with Shoub and De Hertogh (1975) showed that the major period of cell division of the tulip scape occurs during autumn before the lifting of the bulbs, whilst the subsequent development during forcing, either in the field or in the greenhouse, consists primarily of cell elongation.

Evaluation of plant growth over time presented a significant three way interaction between bulbs, cultivar and time (Figure 3). This is thought to be largely the result of early-forcing bulbs (harvested within 23 days in greenhouse) growing over a longer period than late-forcing bulbs (harvested within 11 days in greenhouse). This is in accordance with findings of Roberts and Moeller (1970) who reported that the time required for emergence of three lily cultivars decreased progressively with later harvest. Roberts and Moeller (1970) also reported that the rate of stem elongation and sprouting are accelerated by later harvested (physiologically older) bulbs. De Hertogh and Le Nard (1993) reported that many studies have shown that bulbs harvested later in the season are more responsive to vernalization treatments than bulbs harvested early. Thus it is not unexpected that late-forcing bulbs were more "responsive" to vernalization and thus grew faster than early-forcing bulbs.

For early-forced bulbs, cultivars 'Leen van der Mark' and 'Ill de France' grew in a similar manner and differed significantly from both 'Jan van Nes' and 'Royal Virgin' bulbs (Figure 3). For late-forcing bulbs, cultivars 'Leen van der Mark' and 'Jan van Nes' grew in a similar fashion, which differed significantly from 'Royal Virgin' and 'Ill de France' bulbs which had a similar growth pattern. This is thought to be related to hereditary differences and is in agreement with Nelson and Niedziela (1998) and Sochacki and Chojnowska (2004) who also found significant cultivar growth differences.



ANOVA	F-value	Pr > F	Significance
Scape Growth (mm)			
Nutrient Solution	1.36	0.2541	NS
Bulbs	2024.00	<0.0000	**
Cultivar	38.38	<0.0000	**
time	3830.26	<0.0000	**
Nutrient Solution*Bulbs	0.40	0.7481	NS
Nutrient Solution*Cultivar	1.30	0.2363	NS
Bulbs*Cultivar	21.34	<0.0000	**
Nutrient Solution*time	1.70	0.0834	NS
Bulbs*time	1459.90	<0.0000	**
Cultivar*time	17.03	<0.0000	**
Nutrient Solution*Bulbs*Cultivar	1.24	0.2689	NS
Nutrient Solution*Bulbs*time	0.95	0.4729	NS
Nutrient Solution*Cultivar*time	1.24	0.1828	NS
Bulbs*Cultivar*time	11.69	<0.0000	**
Nutrient Solution*Bulbs*Cultivar*time	0.81	0.7415	NS

* Significant at p=0.05, ** significant at p=0.01, NS not significant at p=0.05, significant interactions at p<0.05 are shown in red

Figure 3: Effect of various cultivars and bulb age on the first 11 days of scape growth (mm) of hydroponically forced cut tulips grown under warm climate conditions.

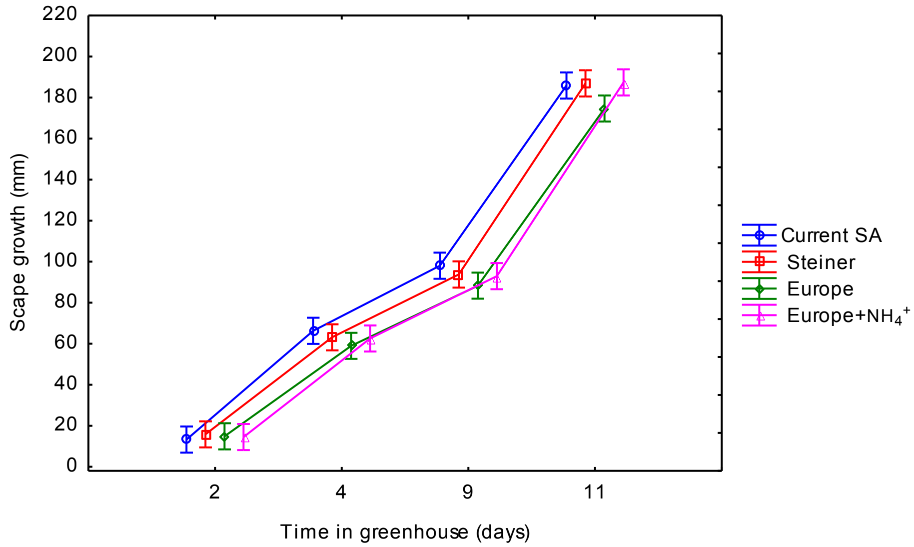


Figure 4: The effect of nutrient solution composition on the scape length (mm) over time of cut tulips produced hydroponically in a warm climate.

Scape length of tulip plants indicated no significant interactions between nutrient solution and any factors (Figure 3). Growth measured as plant height was not significantly affected by the different nutrient solutions (Figure 4). This could possibly be attributed to the fact that adequate nutrients and carbohydrates, stored in tulip bulbs, are sufficient to fully support growth of aerial parts and thus perhaps exposure to a specific nutrient solution during forcing is less significant. According to Charles-Edwards and Rees (1975), during forcing, the growth of roots and aerial parts is primarily at the expense of the reserves stored in the mother bulbs prior to lifting. There is considerable evidence that shoot growth is directly dependent on soluble carbohydrate reserves in the mother bulb and that these reserves increase with both the duration and intensity of the cold treatment (Algera 1936). The results found in this research is also in accordance with the findings of Osorio et al. (2009) who reported no significant differences for tulip plant height in plants grown in different nutrient solutions. Osorio et al. (2009) reported that plants watered with Steiner solution at 50% had stems of ±58 cm, those watered with only water had stems of ±57 cm, and those watered with 100% Steiner and received a foliar application of bee honey had stems of ±56 cm. Conversely, Khan et al. (2006) found that application of different nutrients to soil individually exerted significant effects on scape length and tepal diameter in two consecutive years.

Postharvest parameters

Postharvest parameters which were analysed included stem length, leaf area, fresh weight and dry weight. Stem length and leaves are considered features of tulips which directly affect the quality and thus marketability of cut tulips (Personal communication, C Coetzee, 2012).

Table 4: The effect of nutrient solution on various postharvest parameters of cut tulips grown hydroponically under warm climate conditions.

Treatment	Stem Length[1] (mm)	Leaf Area (cm^2)	Fresh Weight (g)	Dry Weight (g)
Current SA	253.02	224.10[b]	52.73	9.32
Standard Steiner	263.99	251.92[a]	51.73	9.18
Europe	262.39	237.70[ab]	51.69	9.01
Europe + NH_4^+	264.00	230.72[b]	50.82	9.25
F value	0.46	3.07	0.52	0.34
p value	0.71	0.03	0.67	0.79
Significance	NS	*	NS	NS

[1]Any significant interactions between main effects that emerged for parameters measured are presented in graphs below, * Significant at p=0.05; ** significant at p=0.01; NS not significant at p=0.05; Significant differences between nutrient solutions for means are indicated by different letters in superscript.

Table 5: The effect of cultivar on various postharvest parameters of cut tulips grown hydroponically under warm climate conditions.

Cultivar	Stem Length[1] (mm)	Leaf Area (cm^2)	Fresh Weight (g)	Dry Weight (g)
Leen van der Mark	299.49[a]	238.06[b]	51.08[a]	8.36[b]
Jan van Nes	242.89[b]	214.51[c]	53.79[a]	10.09[a]
Ill de France	285.28[a]	257.37[a]	54.11[a]	9.84[a]
Royal Virgin	215.72[c]	234.52[b]	48.00[b]	8.49[b]
F value	24.55	6.67	6.67	15.09
p value	< 0.0000	0.0002	0.0002	< 0.0000
Significance	**	**	**	**

[1]Any significant interactions between main effects that emerged for parameters measured are presented in graphs below, * Significant at p=0.05; ** significant at p=0.01; NS not significant at p=0.05; Significant differences between cultivars for means are indicated by different letters in superscript.

Table 6: The effect of physiological bulb age on various postharvest parameters of cut tulips grown hydroponically under warm climate conditions.

Bulbs	Stem Length[1] (mm)	Leaf Area (cm^2)	Fresh Weight (g)	Dry Weight (g)	Vase life (days)
Bulbs for early-forcing	269.98[a]	333.56[a]	54.92[a]	10.12[a]	3.70[b]
Bulbs for late-forcing	251.72[b]	138.67[b]	48.57[b]	8.27[b]	7.86[a]
F value	5.52	882.36	33.72	65.02	50.87
p value	0.019	< 0.0000	< 0.0000	< 0.0000	< 0.0000
Significance	*	*	*	*	*

[1] Any significant interactions between main effects that emerged for parameters measured are presented in graphs below; * Significant at p=0.05; ** significant at p=0.01; NS not significant at p=0.05; Significant differences between early and late-forcing bulbs for means are indicated by different letters in superscript.

Table 7: The effect of various nutrient solutions and bulb age on the macro-nutrient content (%) of cut tulip plants grown hydroponically under warm climate conditions.

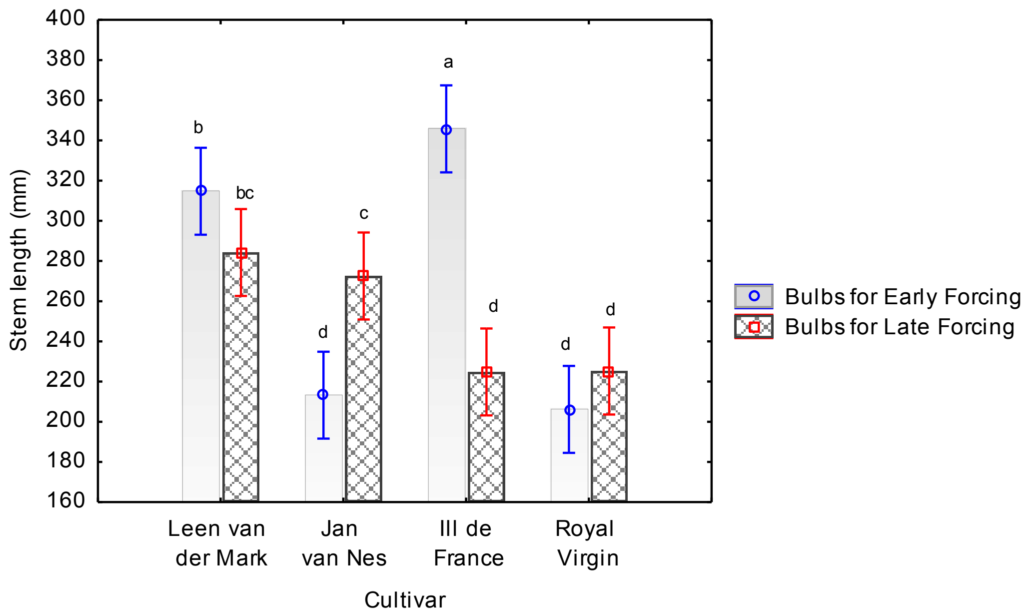
Treatment	NH_4-Nitrogen[1]	Phosphorus	Potassium	Calcium	Magnesium
Bulbs for Early Forcing					
Current SA	1.827	0.291[c]	1.421[c]	0.187	0.147[a]
Standard Steiner	1.986	0.395[b]	1.415[c]	0.205	0.148[a]
Europe	2.002	0.389[b]	1.653[a]	0.234	0.128[b]
Europe+NH_4^+	1.910	0.448[a]	1.539[b]	0.164	0.131[b]
F value	2.530	34.020	11.780	1.520	11.917
p value	0.060	< 0.00	< 0.00	0.210	< 0.00
Significance	NS	**	**	NS	**
Bulbs for Late Forcing					
Current SA	1.728	0.356[b]	1.520[b]	0.135[a]	0.137
Standard Steiner	1.655	0.352[b]	1.576[b]	0.140[a]	0.134
Europe	1.615	0.378[b]	1.747[a]	0.133[ab]	0.131
Europe+ NH_4^+	1.795	0.426[a]	1.555[b]	0.117[b]	0.135
F value	1.070	7.060	4.180	2.720	0.870
p value	0.36	< 0.00	0.008	0.040	0.46
Significance	NS	**	**	*	NS

[1] Any significant interactions between main effects that emerged for parameters measured are presented in graphs below; * Significant at p=0.05; ** significant at p=0.01; NS not significant at p=0.05; Significant differences between nutrient solutions for means are indicated by different letters in superscript.

Stem length

The length of cut tulip flower stems is a characteristic that directly influences quality (Pasterkamp 1996; Personal communication, C Coetzee, 2012[26]). In South Africa the consumer and industry prefers tulip stem lengths of ≥300 mm[27]. Tulip stem length[28] indicated a two way interaction between cultivar used and bulb age at forcing (Figure 5). Cultivars ‘Jan van Nes’ and ‘Ill de France’ had significantly different stem lengths when early-forcing and late-forcing bulbs were compared. However, the trend was opposite for these two cultivars: ‘Jan van Nes’ had significantly longer stems (21.7%) when late-forcing bulbs were used, whereas ‘Ill de France’ had significantly longer stems (35%) when early-forcing bulbs were used (Figure 5). For early-forcing bulbs ‘Leen van der Mark’ and ‘Ill de France’ had significantly longer stem lengths than both ‘Jan van Nes’ and ‘Royal Virgin’, which had stem lengths that were less than 250 mm, a length generally considered unmarketable. These significant differences found between the mean stem length of early-forcing (269.97 mm) and late-forcing (251.71 mm) bulbs could possibly be associated with the generally longer production period to flowering, thus providing more opportunity for stem elongation. However, this argument is not valid for 'Leen van der Mark’ and ‘Royal Virgin’ where no significant differences were measured for stem length between early- and late-forced bulbs. In addition, Roberts and Moeller (1970) and De Hertogh and Le Nard (1993) reported conflicting results which stated that later harvested (physiologically older) bulbs are more responsive to vernalization than early-forcing bulbs. Cultivar differences that were observed in this study are largely ascribed to genetic differences. Nelson and Niedziela (1998) also reported that different cultivars responded differently to calcium sources tested. In another study Sochacki and Chojnowska (2004) support this finding by reporting that the cultivars ‘Leen van der Mark’ (246 mm) and ‘Yokohama’ (414 mm) when grown on the same farm using the same forcing medium had significantly different stem lengths.

[26] The Woolworths specific requirements for tulip cut flowers are attached as Appendix B.
[27] This is measured by industry and consumers from the base of the stem to the tip of the flower, contrary to what is measured in the data presented.
[28] The stem length was measured from the base of the flower to the bottom of the stem.



ANOVA	F-value	Pr > F	Significance
Postharvest stem length			
Intercept	4506.91	<0.0000	**
Cultivar	24.56	<0.0000	**
Nutrient Solution	0.46	0.71	NS
Bulbs	5.52	0.02	*
Cultivar*Nutrient Solution	0.48	0.89	NS
Cultivar*Bulbs	24.99	<0.0000	**
Nutrient Solution*Bulbs	0.75	0.53	NS
Cultivar*Nutrient Solution*Bulbs	0.45	0.91	NS

Figure 5: The effect of bulb age and cultivar on postharvest stem length (mm). Treatment combinations with different letter symbols differ significantly (P<0.05).

Stem length of tulip plants at harvest indicated no significant interactions between nutrient solution and any other factors (Anova table, Figure 5). Also, no significant differences were found between the various nutrient solutions for tulip stem length (Table 4). This is again most likely the result of sufficient nutrients and carbohydrate reserves that are stored in tulip bulbs for stem development and elongation. Similar results were also found by Lee and Suh (2005), on cultivars ‘Golden Apeldoorn’ and ‘Ill de France’ where stem length was not significantly affected by nutrient solution composition. Osorio et al. (2009) also reported that stem length did not differ significantly between water, 50% and 100% Steiner solution treatments. According to Rees (1969) much of the shoot produced by the tulip bulb is predetermined, and thus it would explain why nutrient solutions did not have a significant effect on tulip stem length in this study.

Leaf area

Leaves are an integral part of the marketable product when producing cut tulips. Healthy leaves are thus essential on each tulip stem in order to be aesthetically acceptable (Personal communication, A van Wyk, 2012). In addition, vigorous leaves also implicate access to optimum photosynthesis to ensure sufficient reserve status both in the leaves, but also to supply to sink structures such as the elongating stem or developing floral parts (Taiz and Zeiger 2010). However, little attention in published literature is paid to leaf quality during tulip production and the minimum leaf area required for quality tulips is not available.

No significant interactions between the factors cultivar, bulb age and nutrient solution (p=0.59) or any combination of factors were obtained for the parameter leaf area (cultivar * bulb age, p= 0.09; cultivar * nutrient solution, p= 0.75; nutrient solution * bulb age, p=0.10). However, significant differences (p=0.03) were found for leaf area in stems produced within the various nutrient solutions (Table 4). The nutrient solution "Standard Steiner" produced plants with significantly the largest leaf areas compared to either the "Europe+NH_4^+" and "Current SA" nutrient solutions. Leaf areas of plants grown in the nutrient solution "Europe" was also high, but did not differ significantly from that of either the "Standard Steiner" grown plants or that of plants grown in the "Europe+NH_4^+" or "Current SA" nutrient solutions. However plant nutrient analysis did not indicate any significant differences in nitrogen uptake between nutrient solutions for both early- or late-forced bulbs (Table 7), which may have potentially explained these differences. In work done by Cheal and Hewitt (1964) it was found that tulip leaf area responded significantly to nitrogen treatments as an increased nitrogen content of the leaves could possibly up regulate photosynthesis and stimulate leaf area expansion (Meziane and Shipley 2001).

Significant differences (p=0.0002) were evident between the leaf areas of the various cultivars (Table 5). The cultivar 'Ill de France' had the largest leaf area and was followed by 'Leen van der Mark' and 'Royal Virgin', which had similar leaf areas which differed significantly from the cultivar 'Jan van Nes' which had the smallest leaf area. As with stem length, these cultivar differences are probably largely the result of genetic differences. Similarly, Benschop and De Hertogh (1971) found that different cultivars responded differently to environmental factors. Data from Cheal and Hewitt (1964) support the study of Benschop and De Hertogh (1971) by reporting that cultivars 'Golden Harvest' and 'Elmus', when subjected to the same nutrient treatments, had significantly different leaf areas.

Across all cultivars and nutrient solutions, significant leaf area differences (p=0.019) were found between early-forcing (333.56 cm^2) and late-forcing (138.67 cm^2) bulbs (Table 6). This is interesting since the formation of leaves and growth is initially dependent entirely on reserves in the mother-bulb scales, but later on when leaves have emerged the further growth of all new organs is supported by assimilates from these leaves (Ho and Rees 1977). Therefore, it is not surprising that late-forcing bulbs had significantly shorter stems than early-forcing bulbs (Table 6). Fortanier (1973) as well as De Hertogh and Le Nard (1993) reported that tulip leaf area, similar to that of stem length, continue to increase up until senescence. Thus, the much longer development time required for early forcing bulbs to reach the harvest ready stage would have provided more opportunity for leaf area expansion than would have been the case in late-forcing bulbs.

Fresh weight

When considering fresh weight (FW) of the hydroponically produced tulips, a two way interaction between nutrient solution and bulb age emerged (Figure 6 A). This interaction is most probably a result of the significant difference in fresh weight between plants produced from early- versus late-forcing bulbs, as the FW of plants produced by late-forcing bulbs was 11.5% lower than that produced by early-forcing bulbs. This may be linked to the fact that early-forcing bulbs took longer to flower and thus had more time available to take up water and nutrients, and produce carbohydrates (Lambrechts et al. 1994). Additionally it is assumed that late-forcing bulbs, that were stored for an extended period compared to early-forcing bulbs, continue respiring during storage, even if at a very low rate. This may result in late-forcing bulbs having fewer reserves available in bulb scales necessary for initial growth and emergence of leaves, which may have resulted in late-forcing bulbs having a smaller leaf area (Table 6), thus less assimilates available for further growth of new organs (Ho and Rees 1977). Less assimilates available for further growth of new organs due to smaller leaf area may have resulted in a FW that was less for late-forcing bulbs.

Fresh weight also indicated a two way interaction between cultivar and bulbs (Figure 6 B). All cultivars except 'Jan van Nes' produced plants with significantly different FW's when comparing the use of early- and late-forcing bulbs. Cultivar 'Royal Virgin' had the largest significant difference in FW between early- and late-forcing bulbs, followed by 'Ill de France' and 'Leen van der Mark'. In work done by Uragami et al. (2002) where tulips were grown using tap water controlled at 13°C, 18°C, and 23°C respectively without the addition of fertilizers, significant differences were found between fresh weight of the cultivars 'Ben van Zantan' and 'Gander'. Similarly, De Hertogh et al. (1978) showed that the respective fresh weights of cultivars 'Apeldoorn', 'Golden Melody' and 'Orient Express' grown under the same conditions differed significantly from one another.

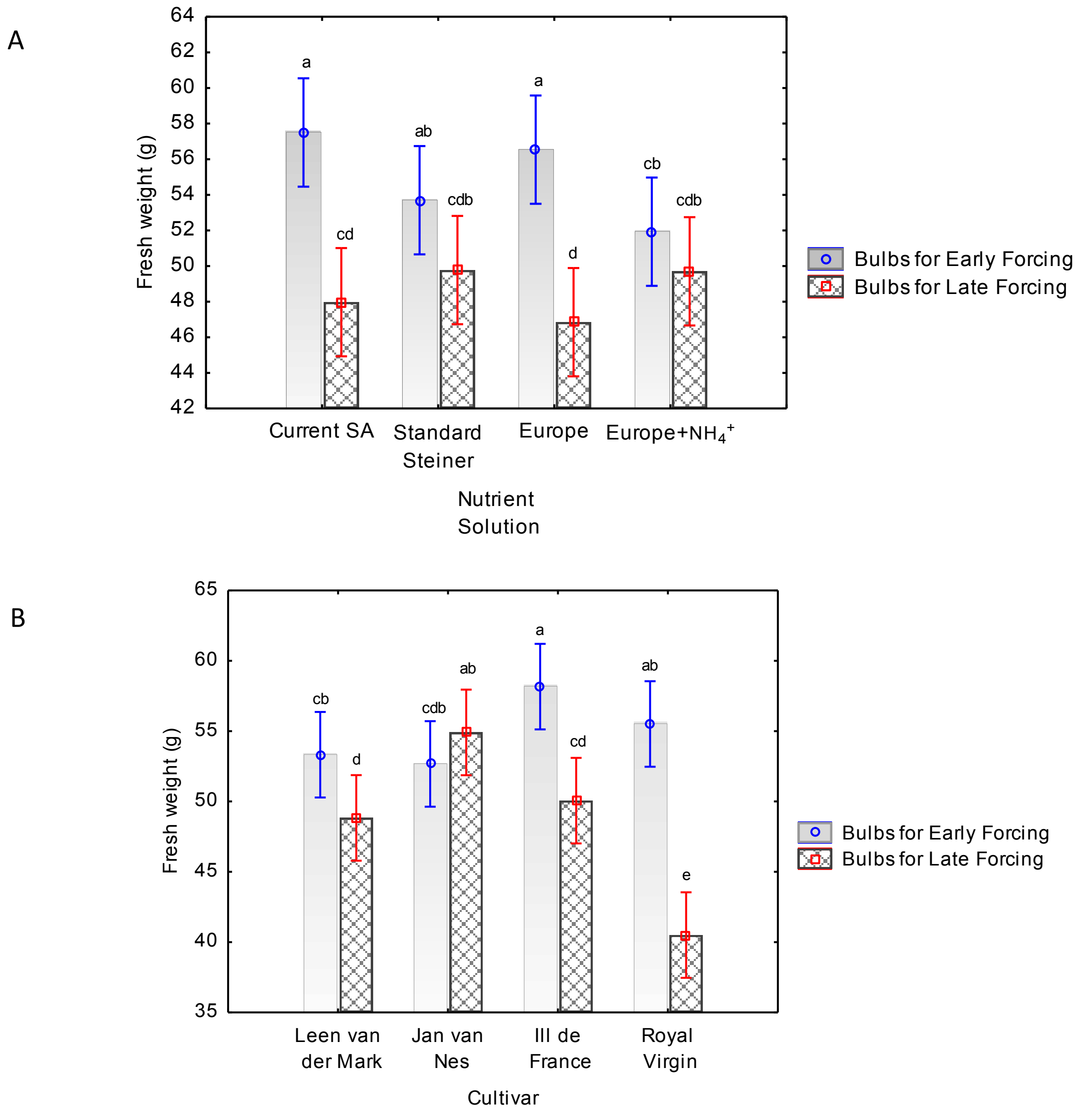
Dry weight

Carbohydrates derived directly from current photosynthesis account for 90% of the dry weight in crops (Guo et al. 2012). The dry weights (DW) of tulip plants indicated a two-way interaction between cultivar and bulb age (Figure 7). All cultivars, except 'Ill de France', had significantly different DW's between early- and late-forcing bulbs. Cultivar 'Royal Virgin' had the largest significant difference in DW between early- and late-forcing bulbs, followed by 'Jan van Nes' and 'Leen van der Mark' and 'Ill de France' had a DW that was similar for early- and late-forcing bulbs. For early-forcing bulbs 'Leen van der Mark' had a significantly lower DW than the other cultivars and for late-forcing bulbs 'Ill de France' and 'Jan van Nes' had the largest DW's followed by 'Leen van der Mark' and 'Royal Virgin' which also differed significantly. These cultivar differences for DW are not unexpected since FW differed significantly between cultivars; these differences could be the result of genetic cultivar differences.

The difference obtained in DW between early- and late-forcing bulbs is probably partly a result of the time required to flower (duration of active photosynthesis). The longer time taken for early-forcing bulbs to flower (23 days compared to 11 days for late-forcing bulbs) meant that these bulbs could accumulate nutrients and produce carbohydrates over a longer period of time than late-forcing bulbs did, which in turn could result in a larger DW (Guo et al. 2012).

The difference in DW between early- and late-forcing bulbs could also be a result of the duration of bulb chilling received. Inamoto et al. (2000) reported a correlation between the final dry weight of tulip plants and several growth parameters, most of these growth parameters can however be represented as a function of the duration of bulb chilling. It was found that dry weight of tulip plants is affected by the duration of bulb chilling and that the dry weight at anthesis of shoots increased with increasing bulb chilling up to 12 weeks where after it decreased. Since late-forcing bulbs did receive more than 12 weeks of bulb chilling, it is not unexpected that late-forcing bulbs had a significantly lower DW than early-forcing bulbs.

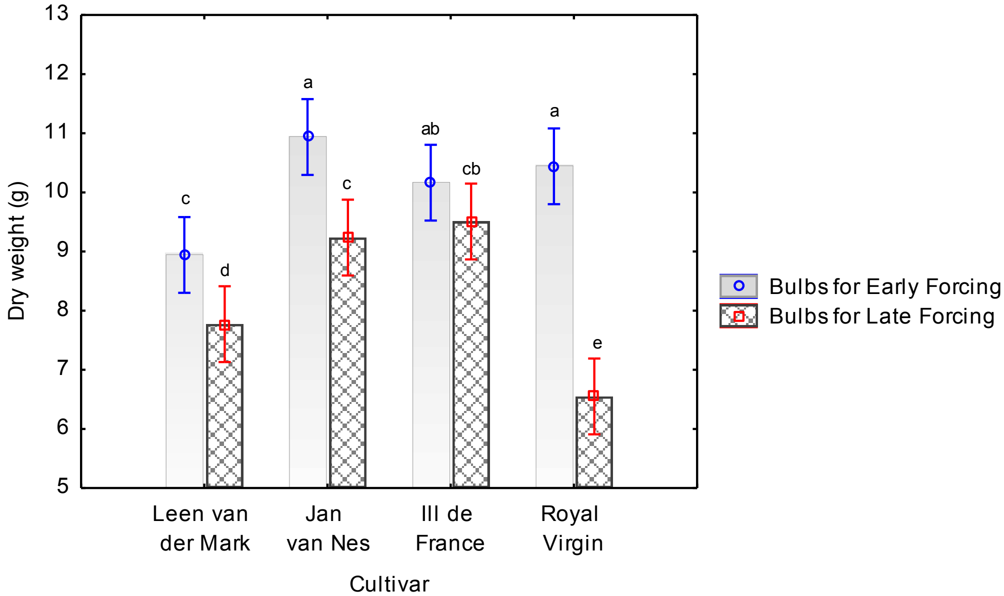
The DW of tulip plants indicated no significant interaction between nutrient solution and any other factors. As reported for the FW, no significant differences were found for DW between plants grown in the various nutrient solutions (Table 4). This response is perhaps the result of nutrient solutions facilitating similar rates of photosynthesis and subsequently dry matter production (Guo et al. 2012).



ANOVA	F-value	Pr > F	Significance
Fresh weight			
Cultivar	6.77	0.0002	*
Nutrient Solution	0.52	0.67	NS
Bulbs	33.73	< 0.0000	*
Cultivar*Nutrient Solution	0.41	0.93	NS
Cultivar*Bulbs	10.85	< 0.0000	**
Nutrient Solution*Bulbs	3.09	0.03	*
Cultivar*Nutrient Solution*Bulbs	0.88	0.54	NS

* Significant at p=0.05; ** significant at p=0.01; NS not significant at p=0.05; significant interactions at p<0.05 are shown in red.

Figure 6: The interaction between the main effects of nutrient solution and bulb age (A) as well as that of cultivar and bulb age (B) on the fresh weight (g) (FW) of cut tulips that were forced hydroponically under warm climate conditions.



ANOVA	F-value	Pr > F	Significance
Dry weight			
Cultivar	15.09	< 0.0000	*
Nutrient Solution	0.34	0.79	NS
Bulbs	65.02	< 0.0000	*
Cultivar*Nutrient Solution	0.43	0.92	NS
Cultivar*Bulbs	9.58	< 0.0000	**
Nutrient Solution*Bulbs	1.95	0.12	NS
Cultivar*Nutrient Solution*Bulbs	0.60	0.79	NS

* Significant at p=0.05; ** significant at p=0.01; NS not significant at p=0.05; significant interactions are shown in red.

Figure 7: The interaction between the main effects of cultivar and bulb age on dry weight (DW) (g) of cut tulips grown hydroponically under warm climate conditions.

Plant nutrient analysis

Plant nutrient analysis indicated no significant interactions between cultivar and nutrient solution at p <0.05 for any nutrients analysed for both early- and late-forcing bulbs (Table 7). For both early- and late-forcing bulbs no significant differences were found between the various nutrient solutions for plant nitrogen content. This is probably partly the result of nutrient solutions which did not contain considerably different quantities of nitrogen (Table 3), although water and minerals are not taken up from a nutrient solution in the same proportion in which the components are present, the rate of absorption depends upon the plant type, the climatic and environmental conditions, as well as the type of culture and the stage of development of the crop (Lee et al. 2004). However, in this study the environment (humidity and temperature) was controlled in the glasshouse such that both early- and late-forcing bulbs grew under comparable conditions, thus comparable nitrogen content in the leaf tissue was not unexpected.

Plant nutrient analysis indicated that the phosphorus (P) content of tulip plants differed significantly between the various nutrient solutions for both early- and late-forcing bulbs (Table 7). For both early- and late-forcing bulbs, plants grown in nutrient solution “Europe+NH_4^+” had a significantly greater P content compared to other nutrient solutions. As this nutrient solution contained the largest amount of P, more phosphorus was available for uptake compared to other nutrient solutions (Table 3). This is in agreement with results of Riley and Barber (1971) who found that ammonium-fertilized soybeans absorbed more P and had a higher P concentration than NO_3-fertilized soybeans. An increased availability of P where NH_4^+ was used as the nitrogen source seems to be mainly due to the effect of the nitrogen source on the pH of the nutrient solution (Table 8).

The plant nutrient analysis indicated that the potassium (K) content of plants was significantly different between the various nutrient solutions for both early- and late-forcing bulbs. For both early- and late-forcing bulbs plants grown in nutrient solution “Europe” contained significantly more K than plants grown in other nutrient solutions. Nutrient solution “Europe” also contained the highest amount of potassium (Table 3), thus more potassium was available for uptake.

Plant nutrient analysis indicated that the calcium content of early-forcing tulip plants did not differ significantly between the various nutrient solutions (Table 7). This is interesting since nutrient solution Current SA contained more calcium than other nutrient solutions, and since the NH_4^+ in “Europe+NH_4^+” decreased the pH (Table 8) it was anticipated that the calcium uptake would be much lower than for plants grown in that nutrient solution. However, for plants produced by late-forcing bulbs and grown in different nutrient solutions, significantly different amounts of calcium were detected between the various treatments. Plants grown in nutrient solutions “Current SA” and “Standard Steiner” contained significantly more calcium than plants grown in “Europe+NH_4^+”. This is not unexpected since “Current SA” and “Standard Steiner” contained significantly more calcium and the pH of “Europe+NH_4^+” was lower throughout the trial (Table 8) and thus calcium uptake may have been restricted at this lower root zone pH (Combrink and Kempen 2011).

The magnesium content of plants was significantly different between the various nutrient solutions for early-forcing bulbs, but not for late-forcing bulbs. This is unexpected since both early- and late-forcing bulbs were grown using the same nutrient solutions and under comparable climatic conditions (temperature and humidity). For early-forcing bulbs, plants grown in “Current SA” and “Standard Steiner” contained significantly more magnesium than other nutrient solutions. This was as anticipated since “Current SA” and “Standard Steiner” contained more magnesium than the other nutrient solutions (Table 3), thus more magnesium was available for uptake.

Table 8: Average pH of each nutrient solution for both early- and late-forcing bulbs throughout the trials.

Nutrient Solution	Average pH ± Standard deviation
Current SA	6.90±0.6
Standard Steiner	6.65±0.8
Europe	6.72±0.7
Europe+NH4+	5.49±0.9

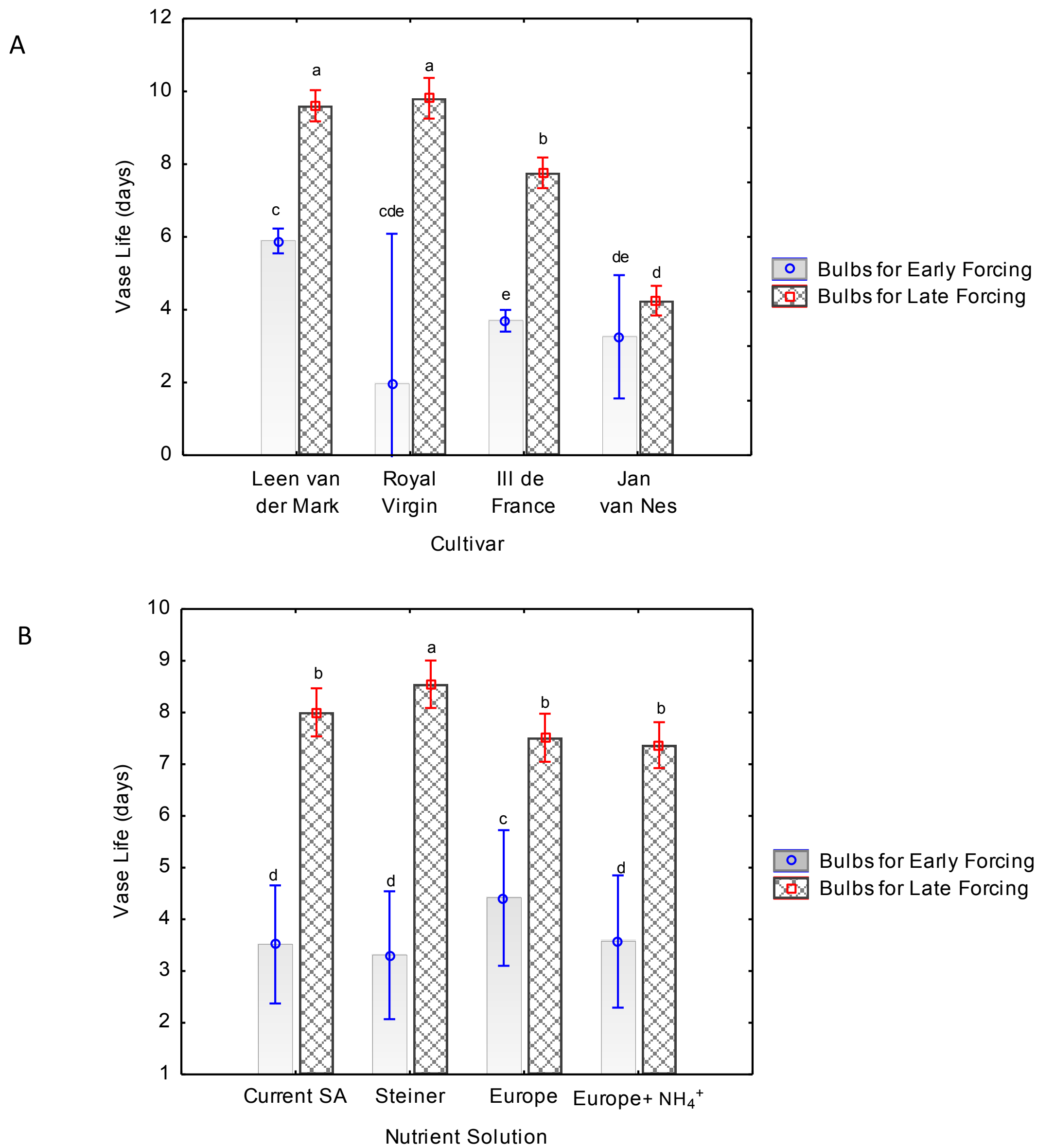
Vase life

The value a consumer gets from a cut flower is for a pronounced part determined by characteristics that are only observed after purchase, such as vase-life and the sensitivity to transport (Pasterkamp 1996). Vase life is an important quality characteristic (Van Eijk and Eikelboom 1976) and the duration of vase life is generally limited by tepal senescence for most tulip cultivars (Van Doorn et al. 2011).

Vase life produced a two way interaction between cultivar and bulb age (Figure 8 A). All cultivars except 'Jan van Nes' had significantly different vase lives between early- and late-forcing bulbs. 'Royal Virgin' had the largest difference in vase life between early- and late-forcing bulbs, followed by 'Ill de France' and 'Leen van der Mark' respectively, whilst 'Jan van Nes' had a similar vase for both early- and late-forcing bulbs. Consequently for all cultivars except 'Jan van Nes' the vase life of late-forcing bulbs was significantly longer than for early-forcing bulbs. This is in accordance with Pasterkamp (1996) who found that vase life is cultivar dependent. No literature was available regarding the effect of bulb age on vase life.

An interesting finding of this study was that early-forcing bulbs, which produced plants with a significantly greater leaf area than late-forcing bulbs (Table 6), had a significantly shorter vase life. Larger leaf areas are often associated with increased photosynthetic capacity and ability to accumulate reserves, with an extended vase life as a consequence. However, in this study, this was not the case. It is, therefore, suggested that since water stress is generally the most common reason for termination of vase life (Halevy 1976), it is likely that stems produced by early-forcing bulbs which had a significantly larger leaf area, would have experienced a higher incidence of transpiration (Grier and Running 1977) and possibly water stress, which could be accountable for a reduced vase life.

As with the previous reported interaction, the parameter vase life also resulted in a two way interaction between nutrient solution and bulb age (Figure 8 B). The vase life of cut tulip stems grown in all four nutrient solutions differed significantly between early- and late-forcing bulbs. For early-forcing bulbs, nutrient solution "Europe" produced tulips with the longest vase life (5.37 days) which differed significantly from "Current SA" (4.72 days), "Standard Steiner" (4.61 days) and "Europe+ NH_4^+" (4.44 days). Although only significant for potassium, plant nutrient analysis indicated that plant material produced by early-forcing bulbs when grown in nutrient solution "Europe" contained the most nitrogen, potassium and calcium when compared with plant material that was produced with the other nutrient solutions (Table 7). For late-forcing bulbs, nutrient solution "Standard Steiner" produced tulips with the longest vase life (8.54 days) which differed significantly from “Current SA” (8.00 days), “Europe” (7.53 days) and “Europe+ NH_4^+” (7.38 days). Although not significant, plant nutrient analysis indicated that late-forcing bulbs forced in “Standard Steiner” contained more calcium than other nutrient solutions (Table 7). An increase in vase life by nutrient treatment could possibly be ascribed to a healthy scape and leaves, which may have accessed more reserves to be utilized during the vase period when the bulb was removed. A healthy scape may also facilitate better water uptake, vital for maintaining turgor, and the freshness of the cut flower. Calcium and potassium have been shown to be essential in producing quality tulips (Klougart 1980; De Hertogh and Le Nard 1993; Gomez-Merino et al. 2009). High potassium levels in plant tissue may also contribute directly to maintaining turgor and thus result in increased vase life (Khan et al. 2006). Since plant nutrient analysis indicated that early-forcing bulbs grown in nutrient solution “Europe” contained significantly more potassium than plants grown in other nutrient solutions, perhaps these plants were able to maintain better turgor and thus had a longer vase life. Similarly, Khan et al. (2006) reported an increase in vase life of tulips owing to nutrient treatment, as compared to forcing in distilled water. A general higher calcium level in the early forcing bulbs however did not contribute to a longer vase life, despite claims in the literature that it should assist in extended vase life.



ANOVA	F-value	Pr > F	Significance
Vase Life			
Nutrient Solution	1.26	0.29	NS
Cultivar	50.98	< 0.0000	*
Bulbs	50.87	< 0.0000	*
Nutrient Solution*Cultivar	1.52	0.14	NS
Nutrient Solution*Bulbs	6.018	0.0004	**
Cultivar*Bulbs	4.90	0.0022	**

* Significant at p=0.05; ** significant at p=0.01; NS not significant at p=0.05; significant interactions are shown in red.

Figure 8: The interaction between the main effects of cultivar and bulb age (A) as well as that of nutrient solution and bulb age (B) on the vase life of cut tulips grown hydroponically under warm climate conditions.

Conclusions

In general, the scape growth of hydroponically forced cut tulips was not significantly influenced by nutrient solution composition. It seems likely that high quality tulip bulbs of an appropriate pre-forcing size contain sufficient reserves for scape growth and that nutrient solution composition has a minimal impact on cut tulip scape growth. However, the nutrient solution in which bulbs were grown hydroponically had a significant influence on the leaf area of the flowering stems. Although leaves are part of the final product when marketing cut tulips, no published research is available with regards to a threshold minimum leaf area required for quality tulips, although for the domestic market in South Africa it is normally only expected that tulip leaves should be green and healthy (Personal communication, C Coetzee, 2012) (Appendix B). It was found that for early-forcing bulbs nutrient solution “Europe” produced tulips with a significantly longer vase life than was recorded for stems grown in any of the other nutrient solutions. For late-forcing bulbs, the nutrient solution “Standard Steiner” produced tulips with a significantly longer vase life than was produced with any of the other nutrient solutions evaluated. Therefore, although not consistent for plants produced from both early and late-forced bulbs, the nutrient solutions “Standard Steiner” and “Europe” generally produced cut tulips of the highest quality for the four cultivars evaluated.

There were significant differences found in scape growth between the various cultivars evaluated. Since more scape growth would result in longer stems and longer stems are preferred for cut flowers (Personal communication, C Coetzee, 2012), more scape growth is preferred. ‘Leen van der Mark’ also resulted in the longest stem length and greatest fresh weight of all the cultivars evaluated. For early-forcing bulbs, ‘Leen van der Mark’ resulted with a significantly longer vase life than ‘Jan van Nes’ and ‘Ill de France’. For late-forcing bulbs ‘Leen van der Mark’ and ‘Royal Virgin’ had vase life that was significantly longer than ‘Jan van Nes’ and ‘Ill de France’. It was remarkable to find that ‘Royal Virgin’ gave such a long vase life for late-forcing bulbs, since ‘Royal Virgin’ was expected to be a poor performing cultivar (Personal communication, A van Wyk, 2012). ‘Royal Virgin’ is thus a cultivar that holds potential to produce hydroponically using late-forcing bulbs under warm climatic conditions. The cultivar ‘Leen van der Mark’ had rather robust growth and emerged as a low risk cultivar in terms of quality and vase life when forced hydroponically under warm climatic conditions using both early- and late-forcing bulbs. Hydroponic production of ‘Leen van der Mark’ under warm climatic conditions should thus be promoted.

Scape growth of cut tulips was significantly different between early- and late-forcing bulbs. Late-forcing bulbs resulted in much faster scape growth in the greenhouse, but did not result in more overall growth. Early-forcing bulbs resulted with significantly longer stems, significantly larger leaf areas and significantly greater fresh- and dry-weights than late-forcing bulbs. Having said this, late-forcing bulbs gave a vase life that was significantly longer than early-forcing bulbs. In order to produce cut-tulips year round one cannot discriminate between early- and late-forcing bulbs, but it is important to note the differences in quality that can be achieved using bulbs of a different physiological age.

A trend is evident that the nutrient content of tulip plants forced hydroponically under warm climatic conditions is increased proportionally as the available nutrients in solution increase. Further research needs to be done to determine the minimum concentration of nutrients required in order to ensure quality cut tulips.

This study provides evidence that the use of an optimized nutrient solution can be a significant aid towards an extended vase life. However, the extent to which a balanced nutrient solution can assist in the production of quality cut tulip stems is heavily dependent on the cultivar choice as well as the physiological age of the bulbs. It can be recommended from this study that for early-forcing bulbs the use of nutrient solution “Europe” and cultivar ‘Leen van der Mark’ produced tulips of the highest quality and longest vase life compared to other nutrient solutions and cultivars, and for late-forcing bulbs nutrient solution “Standard Steiner” and cultivar ‘Leen van der Mark’ facilitates plants of the highest quality and longest vase life compared to other nutrient solutions and cultivars.

Future research can be focused on further evaluating the effect of nutrient solutions “Standard Steiner” and “Europe” on the vase life of cut tulips produced hydroponically in warm climates using different EC’s to fine tune and also using more cultivars. Also, alternatives for future research are to evaluate the effect of foliar nutrition in combination with hydroponic nutrition on cut tulips since foliar nutrition has been used to successfully increase postharvest quality in many horticultural crops (Sams 1997; Conway et al. 2001; Lötze and Theron 2007).

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4. Paper 2: The effect of foliar sprays on the occurrence of stem topple and vase life of cut tulips

Abstract

An important factor in the quality of cut tulips is the firmness of the stem. Tulip stems that lack firmness may topple. Stem topple has been shown to be prevented by the application of calcium fertilizers. The effect of various foliar sprays including calcium nitrate ($CaNO_3$), CalTrain, NonTox Silica® and a control were evaluated for their effect on the occurrence of postharvest stem topple and vase life of two Triumph tulip cultivars, 'Jumbo Pink' and 'Strong Gold'. Cut tulips treated with foliar fertilizer sprays which contained calcium sources, "$CaNO_3$" and "CalTrain", had a vase life that was significantly (2 days) longer than tulips from the control treatment. Cultivars differed significantly in terms of vase life. 'Strong Gold' had a vase life (11.2 days) that was significantly longer than that of 'Jumbo Pink' (7.2 days). Calcium containing foliar sprays namely "$CaNO_3$" and "CalTrain", significantly reduced the incidence of postharvest stem topple by around 21.67% on average.

Key words: stem, quality, vase life, calcium, CalTrain, $CaNO_3$, NonTox Silica®.

Introduction

Tulips generally have a relatively short vase life (Iwaya-Inoue and Takata 2001). Stem topple, a physiological disorder which can further reduce vase life is found to be especially prevalent under tulips grown hydroponically in South Africa (Nelson et al. 2003; Personal communication, A van Wyk, 2012[29]). Stem topple is also known by producers as "Sugar stem", "Leatherneck" and "Wet stem" (De Hertogh et al. 1983). For tulips, irrespective of the thickness of the stem and the weight of the flower, if the stem lacks firmness it will have the tendency to topple (De Munk and Kamerbeek 1975). This condition affects mainly the flower scape, but can also affect the leaves where epidermal cells may burst (De Hertogh and Le Nard 1993). Topple is characterized by the appearance of glassy, water-soaked areas on the flower stem, usually occurring just before or during flowering. This is normally followed by shrinkage and furrowing at the site of the disorder, resulting in the toppling of the stem portion above the lesion.

Stem topple is usually observed 5-7 days before flowering and 2-3 days after harvest (De Hertogh and Le Nard 1993). Cultivars vary in their susceptibility to this disorder (De Hertogh and Le Nard 1993). Toppling is always found in those parts of the stem showing tissue infiltration and sap exudation, where the most elongation growth took place. The earlier the aberration occurs, the lower the internode where toppling will occur. Postharvest topple occurs most frequently in the uppermost internode (De Munk and Kamerbeek 1976). Similarly to blossom end rot (BER) found in tomatoes, stem topple can be caused by a host of different factors.

[29] Prominent Tulips, Rawsonville, South Africa.

Toppling is promoted by the administration of glucose to cut stems, as this causes more rapid elongation of the stem (Algera 1936). Excessive elongation of the uppermost internode of cut tulips can be prevented by adding 25 $mg.L^{-1}$ ancymidol to the vase solution. By preventing this excessive elongation, toppling may also be prevented. Vase solutions that contain 20-40 $mg.L^{-1}$ ancymidol[30] can significantly reduce elongation of the last internode of cut tulips without having an effect on vase life or flower quality (Einert 1975).

The collapse (topple) of the flower stalk is described as a symptom of calcium deficiency, and is characterized by the curvature of peduncles at the top of the neck of the plant, during flower formation (Gomez-Merino et al. 2009). The calcium content in toppling internodes shows a marked decrease when compared to healthy internodes (De Munk and Kamerbeek 1975). To explain this deficiency, Algera (1936) found evidence that Ca^{2+} ions are taken up, mobilized or transported more slowly than other mineral components. When the stem elongates rapidly, calcium is not supplied in the region of most rapid growth at a sufficient rate. A relative deficiency will increase upwards in the stem to such an extent that the cells can no longer develop normally and will then become dysfunctional (Algera 1936). It is suggested that this disorder can be suppressed by irrigating tulips with Ca^{2+} enriched water (De Munk and Kamerbeek 1976). Topple was found in both large and small bulbs of cultivar 'Elmus' despite a continuous supply of calcium, contradicting the common belief that this disorder is caused by a deficient uptake of calcium during forcing (Cheal and Hewitt 1964). Calcium is transported in the xylem sap to the exposed leaves where it is deposited. As calcium is phloem immobile, almost no translocation of Ca occurs. It has been reported that tulips of the cultivar 'Elmus' developed topple when receiving fertilizers containing adequate calcium, but lacking nitrogen, and high in potassium (Cheal and Hewitt 1964). An interaction between nitrogen and potassium was found and topple did not occur when nitrogen was supplied at the standard rate, but when nitrogen was deficient, increasing the amount of potassium was detrimental (De Hertogh et al. 1983).

In trials done by Klougart (1980) the effects of different calcium fertilizers were evaluated and results showed that calcium nitrate was the best calcium source to ensure high levels of calcium uptake. Topple is caused not only by a calcium deficiency in the growth medium, but also by circumstances that increase requirements of the tulip for calcium. These circumstances are similar to conditions that are conducive to the development of "blossom-end rot" in tomatoes. Such conditions include a high potassium supply as well as water stress associated with a high salt content of the rooting medium (Cheal and Hewitt 1964). The use of sulphate and potassium in combination might also be regarded as related factors in the cause of topple. The excess of sulphate over calcium, especially in the presence of potassium, is believed to be a causal factor of this disorder (Cheal and Hewitt 1964).

Some symptoms of boron (B) deficiency are similar to those of calcium deficiency. Ca and B deficiency can result in topple, although B deficiency causes transverse cracks on the upper part of flower scapes. Application of a complete nutrient fertilizer decreased the Ca^{2+} uptake. This may be due to

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[30] Ancymidol is a height retardant chemical (Nelson and Niedziela 1998a).

ammonium (NH_4^+) and potassium (K^+) competing with Ca^{2+} for uptake in the complete fertilizer (Nelson and Niedziela 1998a).

Pre-harvest calcium foliar sprays have been found to be beneficial in the quality of many horticultural crops (Kaya et al. 2002; Lötze and Theron 2007). Poinsettia plants sprayed and drenched with calcium and treated with the plant growth retardant, uniconazole, had greater levels of foliar calcium; however, this was not significantly greater than the control plants treated with uniconazole alone (Harris et al. 1990).

Silicon (Si) exerts beneficial effects on plant growth and production by alleviating both biotic and abiotic stresses as well as diseases, pests, lodging, drought, and nutrient imbalance (Ma and Yamaji 2008). Plants absorb Si through the roots and transport it upwards to stems, leaves and fruit. No basipetal movement of Si takes place and for all practical purposes Si is not relocated within the plant. Foliar sprays of Si will be absorbed by the leaves, but not relocated to the roots. However, those products resulting from the foliar application of silicon, like phenols, will be translocated to the roots (Coetzee and Pretorius 2007).

In South Africa there is interest among flower bulb growers in the use of foliar fertilizer sprays. Some growers are already using such sprays with claims of improved quality and yield (Personal communication, A van Wyk, 2012). Earlier research has shown that foliar fertilizer sprays are effective in increasing growth and bulb yield of field cultivated tulips (Rees 1969; Doss et al. 1979; Mugge and Richter 1980; Hetman and Laskowska 1992). However, only isolated published results could be traced on the effect of foliar fertilizer sprays on the vase life of tulips. Osorio et al. (2009) reported that plants which received nutrient solution that was complemented with a foliar fertilization consisting of bee honey had a postharvest vase life of 18% in excess to plants which received no foliar fertilization. Stem topple is considered a serious physiological disorder in tulips (Cheal and Hewitt 1964; Klougart 1980; De Hertogh and Le Nard 1993; Nelson and Nieziela 1998b), although it is not normally considered the natural or typical reason for senescence and the termination of vase life. It is therefore critical to mitigate stem topple as this physiological disorder may severely and prematurely shorten the vase life of tulip cut flowers, thereby negatively affecting the confidence with which consumers will consistently purchase this exquisite floral product.

Material and methods

Plant material

Top quality[31] tulip bulbs (>10-12 cm in circumference) were imported dry from the Netherlands from B&B Bulbs (De Gouw 41-E 1602 DN Enkhuizen, Netherlands). Two cultivars were used, namely, 'Jumbo Pink' and 'Strong Gold' (Figure 1).

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[31] All bulbs must meet phytosanitary requirements set by Government in order to be imported (see Appendix A).

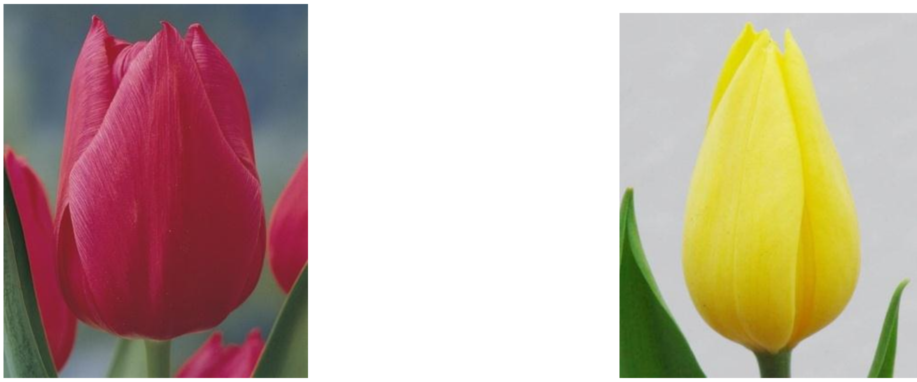

Figure 1: Two cultivars, 'Jumbo Pink' on the left and 'Strong Gold' on the right, were selected for the evaluation of the efficacy of various foliar sprays to reduce the incidence of toppling in hydroponic production under warm climatic conditions in the western Cape, South Africa.

Bulbs were planted in standard pin forcing trays similar to those described in Paper 1, according to a split-plot design. Bulbs were planted in 20 trays where each tray (experimental unit) contained 20 bulbs with 10 bulbs of each cultivar. A standard Steiner solution (Steiner 1961) was used to force all plants (Table 1).

Table 1: Macro-nutrient composition (meq.L^{-1}) of the Standard Steiner (Steiner 1961) nutrient solution used to hydroponically force two cut tulip cultivars in South Africa.

Treatment	Na^+	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	Cl^-	HCO_3^-
Standard Steiner nutrient solution	0.109	0.041	5.791	7.780	3.424	9.925	0.841	5.942	0.341	0.372

Electrical conductivity (EC) and pH of the nutrient solutions were monitored throughout the trial using Milwaukee apparatuses (Milwaukee models EC60 and pH56 respectively, Milwaukee Electric Tools, 13135 West Lisbon Road, Brookfield, USA). Nutrient solutions were replaced with fresh ones (EC~1.6-1.8 mS.cm^{-1} and pH~5.5-6.5) at the start of each week to prevent salinization or depletion of nutrients. The EC, which was adjusted by manipulating municipal water and nutrient levels with the weekly nutrient solution replacement, was not altered during the week. Immediately after removal from storage, bulbs were rooted in sterilized standard forcing trays in a dark rooting room at 3-4°C where roots were bathed with full strength nutrient solution which continuously circulated from the stock tank to the forcing trays. Rooting was completed within 2-3 weeks, when roots were approximately 3-5 cm in length. No toxic amounts of any nutrients were detected in the water analysis and thus no water treatment was required (Combrink and Kempen 2011).

Vegetative growth phase

Once bulbs were sufficiently rooted[32], trays were moved into the glasshouse for the active growing phase. The glasshouse climate was controlled at approximately 20 ± 2°C and humidity was kept at approximately 65%. Again as during the rooting phase, nutrient solutions were replaced at the start of each week.

Treatments

Treatments consisted of three foliar spray treatments and an untreated control. All treatments were applied every third day until runoff, using 1 L pressure spray bottles. Prevention of cross contamination by drifting was achieved by covering all trays with clear plastic, except for the specific tray which received the foliar application. The four treatments were each applied to five trays of 20 plants each.

Table 2: Three foliar fertilizer sprays and an untreated control were applied to hydroponically grown cultivars 'Jumbo Pink' and 'Strong Gold' cut tulips under warm climatic conditions.

Treatment	Formulation	Supplier	Recommended application
$CaNO_3$	$Ca(NO_3)_2.4H_2O$	Yara South Africa & Business Unit Africa, The Pivot at Montecasino No. 1 Montecasino Boulevard, Fourways, Johannesburg, South Africa.	0.998 g $CaNO_3$ granules per 1 L municipal water (EC = 2 $meq.L^{-1}$), mix well till all granules dissolve, spray till runoff.
CalTrain	CalTrain (10.1% $^w/_v$, 8.1% $^w/_w$ Ca) is a highly uptake-able liquid calcium amino acid chelate containing calcium (101 $g.L^{-1}$) as well as boron (1.7 $g.L^{-1}$).	AgriLibrium, Head Office, Vorna Valley, Pretoria, South Africa.	2.5 ml CalTrain with 1 ml fulvic acid (wetter) per 1 L municipal water as recommended by Agrilibrium specialists (Personal communication, T Du Toit, 2013[33]), mix well, spray till runoff.
NonTox Silica®	42 $g.kg^{-1}$ or 50 $g.L^{-1}$ Si soluble in water.	Plant Bio Regulators (Pty) Ltd, 41 Rudolph Street, Sunderland Ridge, Centurion, Pretoria, South Africa.	25 ml already diluted NonTox Silica® per litre of municipal water as recommended by specialist (Coetzee 2013), mix well, and spray till runoff.

[32] Roots of approximately 3 cm long are sufficient (Personal communication, A van Wyk, 2012).
[33] Agrilibrium, Stellenbosch, South Africa.

Harvest

After approximately 21 days of growth in the glasshouse, plants which obtained a stem length of >300 mm and had a well-developed flower with a noteworthy colour change were considered harvest-ready and marketable. Marketable plants were labeled, removed from the cultivation pin trays, with the bulb still attached, and placed vertically in dry trays in a cold room at 2°C for 2-3 days, as is commercial practice (Personal communication, A van Wyk, 2012). Bulking up with flowers was allowed for no longer than five consecutive days, in order to construct ten bunches of six flowers each for each treatment. At the end of each week, bulbs were removed from the base of the flower stems such that maximum stem length was achieved. Stems were bunched and wrapped in plastic sleeves before they were pulsed in a solution of Chrysal BVBplus[34] overnight in a cold room at ±2°C. A retail period was simulated, where flowers were placed in round 5 L buckets, which contained 1 L of tap water and a Chrysal Clear Professional 2 T-bag (new generation)[35] for two days and three nights as is commercial practice.

Vase life

After the retail simulation, the plastic wrapping was removed from flowers and each bunch of flowers transferred to a 1 L cylindrical glass vase containing 0.5 L of standard vase life solution in order for the vase tests to commence. Vase solution was made up using 10 ml Chrysal Universal Flower Food[36] added to 490 ml of tap water. The vase life duration of stems was evaluated daily based on the degree of wilting, colour loss of the tepals, toppling of the stem and yellowing of the foliage. Vase life (days) was determined for each individual flower. The day on which the first flower was removed as well as the day on which 50% of the flowers were removed from each vase was recorded.

Statistical analysis

Data was analysed using the ANOVA procedure, and means compared with Fischer's LSD ($P<0.05$) using statistical software Statistica 12 (Statsoft (SA) Inc., Tulsa, Oklahoma, USA).

Results and discussion

Vase life

No significant interactions between the various treatments and the cultivars were obtained for the duration of the vase life (Figure 2). However, vase life was significantly ($p=0.0039$) influenced by foliar fertilizer treatments. All plants treated with Ca-containing foliar fertilizer treatments recorded significantly longer vase lives compared to the control at 7.95 days (Figure 2). The vase life of plants treated with "$CaNO_3$" (10.04 days), "CalTrain" (9.79 days), and "NonTox Silica®" (8.98 days) were not significantly different from

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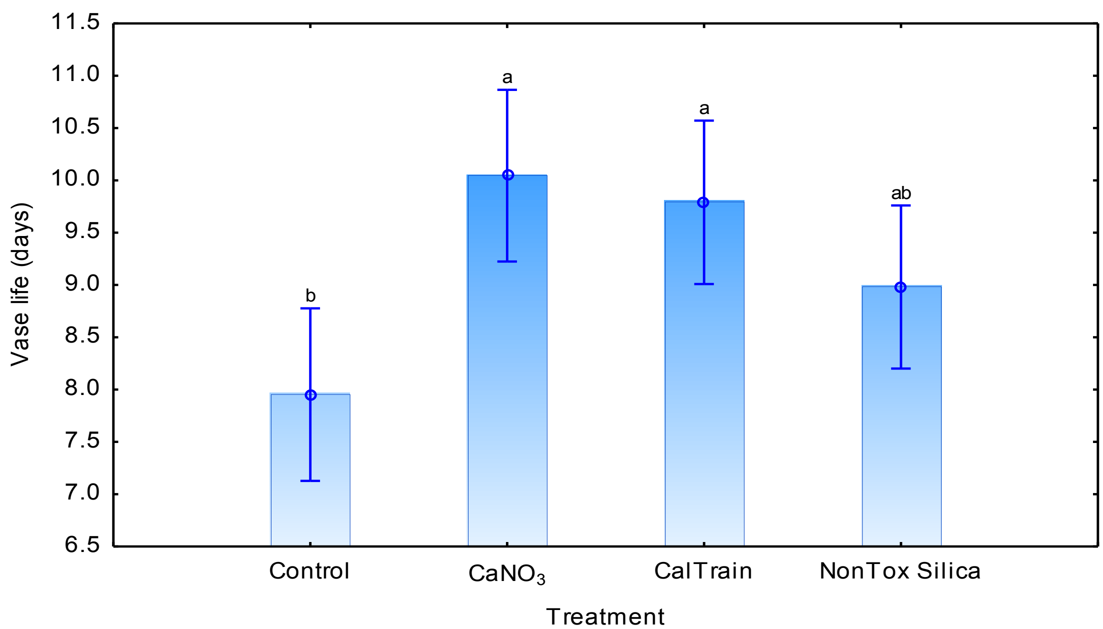
[34] BVBplus is a postharvest conditioner for tulips available from Chrysal (Chrysal International, Gooimeer 7, 1410 AH Naarden, The Netherlands).

[35] New and improved conditioner for use during transport for all cut flowers to improve vase life available from Chrysal (Chrysal International, Gooimeer 7, 1410 AH Naarden, The Netherlands).

[36] Chrysal Clear Universal flower food is flower food for the complete development of all cut flowers. Available from Chrysal (Chrysal International, Gooimeer 7, 1410 AH Naarden, The Netherlands).

each other, whilst the vase life of plants treated with NonTox Silica® were not significantly different from that of control plants.

The increase in vase life which resulted from the Ca-containing foliar sprays may be attributed to the production of a healthy scape and leaves, which subsequently will make more reserves available to be utilized during the vase period when the bulb is removed. A healthy scape may also facilitate better water uptake, essential for maintaining turgor, and the freshness of the cut flower. In the case of the "NonTox Silica®" treatment, the mechanism by which the silica most likely extended vase life was by Si forming cross links with lignin and polyphenols in all cell walls. These compounds are elastic, but insoluble in water and form barriers against fungal attack (Coetzee and Pretorius 2007). Increased vase life with foliar nutrient application confirms the study by Khan et al. (2006) who also reported an increase in vase life of tulips owing to nutrient treatment, when compared to forcing in distilled water. More support for the benefit of foliar application of nutrients in enhancing tulip quality is provided by Osorio et al. (2009) who reported that plants, for which the nutrient solution was complemented with foliar fertilization, had an 18% longer vase life compared to plants which received no foliar fertilization.

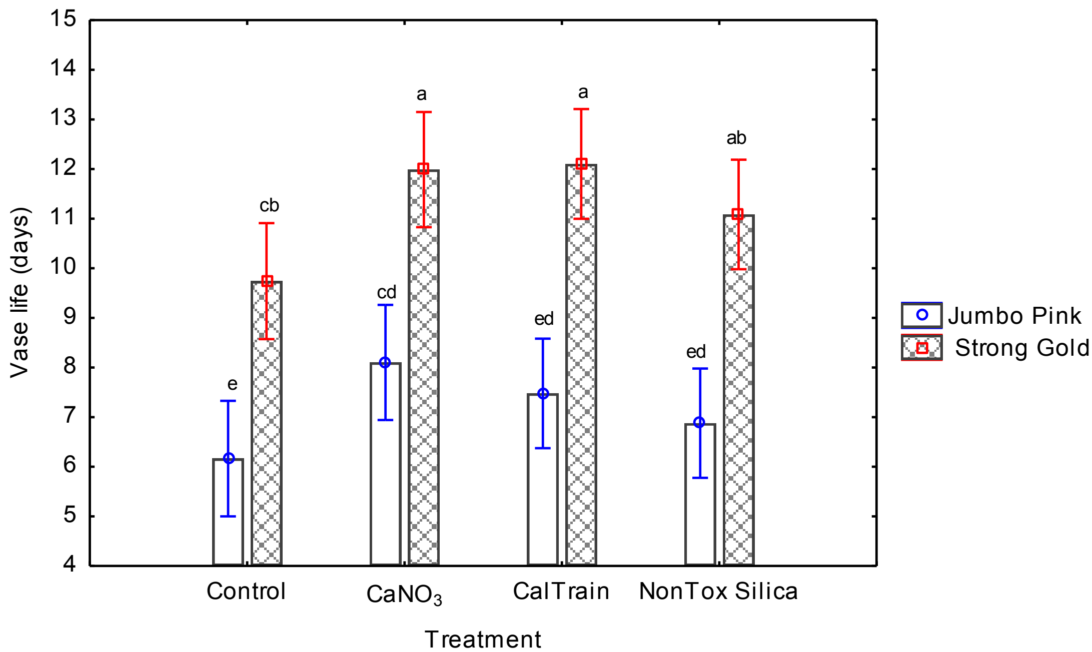


ANOVA	F-value	Pr > F	Significance
Vase life (days)			
Treatment	5.59	0.0039	**
Cultivar	108.27	< 0.0000	**
Treatment*Cultivar	0.32	0.8046	NS

Figure 2: Effect of various foliar fertilizer sprays on the vase life (days) of hydroponically forced cut tulips. Different letter symbols above bars indicate significant differences at $p < 0.05$.

Mean vase life differed significantly between the different cultivars (Figure 3). Cultivar 'Strong Gold' had a significantly longer vase life than 'Jumbo Pink' for all treatments applied as well as the control. Cultivar differences are most probably the result of hereditary differences. Much earlier studies by Benschop and De Hertogh (1970) also reported that cultivars can differ significantly in their senescent characteristics. Despite differences in the vase life duration obtained in this study, both cultivars had mean vase lives that were significantly longer for the treatment "$CaNO_3$" as compared to that observed for the control. For 'Strong Gold' plants sprayed with "CalTrain" performed similar to plants sprayed with NonTox Silica®, but both these treatments provided treated plants with a significantly longer vase life than that recorded for control plants. However for 'Jumbo Pink', stems of plants treated with "CalTrain" or "NonTox Silica®" did not have a significant longer vase life from one another, or from that of control stems.

In 'Strong Gold' this increase in observed vase life of "$CaNO_3$" and "CalTrain" treated plants may be the result of increased calcium acquired by plants treated with the calcium-enriched foliar sprays. Since calcium is important for plant cell wall structure and strength and has been associated with enhanced quality of tulips as well as many other floricultural products, this result is not unexpected (Klougart 1980; De Hertogh and Le Nard 1993; Nelson and Niedziela 1998b, Capedeville et al. 2005; Rasool 2012). However, "CalTrain" was not as effective in 'Jumbo Pink' as in 'Strong Gold' to provide a significantly extended vase life (Figure 3). This result was rather unexpected as it was expected for CalTrain, which also contained boron, to have an additional beneficial effect on vase life, since boron has been shown to increase vase life of tulips (Rasool 2012), but "CalTrain" contained less (0.2525 $g.L^{-1}$) Ca in the final diluted foliar spray than "$CaNO_3$" (0.998$g.L^{-1}$) did (Table 2). Therefore it is probably the effect of the higher concentration of Ca as well as the additional nitrogen(N) recieved by plants in the "$CaNO_3$" treatment that allowed for stronger and healthier scapes which thus had an extended vase life.



ANOVA	F-value	Pr > F	Significance
Vase life (days)			
Treatment	5.59	0.0039	*
Cultivar	108.27	< 0.0000	**
Treatment*Cultivar	0.32	0.8046	NS

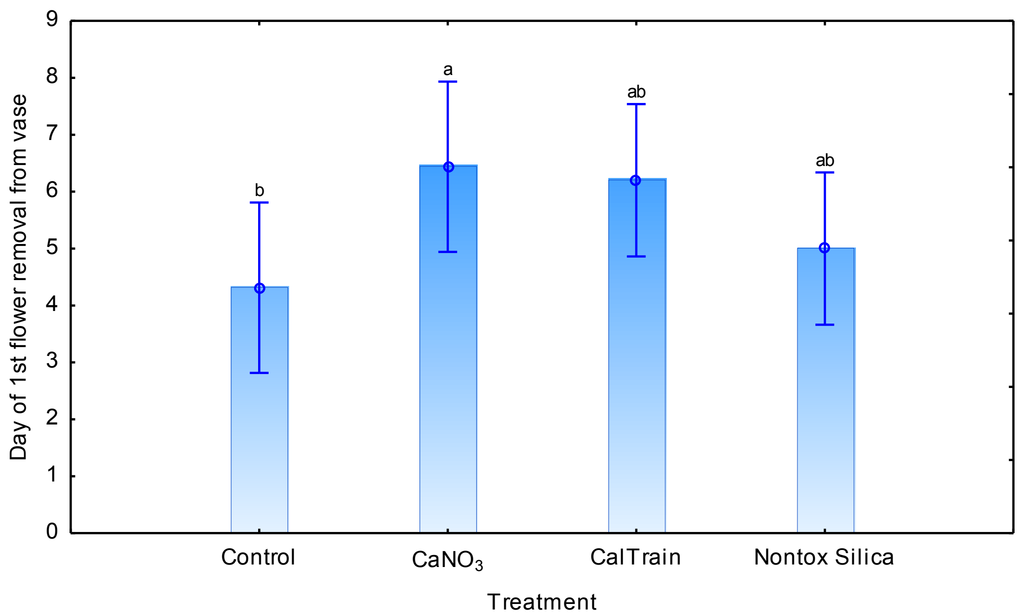
* Significant at p=0.05, ** significant at p=0.01, NS not significant at p=0.05

Figure 3: The effect of various foliar fertilizer treatments on the vase life (days) of two cut tulip cultivars namely 'Jumbo Pink' and 'Strong Gold' that were grown hydroponically under warm climatic conditions. Different letter symbols above bars indicate significant differences at $p < 0.05$.

The mean day on which the first flower[37] was removed from the vase was not significantly different (p= 0.13) between treatments (Figure 4). However, post-hoc tests indicate that plants treated with "$CaNO_3$" took significantly longer (day 6.44) before the first flower was removed from the vase, when compared to the control flowers (day 4.31) (Figure 4). Quality cut tulips are sold in reputable retail shops with a guaranteed vase life of 5 days (Personal communication, A van Wyk, 2012). With the first flower being removed approximately on the fourth day of vase life, the control is below this threshold, whilst stems treated with $CaNO_3$ were safely above this critical value.

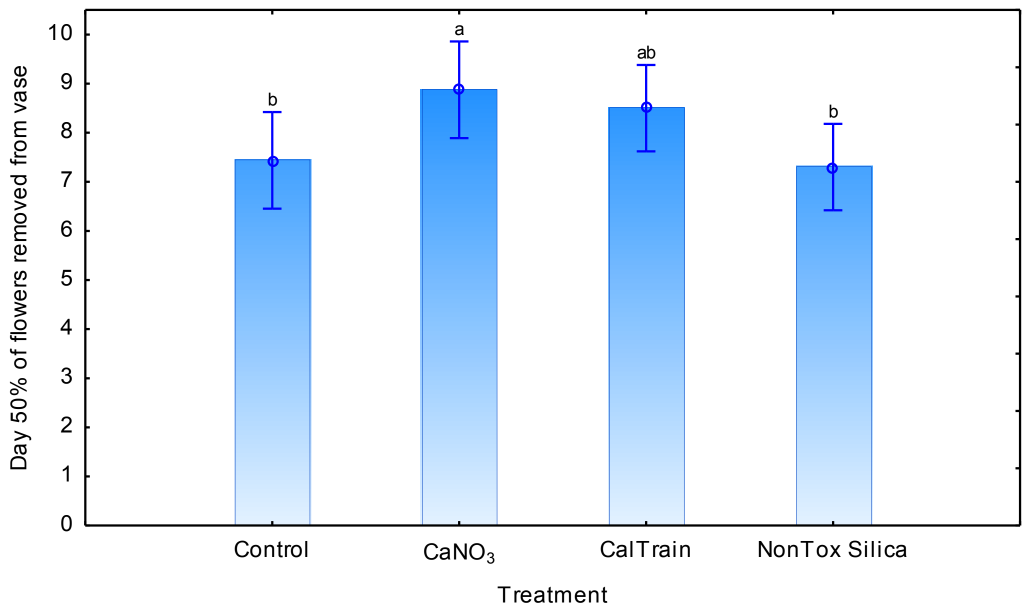
[37] The first day of flower removal is when the consumer has his/her first experience of a loss of quality and satisfaction and the money-back guarantee given when sold is thus also affected by this value.

The mean day on which 50% of the flowers were removed from the vase was not significantly different between treatments (p value = 0.06) at 5% significance level, but proved significant at the 10% confidence interval (Figure 5). Additionally, post-hoc tests indicated that stems treated with “$CaNO_3$” (day 8.87) differed significantly from the control (day 7.44). Similar findings were reported by Capdeville et al. (2005) who found that for the rose cultivar ‘Kiss’, $CaSO_4$ sprays during growth is a practice that can be recommended, if the objectives are to reduce the damage by *Botrytis cinerea* and to increase postharvest life.



F value	Pr > F	Significance
2.2	0.13	NS

Figure 4: The effect of various foliar fertilizer sprays on the day of vase life that the first flower was removed per vase of cut tulips produced hydroponically under warm climatic conditions.



F value	Pr > F	Significance
3.18	0.06	NS

Figure 5: The effect of various foliar fertilizer sprays on the mean day of vase life when 50% of the flowers were removed per vase of cut tulips produced hydroponically under warm climatic conditions.

Stem topple

Tepal senescence was the most frequent reason for removal of flowers from the vase (Table 3; Figure 6). This is not unexpected as for most tulip cultivars the lifespan of the flower head is limited by tepal senescence followed by tepal abscission (Van Doorn et al. 2011). A secondary, reason regularly listed for a short vase life in tulips, is early postharvest stem topple. This has especially been the case for cut tulips forced in South Africa (Personal communication, A van Wyk, 2012; Personal communication, C Coetzee, 2012[38]).

According to De Hertogh and Le Nard (1993) high forcing temperatures are associated with rapid elongation, which subsequently may cause stem topple. Stem topple is considered a physiological disorder (Cheal and Hewitt 1964; Klougart 1980; De Hertogh and Le Nard 1993; Nelson and Nieziela 1998b) and is not normally considered the natural or typical reason for senescence and termination of vase life. It is therefore concerning to note that on average 14% of all tulips had been removed from the vase because of stem topple (Table 3) and these flowers had a shorter mean vase life (Table 4). Across all treatments and cultivars, the mean vase life of tulips that were removed from the vase because of stem topple was 6.03 days compared to the overall mean vase life of 9.18 days (Table 4). It is therefore evident that stem topple accounted for vase life that was cut short by 3.15 days in this research.

[38] Woolworths, Cape Town, South Africa.

Figure 6: Percentages as high as 45% of tulips were typically removed from the vase due to tepal senescence.

Table 3: Effect of foliar fertilizer treatments on the count of stems which were removed from the vase for each deleterious reason.

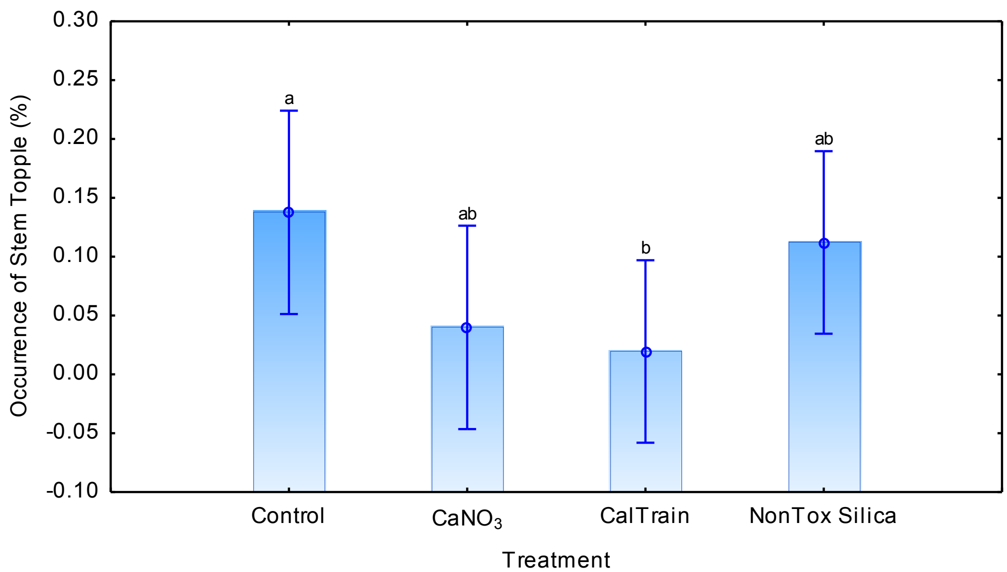
Treatment	Tepal Senescence	Tepal Abscission	Stem Topple	Tepal Discolouration	Leaf Yellowing and Damage	Other[39]
Control	22	6	17	2	7	6
$CaNO_3$	23	14	4	7	5	7
CalTrain	36	15	1	3	3	2
NonTox Silica®	27	12	11	7	2	1
Total	108	47	33	19	17	16
Total as %	45	20	14	8	7	7

Table 4: Effect of various foliar fertilizer treatments on the mean day of vase life on which stems were removed from the vase for each respective deleterious reason.

Treatment	Tepal Senescence	Tepal Abscission	Stem Topple	Tepal Discolouration	Leaf Yellowing and Damage	Other[28]
Control	10.33	7.17	5.00	12.14	10.00	9.33
$CaNO_3$	10.39	8.29	5.06	11.00	10.40	9.33
CalTrain	10.56	8.20	8.25	12.67	10.67	4.5
NonTox Silica®	9.09	6.67	5.82	7.57	10.14	5
Mean vase life	10.09	7.58	6.03	10.85	10.30	7.04

[39] Other reasons for removal from vase included mechanical damage and fungal infections.

The percentage occurrence of stem topple differed significantly (p=0.09) between treatments at the 10% significance level (Figure 7). It can be seen that foliar treatments containing calcium, "$CaNO_3$" and "CalTrain", differed significantly from the control and thus significantly reduced the percentage occurrence of postharvest stem topple (Figure 7). This is not unexpected since calcium has been shown to reduce stem topple (Algera 1936; Cheal and Hewitt 1964; De Munk and Kamerbeek 1976; De Hertogh and Le Nard 1993; Nelson and Niedziela 1998b).



ANOVA	F-value	Pr > F	Significance
% occurrence of stem topple			
Treatment	3.66	0.0981	NS
Cultivar	0.66	0.4386	NS
Treatment*Cultivar	0.01	0.9976	NS
* Significant at p=0.05, ** significant at p=0.01, NS not significant at p=0.05			

Figure 7: The percentage occurrence of postharvest stem topple that resulted. Different letter symbols above bars indicate significant differences at $p < 0.05$.

Conclusions

In this research it was found that foliar treatments which contain calcium, namely "$CaNO_3$" and "CalTrain", significantly increased vase life compared to the control. Cultivars evaluated differed significantly in terms of vase life. 'Strong Gold' had a mean vase life (11.23 days) which was significantly longer than that of 'Jumbo Pink' (7.15 days). The mean day on which the first flower was removed from the vase was significantly longer for stems treated with $CaNO_3$ (day 6.44) compared to control stems (day 4.31). With an average vase life of approximately 5 days that is normally for the customer guarantee the use of

$CaNO_3$ as foliar spray seems promising. The mean day on which 50% of flowers were removed from the vase was significantly different for "$CaNO_3$" (day 8.88) compared to the control (day 7.44) and NonTox Silica® (day 7.30) treatments.

The incidence of postharvest stem topple was significantly reduced by the application of calcium containing foliar sprays, "$CaNO_3$" and "CalTrain". It is thus recommended from this research that cut tulips that are grown hydroponically under warm climatic conditions may benefit from a calcium containing foliar spray of "$CaNO_3$" or "CalTrain" as this may significantly increase the vase life, with up to 2 days compared to no foliar treatment, and may significantly reduce the incidence of postharvest stem topple.

Future research should be focused on evaluating the use of higher concentrations of boron, while remaining within an appropriate range[40], in combination with $CaNO_3$ or calcium foliar sprays for efficacy in reducing stem topple and increasing vase life, since the application of boron has been shown to increase the vase life of 'Apeldoorn' tulips (Rasool 2012). Boron seems promising in potentially increasing vase life of cut tulips and in combination with calcium foliar sprays may prove even more promising. The cost effectiveness of this should also be looked at compared to ready-mixed products already available using more cultivars and bulbs for both early- and late- forcing.

Optimizing the pre-harvest cultivation aspects will only result in quality cut tulips with a long vase life when used in combination with the correct postharvest treatments and thus it is important to consider the pre- and postharvest aspects of cut tulip production as one dynamic interlinked process.

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5. Paper 3: The efficacy of various postharvest treatments on the extension of vase life of hydroponically grown cut tulips

Abstract

As the global demand for ornamental geophytes increases, it is evident that innovative production and marketing efforts are required. The contribution of research to the development of the global flower bulb industry is imperative for the establishment of future priorities and needs and will aid industry and the consumer. The vase life of cut tulips is an important parameter directly affecting quality. The efficacy of three postharvest treatments to extend the vase life of the four cut tulip cultivars 'Margarita', 'Synaeda Orange', 'White Marvel' and 'Deshima' were evaluated. Treatments consisted of an untreated control, an overnight stem pulse with Chrysal BVBPlus, a four hour fumigation of Chrysal Ethylene Buster® (1-MCP) and a combination of the latter two treatments. Vase life, postharvest stem elongation and vase-solution uptake were parameters that were evaluated. Although there were trends seen, these treatments did not have significant effects on any parameters measured. Mean vase life was determined to be 3.26 days, mean postharvest stem elongation was 29.20 mm and the mean vase solution uptake was determined to be 167.25 ml per vase. Trends observed suggest that treatments containing BVBPlus may prolong the vase life, minimize postharvest stem elongation and improve the uptake of vase life solution of hydroponically produced cut tulips under warm climatic conditions. Future research should be focused on further testing the efficacy of BVBPlus on the vase life of cut tulips in warm climates, using more cultivars and possibly higher concentrations as well as longer durations of application, within the current recommendations by Chrysal (2008). Further research can be focused on evaluating the efficacy of BVBPlus on more cultivars and evaluating the use of trehalose and chloramphenicol (CAP) as well as the use of postharvest foliar applications of glycine-betaine.

Key words: Postharvest treatments, pulsing, Chrysal BVBPlus, Chrysal Ethylene Buster® (1-MCP), vase life evaluation

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Introduction

Tulip cut flowers which have always been admired for their array of bold colours and beautiful cup shaped flowers are growing in popularity. The high value of cut flowers has led to a significant increase in the production of these cut flowers in developing countries (Reid and Jiang 2012). However, market analysts stress the importance of the reliable production of cut flowers of consistent quality to ensure an industry-wide standard of excellence. Therefore, quality criteria are required to secure competitiveness in an increasingly demanding global market. The most important aspects of quality are perceived to be "freshness" and an extended vase life. The concept of quality in tulips refer to a number of characteristics such as flower size, leaf quantity, stem firmness and stem length (Pasterkamp 1996). In tulips, as in other cut flowers, achieving these features not only relies on the best possible production techniques, but also depends on optimum postharvest handling (Reid and Jiang 2012).

A minimum acceptable standard for vase life of cut tulips is perceived to be 5 to 6 days (Salunkhe et al. 1990). Postharvest longevity of cut tulips varies by cultivar and can be affected by temperature. Most Darwin hybrids are generally considered to be cut flowers with a short vase life of only 3 to 4 days (Salunke et al. 1990). At 23˚C the expected vase life of cut tulips can range between 3 to 7 days, although lower temperatures can extend this period (De Hertogh et al. 1983). A reduction in marketable cut tulips is mainly associated with bud blasting, toppling and mechanical damage resulting from rough postharvest handling. Cut tulip flowers that are to be stored for any period of time are harvested and stored with the bulbs still attached. Later, bulbs are dissected and stems are cut from the basal plate adding approximately 1-4 cm to the stem length (Dole and Wilkins 2004).

The quality and attractiveness of cut tulips is partly determined by the extent of postharvest floral stalk elongation as well as the factors of floral senescence. Excessive postharvest elongation of the internode immediately below the flower often causes unsightly stem bending due to the weight of the flower and reduces the aesthetic value of the product well in advance of senescence of the flower perianth (Einert 1973). Elongation is apparently regulated by hormones with the primary control site being the floral organs (Einert 1973; De Hertogh and Le Nard 1993). Elongation of the upper (acropetal) internodes is primarily controlled by auxins and gibberellins, which both promote growth and this growth occurs after purchase in the home environment. The rate of stem elongation in tulips is apparently controlled by auxins and gibberellins as well as ethylene, with the latter phytohormone inhibiting stem elongation (Saniewski and De Munk 1981; Okubo and Uemoto 1985). Stem elongation in tulips was also inhibited after inclusion of ethephon, an ethylene-releasing growth regulator in the vase solution. The inhibition of stem elongation by ethephon was fully reversed by silver thiosulphate, which blocks the ethylene receptors. This indicates that ethylene is the active compound (Nichols and Kofranek 1982; Van Doorn et al. 2011). The unfavourable elongation of the upper internodes of tulips is accentuated by warm temperatures and low light levels (Dole and Wilkins 2004).

Tulips typically do not respond well to the general range of postharvest floral preservatives (Salunkhe et al. 1990; De Hertogh and Le Nard 1993; Lukaszewska 1995; Dole and Wilkins 2004) thus, leaving the flower technologist with few options to exploit. In South Africa, it is commercial practice to pulse cut tulip stems with BVBPlus (http://www.chrysal.com/int/Home/Products/Post-harvest-Treatments/Chrysal-BVB-Plus.html) to minimize postharvest stem elongation and extend vase life (Personal communication, A van Wyk, 2012[41]). The active ingredients in BVBPlus include 19 $g.L^{-1}$ gibberellins (GA_{4+7}), 19 $g.L^{-1}$ benzyladenine (BA) and 480 $g.L^{-1}$ ethephon. BVBPlus has the advantages of reducing stem elongation in bunched tulips, and ensures that all stems remain at the same length in mixed bouquets (Chrysal 2008). In addition, BVBPlus is claimed to reduce damage caused by stem

[41] Prominent Tulips, Rawsonville, South Africa.

growth during transport or storage, reduce stem bending in tulips, allow for fewer bent stems during dry transport, prevents premature leaf yellowing, improves the quality of the flowers and leaves, extend the distribution and sales period possible, promises less waste and increases vase life of tulips considerably (Chrysal 2008). Apparently, for tulips treated with BVBPlus, a vase life guarantee of 7 days becomes within reach if an appropriate vase conditioning solution is also provided. When treated tulips are mixed with other flowers in a bouquet, the tulips will not grow out and easily match the vase life guarantee of the other flowers (Chrysal 2008). However, this postharvest treatment which adds considerably to the input costs of the value chain for the producer has not yet been evaluated for its efficacy as a postharvest protocol for cut tulips grown in warmer climates.

Physiological wilting, which results from the inability of cut flowers to rehydrate during the retail and vase life phase, in general greatly added to postharvest loss of ornamental stems (Salunkhe et al. 1990). Wilting is a major factor contributing to cut flower senescence and thus termination of vase life of cut flowers. Wilting is primarily the result of water stress. In cut flowers water potential, water uptake, water loss and water conductivity of the flower stems decline with time (Halevy 1976).

For many flower species (carnation and rose), flower longevity is reduced significantly by exposure to ethylene, due to accelerated senescence of flower parts, resulting in wilting or abscission of the petals, although this is cultivar dependent (Elgar et al. 1999). For a large number of ornamental species, blocking the plant’s response to ethylene is an efficient strategy to enhance the longevity of the flowers (Serek et al. 2006). However in most cases, the vase life of geophyte flowers ends with a collapse of the corolla, a process which does not seem to be associated with the action of ethylene. Inhibitors of the synthesis or action of ethylene have no effect on the longevity of these flowers, except where they inhibit abscission of petals or florets (Reid 1997).

Surprisingly, even though bulb flowers make up a considerable part of the cut-flower trade, there is relatively limited research reported on the senescence and the delay thereof of these flowers compared to more ethylene-sensitive flowers, such as carnations. Petal senescence in the bulb flowers such as *Gladiolus*, *Iris*, *Narcissus*, and *Tulipa*, is generally considered to be ethylene-insensitive, as application of exogenous ethylene indicated that the tepal and stamen fall were not influenced by exogenous ethylene (Jones et al. 1994). In addition, it has been shown that tulip showed no to little benefit when treated with the commonly used anti-ethylene postharvest treatment silver thiosulphate (STS) (Van Doorn et al. 2011). However, this observation in isolation does not necessarily indicate that ethylene has no effect, as natural ethylene production by the cut flowers could saturate the process. Also, the possibility cannot be precluded that ethylene may induce tepal abscission during an ethylene-sensitive window prior to the development of fully swollen buds (Sexton et al. 2000). Furthermore, little is known about the sequence of events controlling petal senescence in ethylene-insensitive flowers, particularly in commercially important bulb flowers such as *Tulipa, Iris, Gladiolus,* and *Narcissus* (Jones et al. 1994).

1-Methylcyclopropene (1-MCP) is considered the new generation anti-ethylene treatment for cut flowers. At standard temperature and pressure, 1-MCP is a gas with the formula of C_4H_6. 1-MCP is believed to occupy ethylene receptors such that ethylene cannot bind and elicit action (Blankenship and Dole 2003). 1-MCP blocks ethylene perception, regardless of the source (Serek et al. 1994). 1-MCP has proven to be effective in extending shelf-life and postharvest quality of many ornamental commodities (Blankenship and Dole 2003). More advantages of 1-MCP are that it is an environmentally friendly product and does not leave residues once applied, and is suitable for operations of any scale. Specific criteria for 1-MCP usage depends on factors such as commodity, cultivar, tissue type, development stage and/or maturity, time between harvest and treatment, and frequency of application (Serek et al. 1995; Yuan et al. 2010). Pre-treatment of the Oriental Lilies with 500 nLL^{-1} 1-MCP for 18 h at 25 °C completely inhibited the ethylene response, but did not prevent the normal senescence, wilting and abscission of the open flowers (Çelikel et al. 2002). When cut carnations and geraniums were treated with 50 nLL^{-1} of 1-MCP for 6 h, flowers were protected from ethylene for 4 and 1–2 days, respectively. However, the efficacy of 1-MCP is generally reduced when applied to overly mature or older tissue (Liou and Miller 2011).

In tulip bulbs, work done by De Wild et al. (2002) reported that ethylene-induced gummosis (secretion polysaccharides), weight loss and respiration were prevented by pre-treating bulbs with 1-MCP. 1-MCP at 0.2 μLL^{-1} protected bulbs against ethylene concentrations up to 200 μLL^{-1}. Under laboratory conditions, repeated applications of 1-MCP on a 12 day cycle protected tulip bulbs against ethylene applications given at 7 day intervals (Liou and Miller 2011). Parts of the tulip plant are clearly sensitive to ethylene and respond well to 1-MCP (Çelikel et al. 2002; Gude and Dijkema 2004; Liou and Miller 2011). It is therefore remarkable that no reports could be sourced concerning the use and efficacy of 1-MCP on tulip cut flowers.

1-MCP has been primarily developed to be a specific inhibitor of the ethylene receptor. However recent work has shown that, even though the ethylene production of non-climacteric grape berries is low, ripening of this fruit is impaired by the presence of 1-MCP (Tesniere et al. 2004). More research has shown that applications of 1-MCP as a postharvest treatment may be beneficial to extend the shelf life of many non-climacteric fruit and horticultural vegetative organs. Responses of non-climacteric fruit and vegetative organs to 1-MCP include delayed chlorophyll and protein degradation in coriander and parsley; delayed yellowing of broccoli and rocket leaves; firmness retention in cucumber and watermelon; suppressed pigment accumulation and softening of strawberry; suppressed degreening of 'Shamouti' orange and other citrus; reduced disorders in carrot and 'Iceberg' lettuce; and delayed lignin deposition and firmness increases in loquat (Huber 2008).

A short vase life of cut tulips, especially when forced hydroponically in warm climates, is currently the most important constraint in the successful production and marketing of this product (Personal communication, A van Wyk, 2012). The objective of this study was to evaluate the efficacy of commonly recommended postharvest ornamental cut flower treatments on cut tulips produced in hydroponics under warm climatic conditions. The hypothesis was that a postharvest pulse treatment with Chrysal BVBPlus would assist in minimizing stem elongation and thereby improve vase life of cut tulips, whilst 1-MCP would delay tepal senescence to improve vase life and a combination of the treatments would result in both minimum stem elongation and extended vase life.

Material and methods

Plant material

Cut tulips (*Tulipa gesneriana)* were grown in hydroponic trays using standard precooled procedures (De Hertogh and Le Nard 1993) at Prominent Tulips in Rawsonville (http://www.prominenttulips.co.za). Glasshouse temperature was controlled at 18±2°C and average relative humidity (%RH) was kept to approximately 65%. The four cultivars used were identified and selected according to results previously obtained by South African growers (Personal communication, A van Wyk, 2012). 'Deshima' and 'White Marvel' represented high performing cultivars, whilst 'Margarita' and 'Synaeda Orange' were considered poor performing cultivars under South African conditions (Figure 1). These flowers were harvested during the first week of February 2013 with bulbs attached at the commercial stage[42] and dry stored at 2°C overnight. During the early hours of the next morning (7:00 am) while temperatures were below 10°C, the flowers were then transported approximately 70 km to the Stellenbosch University Cut Flower Evaluation Laboratory. The trial was arranged in a complete randomized experimental design. On arrival, five bunches (replications) with six flowers each were carefully constructed for each cultivar. Bulbs were removed by dissecting the stem from the basal plate, so as to maximize the stem length. The 4 cultivars and 4 treatments yielded 16 treatment combinations, which were replicated 5 times, thus 80 bunches (experimental units) were monitored.

'Margarita'	'Synaeda Orange'	'White Marvel'	'Deshima'
Double Early Tulip	Lily-flowering Tulip	Triumph Tulip	Triumph Tulip

Figure 1: 'Deshima' and 'White Marvel' representing well performing tulip cultivars under South African conditions, whilst 'Margarita' and 'Synaeda Orange' represent poor performing cultivars. These cultivars were used in the evaluation of various postharvest treatments to extend vase life.

[42] A minimum stem length of 300 mm with healthy leaves and a well-developed flower with a note-worthy colour change.

Postharvest treatments

All postharvest treatments were applied one day after harvest, following the removal of bulbs. Three treatments and control were evaluated for efficacy in extending vase life of cut tulips.

Table 1: Different postharvest treatments and a control evaluated for efficacy in extending vase life of hydroponically grown cut tulips.

Control	BVBPlus	1-MCP	BVBPlus+1-MCP
Stems were placed in clean plastic buckets containing 1 L of tap water at room temperature (±20°C) for 4 hours where after stems were transferred to 2°C for an overnight period (±12 hours).	Stems were placed in clean plastic buckets containing a 0.2% $^{v}/_{v}$ BVBPlus (http://www.chrysal.com/int/Home/Products/Post-harvest-Treatments/Chrysal-BVB-Plus.html) solution at room temperature (±20°C) for 4 hours, where after stems were transferred to a 2°C overnight period (±12 hours).	Stems were placed in clean plastic buckets containing tap water, were placed in a sealed 4 m^3 incubator at room temperature (±20°C) and were fumigated for 4 hours with 1-MCP using Ethylene Buster®. To commence fumigation, one Ethylene Buster® tablet and two activator tablets were placed in the activator solution as recommended on the Ethylene Buster® Activator Kit product packaging (http://www.chrysal.com/int/Home/Products/Plant-Care/Chrysal-Ethylene-Buster.html). Thereafter stems were transferred to a 2°C overnight period (±12 hours).	Stems were placed in clean plastic buckets containing a 0.2% $^{v}/_{v}$ BVBPlus solution, were placed in a sealed 4 m^3 incubator at room temperature (±20°C) and were fumigated for 4 hours with 1-MCP using Ethylene Buster®. To commence fumigation, one Ethylene Buster® tablet and two activator tablets were placed in the activator solution as recommended on the Ethylene Buster® Activator Kit product packaging (http://www.chrysal.com/int/Home/Products/Plant-Care/Chrysal-Ethylene-Buster.html). Thereafter stems were transferred to a 2°C overnight period (±12 hours).

Retail and vase life

Retail and vase life evaluation was performed in a climate controlled room (Figure 2). Temperature was controlled at approximately 20°C, a relative humidity of approximately 60% was regulated using a humidifier and 15-25 $\mu M.m^2.sec^{-1}$ of light was provided with cool white fluorescent lamps for 12 hours per day.

Figure 2: Vase life tests were conducted in the Stellenbosch University Cut Flower Evaluation Laboratory in the Lombardi Building, Dept. Horticultural Sciences.

Following the postharvest treatment application and overnight cold storage at 2°C, the stems were subjected to a retail/shelf life simulation: For the retail phase, all bunches were placed in clean black plastic 3 L buckets containing tap water and Chrysal Clear Professional 2 T-bags (new generation) (http://www.chrysal.com/int/Home/Products/Transport-ampamp-Display-Solutions/Chrysal-Clear-Professional-2-T-Bag.html) for a period of two days and three nights as is commercial practice. Once this retail simulation was completed, each bunch of flowers was transferred to a 1 L cylindrical glass vase containing 0.5 L of standard vase life solution[43].

Data collection

Record of the stem length (mm) of each flowering stem was taken prior to the start of vase life to determine postharvest stem elongation. Vase life was monitored daily by scoring product quality of each vase out of a total of six as indicated in Table 2.

[43] Standard vase solution compromised of 1 sachet of Chrysal Universal Flower Food per 1 L of tap water (http://www.chrysal.com/int/Home/Products/Consumer-Flower-Food/Chrysal-Trend-Selection-liquid-Universal-flower-food.html)

Table 2: Product quality of each vase was scored daily until senescence according to a rating scale out of a total of six (Floral Solutions 2006).

Score	Appearance of flowers in vase
1	Very poor quality, very big quality problems, all consumers will discard the flowers
2	Poor quality, big quality problems, most consumers will discard the flowers
3	Reasonable quality, moderate quality problems, most consumers will not yet discard flowers
4	Reasonable quality, small quality problems, all consumers will not discard the flowers
5	Good quality, small quality problems, all consumers will not discard the flowers
6	Very good quality

Throughout the vase life the following parameters were monitored and documented: the vase life day on which each flower was removed from the vase, the vase life day on which the first flower was removed from each vase as well as the day on which 50% of the flowers were removed from each vase. Flowers were removed from the vase when tepals had completely senesced (withered) or petals abscised, leaves were completely yellowed, or stems had toppled over. On removal from the vase, stem length was again recorded to determine any possible stem elongation.

When all flowers were removed from a particular vase, the amount of vase solution used was recorded.

Statistical analysis

Data was analysed using ANOVA, and means compared with Fischer's LSD ($P<0.05$) using the statistical software Statistica 12 (Statsoft (SA) Inc., Tulsa, Oklahoma, USA).

Results and discussion

Vase life

Tulips have a disappointingly short vase life, despite the fact that tulips are considered ethylene insensitive. This negative postharvest characteristic is considered a major impediment in the value chain of this important and sought after floricultural product.

No significant interactions were found for vase life between the various cultivars and treatments evaluated (Table 3). There were no significant differences found between the efficacies of the different postharvest treatments to extend vase life of the specific cultivars evaluated (Table 3). Similarly, no significant interaction was found between treatment and cultivars for both parameters measured as presented in Table 4. Also, no significant differences could be detected for first day of flower removal from the vase, as well as the day when 50% of the flowers were removed from the vase (Table 4). For the treatment using Ethylene Buster® (1-MCP) results are consistent with the findings of Boontiang et al. (2010), who found that the interaction of different exposures of 1-MCP to four and eight hours had no effect on extending the flower longevity of two Siam Tulip species (*Curcuma alismatifolia* and *Curcuma aeruqinosa*), even though these flowers are considered ethylene sensitive. Similarly, Chutichudet et al.

(2011) and Macnish et al. (2000) found that 1-MCP had no effect on the vase life of Siam Tulip flowers or any of the native Australian cut flower species[44] evaluated. However, when broccoli florets as ethylene sensitive products were treated with 1-MCP the shelf life was extended to two times that of control florets (Sun et al. 2010).

Although tulip bulbs are sensitive to ethylene (Gude and Dijkema 2004), tulip tepals are not affected by exposure to ethylene or previous anti-ethylene treatments such as STS (Sexton et al. 2000). The lack of response to 1-MCP may be partly due to plant tissues varying in their ability to respond to 1-MCP (Blankenship and Dole 2003), however there is no published research available on the efficacy of 1-MCP on postharvest longevity of cut tulip flowers, nor is the mechanism by which ethylene affects tulips known (De Munk and Kamerbeek 1976). Further research is thus required to determine the effects of 1-MCP on the physiological characteristics of cut tulips, since tulip bulbs clearly benefit from anti-ethylene treatments (Gude and Dijkema 2004; Liou and Miller 2011). In addition other non-climacteric ethylene insensitive crops have been shown to benefit from anti-ethylene treatments (Tesniere 2004; Huber 2008).

The lack of BVBPlus to significantly affect tulip vase life is rather unexpected (Table 3 and 4) since previous research showed that BVBPlus significantly improved the vase life and postharvest quality of cut tulips (Chrysal 2008). Also, BVBPlus is recommended and sold as a commercial treatment internationally to specifically extend the vase life and improve the general postharvest quality of cut tulips (Chrysal 2008). Our results are, however, in accordance with work done by Halevy et al. (1966) where benzyladenine (a component of BVBPlus) stimulated respiration and accelerated senescence in leaf lettuce, which lead to the conclusion that BA cannot be considered a universal senescence inhibitor. Interestingly, although not significantly different, BVBPlus did provide the longest vase life (Table 3) in comparison to other treatments and the control used in this study. This benefit was however not retained when used in combination with Ethylene Buster®. The BVBPlus formulation includes 1.9 $g.L^{-1}$ gibberellins (GA_{4+7}), 1.9 $g.L^{-1}$ benzyladenine (BA) and 480 $g.L^{-1}$ ethephon (Personal communication, A van Wyk, 2012). Dole and Wilkins (2004) reported that BA slows down stem elongation whereas ethrel/ethephon has been shown to assist with reduction in stem elongation, whilst GA_3 enhances general longevity, although it may cause excessive stem elongation. However, when GA_3 is used in combination with ethrel/ethephon, the excessive elongation is eliminated, but the positive effects of GA_3 are negated.

The apparent positive result obtained by the BVBPlus, although not significant, leads to speculation that the dosage as recommended for tulips grown in cooler climate countries may not be optimal for South African grown cut tulips and requires further investigation in terms of a possible higher dosage for improved efficacy. The growth rate of plants is normally accelerated under the accumulation of more temperature degree units (Went 1953) and a higher respiration rate is measured at elevated temperatures, thus the physiology of warm-climate produced tulips might not be similar to that of tulips produced in cooler climates.

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[44] *Verticordia nitens*, *Ceratopetalum gummiferum*, *Cassinia adunca*, *Platysace lanceolata, Grevillea, Chamelaucium uncinatum, Leptospermum petersonii*, *Ozothamnus diosmifolius*, *Zieria cytisoides, Eriostemon scaber, Thryptomene calycina*, *Telopea*, *Leptospermum scopariu.*

Table 3: The mean vase life (days) of four tulip cultivars produced hydroponically under warm climatic conditions where after stems were treated with four different postharvest treatments prior to vase life evaluations.

Treatment		**Vase life (days)**	
Control		3.29	
BVBPlus		3.37	
Ethylene Buster®		3.23	
BVBPlus + Ethylene Buster®		3.15	
ANOVA	**F-value**	**Pr > F**	**Significance**
Vase life			
Treatment	1.100	0.3557	NS
Cultivar	33.276	<.0001	***
Treatment x Cultivar	0.950	0.4891	NS

* Significant at p=0.05, ** significant at p=0.01, NS not significant

Table 4: Effect of four postharvest treatments on the day of first flower removal and the day on which 50% of the flowers were removed from the vase for four tulip cultivars grown hydroponically under warm climatic conditions.

Treatment	**Day of first flower removal**	**Day that 50% flowers removed**	
Control	2.25	3.95	
BVBPlus	2.50	4.25	
Ethylene Buster®	2.35	3.80	
BVBPlus + Ethylene Buster®	2.55	3.95	
ANOVA	**F-value**	**Pr>F**	**Significance**
Day of first flower removal			
Treatment	0.58	0.59	NS
Cultivar	20.22	< 0.0000	***
Treatment * Cultivar	1.57	0.14	NS
Day that 50% flowers removed			
Treatment	0.59	0.62	NS
Cultivar	16.01	< 0.0000	***
Treatment * Cultivar	1.33	0.24	NS

* Significant at p=0.05, ** significant at p=0.01, NS not significant, significant interactions at p<0.05 are shown in red

There were significant differences found between the vase lives of the different cultivars (Table 5). Cultivars ‘White Marvel’ and ‘Deshima’ had mean vase lives that were more than 4.5 days, whereas cultivar ‘Synaeda Orange’ had a significantly shorter mean vase life of only 2.5 days. Cultivar ‘Synaeda

Orange' had a mean vase life that was significantly shorter than those of the other cultivars. 'Synaeda Orange' is a Lily Flowing tulip whereas the other cultivars are double-early and triumph tulips (International Flower Bulb Centre, http://www.bulb.com/ibc/us_en/publiek/collection.jsf/bulbs_gardening/spring-blooming-bulbs/tulipa). The shorter vase life of 'Syneada Orange' is most probably related to hereditary reasons. It is interesting to note also that 'Margarita', which is a double-early tulip, had a vase life that was shorter than that of the triumph tulip cultivars. Pasterkamp (1996), Aung et al. (1969) as well as Benschop and De Hertogh (1971) reported that the vase life of tulips is highly cultivar dependent. Similarly, it was reported that cup shaped (Triumph) tulips tend to have a longer vase life than either semi-cup or open flowers (Benschop and De Hertogh 1969). It is thus likely that triumph tulip cultivars are better adapted to warm climates; however this will need to be confirmed by further studies.

Table 5: The vase life (days) of four tulip cultivars produced under warm climatic conditions and exposed to four postharvest treatments prior to vase life evaluation.

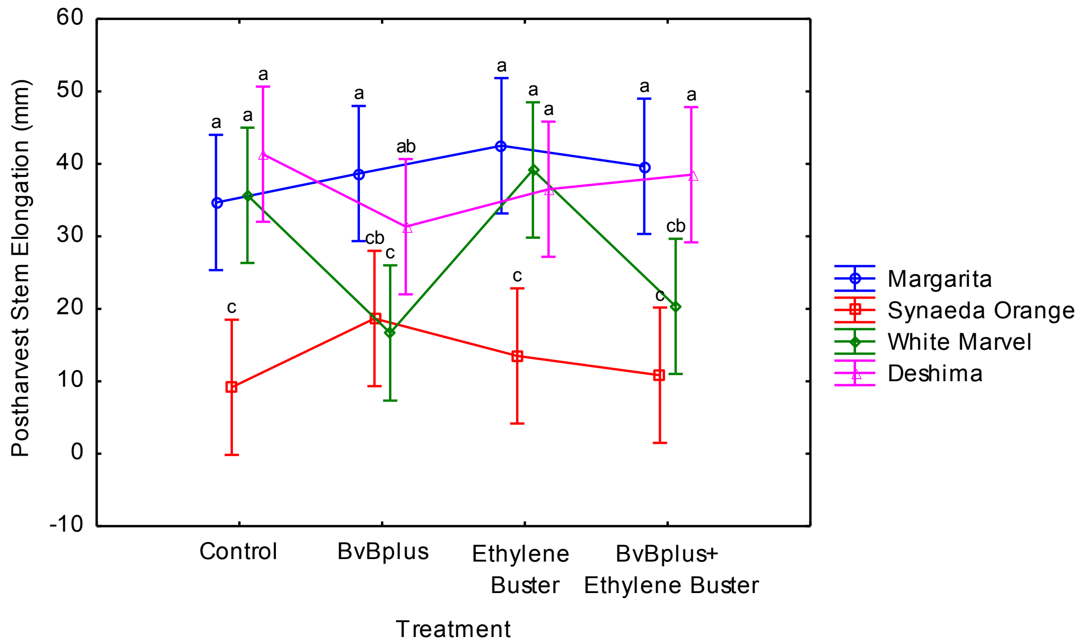
Cultivar	**Vase life (days)**	**Least significant differences (LSD) at p=0.05**
Margarita	4.35	b
Synaeda Orange	2.73	c
White Marvel	5.25	a
Deshima	4.83	ab

ANOVA	**F-value**	**Pr >F**	**Significance**
Vase life			
Treatment	1.100	0.3557	NS
Cultivar	33.276	<.0001	***
Treatment x Cultivar	0.950	0.4891	NS

* Significant at p=0.05, ** significant at p=0.01, NS not significant, significant interactions at p<0.05 are shown in red

Postharvest stem elongation

For postharvest stem elongation a significant interaction was found between the various postharvest treatments and cultivars evaluated (Figure 3). Both cultivars 'Deshima' and 'Margarita' did not respond to the various postharvest treatments, since no significant differences were obtained in postharvest stem elongation between the different treatments, whilst a comparative stem elongation was recorded between these respective cultivars. These two cultivars also exhibited significantly more postharvest stem elongation than 'Synaeda Orange' and to a lesser extent more stem elongation than 'White Marvel'. However, both 'White Marvel' control stems and stems treated with Ethylene Buster® resulted in significantly more postharvest stem elongation when compared to stems treated with either BVBplus or the combination of Ethylene Buster® and BVBplus. More pronounced stem elongation in the first mentioned treatments can most likely be ascribed to the absence of ethephon in these treatments as ethephon has been shown to inhibit stem elongation (Sanlewski and Kawa-Miszczak 1992). Since the mechanism of Ethylene Buster® (1-MCP) is exclusively to block ethylene receptors, regardless of the source (Serek et al. 1994), thereby preventing ethylene (or ethephon) perception which is required to elicit action (Blankenship and Dole 2003), any possible ethylene present in the atmosphere would have been unable to bind to stem receptors treated with Ethylene Buster® and thus would have effectively prevented any ethylene-mediated effect on stem elongation. For 'White Marvel', when stems were treated with the combination treatment of BVBPlus and Ethylene Buster® stem elongation was significantly less compared to that of stems treated with Ethylene Buster® alone, but comparable to that of stems treated with BVBplus. This result suggests that the ethylene action of BVBplus could not be reversed by the rate and concentration of 1-MCP applied as Ethylene Buster® in the study. 'Synaeda Orange' stems resulted in significantly less elongation in comparison to the other cultivars, although the stem elongation did not differ significantly between treatments.



ANOVA	F-value	Pr >F	Significance
Postharvest stem elongation			
Treatment	1.62	0.1932	NS
Cultivar	25.41	< 0.0000	***
Treatment x Cultivar	2.04	0.0484	*

* Significant at p=0.05, ** significant at p=0.01, NS not significant, significant interactions at p<0.05 are shown in red

Figure 3: Significant interaction found between mean postharvest stem elongation and four cut tulip cultivars evaluated. Letter(s) above bars indicate least significant differences (LSD). Treatments with different letter symbols differ significantly (P<0.05).

Vase solution uptake

The most common reason for termination of vase life of most cut flowers is wilting (Halevy 1976). According to Benschop and De Hertogh (1971) the overall pattern of water (or vase solution) uptake by cut tulips is similar for most cultivars, but the total quantity taken up will vary with cultivar. It is reported that initially (during the first hour) water is taken up at a rapid rate, and then followed by a slow decline and after about 5 hours a steady rate of water uptake is observed. A clear drop in water uptake can be noted 24 hours prior to the end of vase-life. No significant interactions were found between the various treatments and cultivars evaluated for vase solution used (Table 6). Postharvest treatments did not significantly affect the volume of vase solution taken up per vase at p<0.05, although differences are significant at p<0.1 and post-hoc tests indicate a trend that BVBPlus differs from the control and Ethylene Buster®. Biologically, significant trends suggest that tulips treated with BVBPlus show the highest vase solution uptake. Similarly, earlier trends (Table 3) indicate that tulips treated with BVBPlus had the longest vase life, although not significantly so. The possible improved vase solution uptake by tulips treated with BVBPlus may be due to the presence of gibberellins in the BVBPlus solution. Gibberellins are known to improve the water balance of other cut flowers and also in cut tulips. Emongor (2004) reported that gibberellic acid (GA_3) reduced water loss (transpiration) in cut gerberas by significantly decreasing the cell water potential, where after as a result of the decreased water potential, water entered more rapidly, causing cell expansion and diluting the sugars in the tissues. Thus similarly, the gibberellins (GA_{4+7}) in BVBPlus in this study may also have decreased the water potential of cells to allow for enhanced solution uptake, explaining the observed trend that tulips treated with BVBPlus used more vase solution and had a longer vase life than treatments that did not contain BVBPlus.

Table 6: Vase solution uptake (ml) per vase of tulips that were grown hydroponically under warm climatic conditions and treatment with four postharvest treatments.

Treatment	**Vase solution used (ml)**	**Least significant differences (LSD) at p=0.05**
Control	151.00	b
BVBPlus	191.75	a
Ethylene Buster®	159.25	b
BVBPlus + Ethylene Buster®	167.00	ab

ANOVA	**F-value**	**Pr >F**	**Significance**
Vase Solution Used			
Treatment	2.50	0.0672	NS
Cultivar	6.20	0.0009	***
Treatment * Cultivar	1.66	0.1135	NS

* Significant at p=0.05, ** significant at p=0.01, NS not significant.

When the vase solution uptake was compared between the different cultivars, significant differences between cultivars emerged (Table 7). The cultivar 'White Marvel' used significantly more vase solution compared to the cultivars 'Margarita' and 'Syneada Orange'. Since vase solution uptake is normally terminated 24 h before the termination of vase life (Benschop and De Hertogh 1971), a longer vase life, would imply more vase solution used since an active metabolism means intact physiological processes such as transpiration. If a cultivar had a superior water balance, allowing it to transpire more effectively compared to other cultivars, it may have in fact contributed to this cultivar actually having a longer vase life. These cultivar differences for vase solution uptake are in accordance with the findings of Benschop and De Hertogh (1971).

Table 7: Vase solution uptake (ml) per vase of four tulip cultivars that were grown hydroponically under warm climatic conditions.

Treatment	Vase Solution Used (ml)	Least significant differences (LSD) at p=0.05
Margarita	151.50	bc
Synaeda Orange	139.50	c
White Marvel	202.00	a
Deshima	176.00	ab

ANOVA	F-value	Pr >F	Significance
Vase solution used			
Treatment	2.50	0.0672	NS
Cultivar	6.20	0.0009	*
Treatment x Cultivar	1.66	0.1135	NS

* Significant at p=0.05, ** significant at p=0.01, NS not significant.

Conclusions

South African cut tulip producers largely make use of BVBPlus as a postharvest treatment with the expectation of minimizing the rate of senescence and sustaining the quality of their product. This postharvest treatment adds, to a certain degree, to the already high costs of producing quality cut tulip flowers (Personal communication, A van Wyk, 2012). In order to maximize profits, costs need to be kept at a minimum and all inputs used should be justified in terms of their significant impact on the quality of the end product. It is thus imperative to determine the efficacy of postharvest treatments in order to decide whether to include them in the postharvest treatment program of South African produced cut tulips.

Evaluation of the four cut tulips cultivars, 'Margarita', 'Synaeda Orange', 'White Marvel' and 'Deshima', elucidated that the use of BVBPlus at the standard dosage recommendations does not significantly influence the vase life, stem elongation or vase solution uptake of cut tulip flowers that were forced hydroponically in a warm climate. Trends were, however, observed which suggest that cut tulips treated with BVBPlus had the longest vase life, minimum postharvest stem elongation and these flowers took up more vase solution when compared to other treatments and the control. Conceivably, in warm climates higher concentrations of BVBPlus need to be applied as plants grow, develop and respire faster at higher temperatures (Went 1953). There were significant differences found between cultivars for all parameters measured. 'White Marvel' resulted in the longest vase life, the least stem elongation and had the highest uptake of vase solution. These differences are most probably the result of genetic differences between cultivars and could be useful in determining which cultivars will be more suitable for forcing in warm climates.

Further research should be focused on testing the efficacy of BVBPlus on the vase life of cut tulips in warm climates, using more cultivars and possibly higher concentrations as well as longer durations of application, within the current recommendations by Chrysal (2008) no more than 5 ml of BVBPlus should be applied per litre of water for no more than 10 hours, 2 ml BVBPlus for 10-48 hours and only 1 ml should be used when pulsing more than 48 hours. Alternatives for future research are to evaluate the efficacy of using postharvest pulse treatments of trehalose[45] and chloramphenicol[46] (CAP) and postharvest foliar applications of glycine-betaine to prolong the vase life of cut tulips produced hydroponically in warm climates. Postharvest pulse treatments with 50 mM trehalose in combination with 50 μM CAP were found to play an important role in prolonging tulip vase life, although the mechanism of action remains unknown (Iwaya-Inoue and Takata 2001). The use of 0.5mM glycine-betaine as a postharvest foliar application was shown to delay senescence of tulips (Somersalso et al. 1995). A better understanding of the postharvest biology of cut tulips produced hydroponically under warmer climates will enable the development of suitable postharvest treatments to ensure a high quality product for the export market.

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[45] A nonreducing disaccharide consisting of two α-[1, 1]-linked glucose units.
[46] Inhibits protein biosynthesis in prokaryotic cells and reduces bacterial growth

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6. Summary and general conclusions

The South African horticultural sector is developing fast in order to supply both domestic and international markets. Technological advances are necessary in the entire value chain to further improve aspects such as production, product quality and logistics. Due to the rising costs of many inputs such as irrigation water, energy and fertilizers, the sector must perform more efficiently and sustainably in order to remain competitive in the consumer markets.

While the floriculture retail is for ever seeking new exciting products to stimulate the market, firm favourites with both florists and consumers such as roses, chrysanthemum and definitely tulips, remains corner stone crops for this industry. Recently, major shifts in the world economy, societies and technology have led to dramatic changes in the floriculture industry, especially with regards to the development of new production centres outside the traditional (Northern Hemisphere) bulb producing regions, such as Latin America, Asia and to a limited extent, Africa. Despite harsh economic conditions, South Africa is currently experiencing a growing domestic market for cut flowers, especially with regard to speciality products. In addition, if quality cut flowers can be produced, South Africa has the advantage of being in the alternative season to that of Europe and North America, in order to complement the supply chain for year-round availability of floral products. Good infrastructure, the availability of labour as well as an abundance of natural resources, such as high quality water and sufficient sunlight together with an established export market through the fynbos sector are further advantages which South African tulip producers can exploit in order to be competitive globally.

Competitive tulip production for the global market relies largely on cutting edge technology to provide both bulb production and forcing conditions which will ensure quality cut flower stems with an extended vase life. Earlier research mainly focussed on optimum environmental conditions, mostly in soil, for growth in temperate, Northern Hemisphere countries, such as the Netherlands, with the result that very little is known about specific cultivation requirements for cut tulip production under warm climatic conditions, such as in South Africa.

Year round cut tulip production is limited in South Africa, mainly due to supra-optimal climatic conditions in summer which would then require expensive climate control to produce quality cut tulips. A further limitation to producing year-round quality cut tulips in South Africa is the high cost of importing quality bulbs, from either the Netherlands or Chile. Transportation of these bulbs by sea freight may further introduce risks such as ethylene exposure through *Fusarium* infections or inappropriate temperature storage regimes. This may lead to substandard bulb quality which, together with bulbs which are physiologically older, may offer challenges to ensure that the occurrence of physiological disorders is minimized. Physiological disorders can be avoided and quality tulips can be produced by optimizing cultivation aspects such as nutrition, cultivar selection as well as postharvest treatments. Thus, in order for cut tulip production in South Africa to advance, scientifically based research is required to develop viable cultivation techniques specifically adapted to our local production conditions.

The aim of this study was therefore; to elucidate some of the cultivation aspects of producing quality cut tulips hydroponically under warm climatic conditions. A series of experiments were conducted at Welgevallen Experimental Farm at the University of Stellenbosch during 2012 and 2013 to investigate the effects of nutrient solution composition, various foliar fertilizer sprays and postharvest treatments on the production of quality cut tulips.

Nutrition

Correct fertilization of tulips is important in order to produce quality flowers. The use of hydroponics specifically allows the accurate control of plant nutrient management. Hydroponic production of tulips is also clean and eliminates the risk of soil-borne diseases. In two experiments four nutrient solutions, namely "Current SA", "Standard Steiner", "Europe and "Europe+NH_4^+", and four cultivars, namely 'Leen van der Mark', 'Jan van Nes', 'Royal Virgin' and 'Ill de France' were evaluated for their effect on the production of quality cut tulips using early- and late-forcing bulbs.

The scape growth of hydroponically forced cut tulips was not significantly influenced by nutrient solution composition. Our results suggest that tulip bulbs contain sufficient reserves for scape growth so that nutrient solution composition has a minimal impact on cut tulip scape growth, but further studies will be required to confirm this finding. Nutrient solution did not have a significant effect on postharvest stem length, fresh weight or dry weight, but had a significant influence on leaf area. It was found that "Standard Steiner" and "Europe" produced plants with the largest leaf areas. Although leaves are part of the final product when marketing cut tulips, no published research is available with regards to minimum leaf area required for quality tulips as the domestic market in South Africa only stipulate that tulip leaves should be green and healthy (Personal communication, C Coetzee, 2012[47]). It was found that for early-forcing bulbs the nutrient solution "Europe" produced tulips with a significantly longer vase life than other nutrient solutions, whereas for late-forcing bulbs the nutrient solution "Standard Steiner" produced tulips with a significantly longer vase life than any of the other nutrient solutions. No correlations were found with vase life and any other parameters evaluated. A trend suggests that nutrient solutions "Standard Steiner" and "Europe" produced cut tulips of the highest quality.

There were significant differences found in scape growth between the various cultivars evaluated. It was found that for early-forcing bulbs the cultivars 'Leen van der Mark' and 'Ill de France' yielded significantly more scape growth than 'Jan van Nes' and 'Royal Virgin', whereas for late-forcing bulbs it was found that 'Leen van der Mark' and 'Jan van Nes' yielded significantly more scape growth than 'Ill de France' and 'Royal Virgin'. 'Leen van der Mark' resulted in the longest stem length and greatest fresh weight of all the cultivars evaluated. It was established that for early-forcing bulbs 'Leen van der Mark' and 'Royal Virgin' resulted in a significantly longer vase life than 'Jan van Nes' and 'Ill de France'. For late-forcing bulbs 'Leen van der Mark' had vase life that was significantly longer than 'Jan van Nes' and 'Ill de France', but was similar to that of 'Royal Virgin'. In general, our study found the cultivar 'Leen van der

[47] Woolworths, Cape Town, South Africa.

Mark' to show reasonably robust growth when forced hydroponically under warm climatic conditions, both when using early- and late-forcing bulbs and that it delivered cut tulips of sound quality and acceptable vase life.

Scape growth of cut tulips was significantly different between early- and late-forcing bulbs. Late-forcing bulbs resulted in much faster scape growth in the greenhouse, but did not result in more overall growth. Early-forcing bulbs resulted in having significantly longer stems, significantly larger leaf areas and significantly greater fresh and dry weights than late-forcing bulbs. Having said this, late-forcing bulbs resulted in a vase life that was significantly much longer than early-forcing bulbs. In order to produce cut-tulips year round one cannot discriminate between early- and late-forcing bulbs. Nevertheless, it is important to note the differences in quality that can be achieved using bulbs of a different physiological age, especially since the consumer market generally demands a consistent quality.

Future research can be focused on evaluating the effect of nutrient solutions "Standard Steiner" and "Europe" on the quality and vase life of cut tulips produced hydroponically in warm climates, but concentrating specifically on using different EC's and including a wider range of cultivars. Additionally, evaluation of the effects of these nutrient solutions in combination with foliar fertilizer sprays on the quality of cut tulips may produce promising results.

Foliar nutrition

Tulips have inherently a relatively short vase life and postharvest physiological disorders such as stem topple may further decrease this time. In the next experimental trial three foliar sprays, namely "$CaNO_3$", "CalTrain" and "NonTox Silica" were evaluated for their effect on the occurrence of stem topple and vase life of two cut tulip cultivars, namely 'Jumbo Pink' and 'Strong Gold'.

The vase life of the cut tulip cultivar 'Strong Gold' was significantly increased by the application of the calcium containing foliar spray treatments, "$CaNO_3$" and "CalTrain", while 'Jumbo Pink' mostly benefitted from the foliar treatment of "$CaNO_3$" only. In general, plants treated with foliar fertilizer treatments containing calcium exhibited vase lives that were on average 2 days longer than the control. The mean vase life differed significantly between the cultivars, with 'Strong Gold' having a significantly longer vase life than 'Jumbo Pink'. The percentage occurrences of stem topple differed significantly between the various treatments. It was found that the Ca-enriched foliar treatments of "$CaNO_3$" and "CalTrain" significantly reduced the percentage occurrence of postharvest stem topple compared to the control which received no foliar spray. Since stem topple has been ascribed to a lack of calcium to provide strength to plant cell wall structures, confirmation by our results was not unexpected.

Thus the foliar sprays containing calcium, "$CaNO_3$" and "CalTrain", proved to a greater and lesser extent effective for 'Strong Gold' and 'Jumbo Pink' respectively at extending the vase life and reducing the occurrence of postharvest stem topple of cut tulips. Future research should be focused on evaluating the use of boron alone or in combination with $CaNO_3$ or other calcium foliar sprays formulations for increased efficacy in reducing stem topple and increasing vase life, especially since the soil application of boron has been shown to increase the vase life of 'Apeldoorn' tulips.

Postharvest treatments

Cut flower quality of consistent excellence has become a consumer expectation and prosperous producers are compelled to strive to accomplish this. South African cut tulip producers largely make use of BVBPlus as a postharvest treatment, with the expectation of minimizing the rate of senescence and sustaining the quality of their product. However, this postharvest pulse treatment adds to a certain degree to the already high costs of producing quality cut tulip flowers. In order to maximize profits, costs need to be kept at a minimum and all inputs used should be justified in terms of their significant impact on the quality of the end product. It is thus imperative to determine the efficacy of postharvest treatments in order to decide whether to include them in the postharvest treatment program of South African produced cut tulips.

Evaluation of four cut tulips cultivars, 'Margarita', 'Synaeda Orange', 'White Marvel' and 'Deshima', elucidated that the use of BVBPlus at the standard dosage recommendations does not significantly influence the vase life, stem elongation or vase solution uptake of cut tulip flowers that were forced hydroponically in a warm climate. Trends were however observed and suggest that cut tulips treated with BVBPlus had the longest mean vase life, minimum postharvest stem elongation and these flowers took up more vase solution when compared to other treatments and the control. Plausibly, under warmer climatic conditions, higher pulse concentrations of BVBPlus may be required. There were significant differences found between cultivars for all parameters measured. 'White Marvel' displayed the longest vase life, the least stem elongation and had the highest uptake of vase solution. These differences are most probably the result of genetic differences between cultivars and could be useful in determining which cultivars will be more suitable for forcing in warm climates.

Further research should be focused on testing the efficacy of BVBPlus on the vase life of cut tulips in warm climates, using more cultivars and possibly higher concentrations as well as longer durations of application, within the current recommendations by Chrysal (2008). Alternatives for future research are to evaluate the efficacy of using the postharvest pulse treatments of trehalose and chloramphenicol (CAP) or possibly postharvest pulse treatments of glycine-betaine as alternatives to prolong the vase life of cut tulips produced hydroponically in warm climates.

A better understanding of the exact nutrient requirements, as well as finding the optimal approach to application of these nutrients, whether hydroponically or foliar or a combination, is fundamental such that tulip plants can effectively utilize the nutrients supplied in order to maximize production and economic reward. Comprehension of the postharvest biology of cut tulips produced hydroponically under warmer climates will enable the development of suitable postharvest treatments to ensure a high quality product for the local and export market.

This research is a pioneer report on the key agronomical aspects of the hydroponic cultivation of cut tulips in South Africa and aims to serve as a basis for future research, and ultimately to support successful commercial cultivation of tulips on a larger scale in South Africa. Cut tulips have unquestionable commercial potential in South Africa. This potential can only be unlocked through in depth knowledge of the cultivation aspects together with the postharvest biology of cut tulips as produced hydroponically under warm climatic conditions in order to ensure the advancement of cut tulip production in South Africa, both for the domestic and international floricultural market.

Appendix A

agriculture,
forestry & fisheries

Department:
Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

Directorate Plant Health and Quality

Permit No. **P0051164**

PERMIT FOR THE IMPORTATION OF CONTROLLED GOODS

In terms of the provisions of section 3(1) of the Agricultural Pests Act, 1983 (Act 36 of 1983) and subject to the conditions stated here under, authorisation is hereby granted to-

PROMINENT TULIPS (PTY) LTD **Tel No: 023 346 1099**

P.O. BOX 300
RAWSONVILLE
6845

to import into the Republic the following controlled goods **BULBS FOR PLANTING**

TULIPA SPP **2000000 BULBS**

Name and address of foreign supplier **VARIOUS SUPPLIERS/COUNTRIES**

Conditions **1. AS ATTACHED**

Port of Entry : **CAPE TOWN HARBOR**
CAPE TOWN INTERNATIONAL AIRPORT

Import authorized from **2012/01/12** TO **2013/01/31**

IMPORTANT : This permit does not exempt the holder from the provisions of any other Act, ordinance or agreement

DEPARTMENT AGRICULTURE, FORESTRY AND FISHERIES
DIRECTORATE PLANT HEALTH
2012 -01- 13
DIRECTORATE PLANT HEALTH
Private Bag X14 GEZINA 0031

....
Date

....
Executive Officer

Reference Number **2/12/68**

INQUIRIES : TEL.: (012) 319 6102 (Jeremiah Manyuwa) **FAX: (012) 319 6370**

***TULIPA* SPP.** **TULIPS** **LILIACEAE**

AD HOC for THE NETHERLANDS & NEW ZEALAND

BULBS (May have sprouted up to 2 cm)

2002-06-12

1. Additional declaration on the phytosanitary certificate that -

1.1 the place of production is free from –
   - (a) *Botrytis tulipae*
   - (b) *Nectria inventa*
   - (c) *Phytophtora erythroseptica*
   - (d) *Puccinia prostii*
   - (e) *Puccinia tulipae*
   - (f) *Rhizoctonia tuliparum*
   - (g) *Ustilago heufleri*

   OR

   that the parent plants were inspected and found free from these organisms.

1.2 the place of production is free from -
   - (a) *Phymatotrichopsis omnivora* [Syn. *Phymatotrichum omnivorum*]

1.3 the consignment was inspected and found free from-
   - (a) *Rhyzoglyphus fumouzi* [Acaridae]
   - (b) *Rhyzoglyphus narcissi* [Acaridae]
   - (c) *Hepialus lupulinus* [Hepialidae]
   - (d) *Phenacoccus avena* [Pseudococcidae]

1.4 the consignment is free from unsterilised growing medium (including soil particles);

2. A random 2% sample of the consignment shall be drawn (to a maximum of 600 bulbs per consignment), at the port of entry and tested for:
   - (a) *Tobacco rattle tobravirus*
   - (b) *Tomato black ring nepovirus*
   - (c) *Tomato bushy stunt tombusvirus*
   - (d) *Ditylenchus dipsaci*
   - (e) *Ditylenchus destructor*

The consignment may not leave the importers premises during the testing period. It may only be planted /distributed/removed from the importers premises once the consignment tested free from the listed pest.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES
DIRECTORATE PLANT HEALTH
2012 -01- 13
DIRECTORATE PLANT HEALTH
Private Bag X14 GEZINA 0031

TULIPA SPP.	TULIPS	LILIACEAE

BULBS (May have sprouted up to 2 cm)

2001-01-16

1. Additional declaration on the phytosanitary certificate that -

1.1 the country of production is free from –

(a) *Tobacco rattle tobravirus*
(b) *Tomato black ring nepovirus*
(c) *Tomato bushy stunt tombusvirus*
(d) *Ditylenchus destructor*
(e) *Ditylenchus dipsaci*

OR

that the consignment was laboratory tested and found free from these organisms.

1.2 the place of production is free from –

(a) *Botrytis tulipae*
(b) *Nectria inventa*
(c) *Phytophtora erythroseptica*
(d) *Puccinia prostii*
(e) *Puccinia tulipae*
(f) *Rhizoctonia tuliparum*
(g) *Ustilago heufleri*

OR

that the parent plants were inspected and found free from these organisms.

1.3 the place of production is free from -
(a) *Phymatotrichopsis omnivora* [Syn. *Phymatotrichum omnivorum*]

1.4 the consignment was inspected and found free from-
(a) *Rhizoglyphus fumouzi* [Acaridae]
(b) *Rhizoglyphus narcissi* [Acaridae]
(c) *Hepialus lupulinus* [Hepialidae]
(d) *Phenacoccus avena* [Pseodococcidae]

1.5 the consignment is free form unsterilized growing medium (including soil particles).

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES
DIRECTORATE PLANT HEALTH
2012 -01- 13
DIRECTOR PLANT HEALTH

agriculture,
forestry & fisheries

Department:
Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

DIRECTORATE: PLANT HEALTH

GENERAL INFORMATION TO IMPORTER/PERMIT HOLDER/AGENT

AGRICULTURAL PESTS ACT, 1983 (ACT NO. 36 OF 1983)

Subject to the provisions of section 3 of the Agricultural Pests Act, the importation of plants, plant products and other controlled goods is subject to a permit.

A copy of the permit and conditions should be communicated to the foreign supplier, by the importer/permit holder/agent.

The National Plant Protection Organization (NPPO) of the exporting country must issue a phytosanitary certificate, complying with the conditions of the South African permit. Each consignment must be accompanied by an original phytosanitary certificate.

Should the NPPO of the exporting country not be able to comply with the conditions of the permit, export cannot proceed. For assistance in this regard, the importer/permit holder should contact this Directorate.

Controlled goods can only be imported through a prescribed port of entry, except where determined otherwise by the Executive Officer.

On arrival, each consignment with relevant documentation must be presented (by the importer/permit holder/agent) to the Executive Officer for inspection at the port of entry. Goods may not be removed from the port of entry without the written authorization of the Executive Officer.

Please note:

(i) where any other place than the port of entry has been determined or when goods are imported via a courier service, the importer/permit holder/agent must on arrival, present the goods to the Executive Officer;

(ii) If brought in per passenger, the material must first be declared at the customs entry control point before presenting it to the Executive Officer. The red line to be taken at the customs control point.

Please take note of the expiry date of a permit. A permit expires on the date indicated on the permit. Should you wish to proceed with a similar import, please apply at least 30 days prior to the expiry date of the permit, for a new permit.

Please accept the above as a guideline, but take note that all stipulations of the Agricultural Pests Act should be complied with. Authorization in terms of this Act does not exempt the holder from the provisions of any other Act, ordinance or agreement.

Other Acts that may be relevant: Plant Improvement Act & GMO Act.

For assistance please contact:

Permit Office:	Mr Jeremiah Manyuwa	Tel: (012) 319-6102
	Ms Anita Snyman	Tel: (012) 319 6396
	Mr. Benie Kgomo	Tel: (012) 319 6130
	Ms Shashika Maharaj	Tel: (012) 319 6383
		Fax: (012) 319-6370

Appendix B

The following are the guidelines as to the specifications required for cut tulips by South African Retailer, Woolworths:

1. No flowers blown before sell by date
2. Leaves green and healthy
3. No visible signs of disease or insect damage
4. No physical damage or bruising
5. Cut stage – cut stage 2 colour visible
6. Stem length min 40 cm
7. Weight per stem 40 g
8. Storage conditions < 5°C
9. Storage life 2 nights
10. Shelf life in stores 2 nights
11. Guarantee 5 days
12. Post-harvest treatment BVBPlus or RVB
13. Transit solution: t/bag
14. Packing: clear sleeve
15. Rejection criteria:
    a. No moulding on leaves
    b. No drooping of stems

WOOLWORTHS

Cobus Coetzee
Technologist: Horticulture

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Cell 0837019989
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