EFFECT OF DAY AND NIGHT TEMPERATURE ON POLLEN CHARACTERISTICS, FRUIT QUALITY AND STORABILITY OF TOMATO.

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ABSTRACT

Tomatoes (*Lycopersicon esculentum*) were grown to extremely high day and low night temperatures (day/night temperatures of 27/14˚C and 30/11˚C) with constant average temperature. This was done by keeping greenhouse closed during daytime to utilize heating from solar radiation to prevent the negative effect of low night temperature. Tomato plants of cultivars Capricia, Mecano and Cederico were grown under low night temperature and high day temperature and flowers were analyzed one and four day after flower opening. This showed positive effect on pollen production and pollen germination percentage when compared with normal growing day/night temperature conditions (24/17˚C). Varieties show similar effect on pollen production and viability. High day temperatures treatment prevents the effect of lower night temperature in pollen quality and viability which also showed higher performance than the normal growing temperature conditions. At harvest, increase in temperature difference from 24/17˚C to 24/17˚C had positive effect on fruit firmness and decrement on further increase in temperature difference. Furthermore, dry matter content, soluble solids and titrable acidity is found to be decreased with increase in temperature range. pH content was higher in tomatoes grown in higher temperature regimes. Significant difference in firmness, dry matter content, soluble solids, titrable acidity and pH could be seen in different varieties and Capricia had shown better quality characteristics followed by Mecano and Cederico respectively. Storing tomatoes at 13˚C could not show predominant effect on dry matter, soluble solids, titrable acidity and pH but firmness shows negative effect during storage with increase in preharvest day and night temperature difference treatments. The results presented could support the development of novel procedure for producing greenhouse tomatoes with minimum energy consumption for heating during winter nights.

Key words: Greenhouse tomatoes, Day temperature, Night temperature, Average temperature, Pollen production, Pollen germination, Fruit quality, Storability, Energy saving

CONTENTS

1. INTRODUCTION

Tomato is a widely consumed vegetable. It is used in both fresh and processed purpose. Tomatoes cannot be cultivated the whole year in the temperate regions because of the freezing temperature in periods (E.Heuvelink 2005). In greenhouses, tomatoes can be grown whole year due to controlled climatic conditions. So in temperate countries like Norway greenhouse production is efficient for tomatoes. Temperature is an important environmental factor in greenhouses, which regulates many aspects of growth and developmental processes in plants. The reproductive parts of the plants are more vulnerable to higher temperatures (32/26˚C day and night) rather than its vegetative parts (Sakata et al. 2000). Tomato is sensitive to temperature in different physiological aspects (Picken 1984) and also one determining factor of floral quality. Pollen viability is very important from agriculture perspective as well as from breeders view since pollen should be viable during fertilization for proper fruit set.

Pollination is one of the most important processes influenced by temperature. Tomato is self pollinated plant. It is very difficult to pollinate in tomato flowers because pollen has to move through small tube to reach stigma for fertilization. The distance is also large between anther and stigma which results in parthenocarpic fruit (Aloni et al. 1999). Tomato fruit is a living part, it continues to respire through its life which results in degradation of the quality with increases towards the senescence (Aguayo et al. 2004). Tomato fruit quality is affected by pre harvest factors followed by post harvest factors. Tomatoes grown at higher day temperatures (>24˚C) as well as lower night temperatures (<18˚C) have negative effect on fruit quality during harvest and also affect post harvest quality (Ohio Vegetable Production Guide. 2010). Grower should also consider how the tomatoes are grown especially climatic factors before determining its final quality. A full environmental control in glasshouse is high energy consuming task. Energy saving can be done by utilizing natural sunlight and changing some set points of temperature. For maximum energy saving and optimal crop growth, climate regimes should be designed especially for this type of greenhouses (Bot 2001). Energy saving can be done by lowering the heating set point when heat losses are higher at night and then increasing set point when losses are lower in greenhouse production (Bailey & Seginer 1988).

This study aims to find the effect of different day and night temperature regimes on quantity and viability of pollen. It also focuses on temperature regime effect on fruit quality of tomatoes. Here we are imposing high day temperature conditions by exploiting solar radiation which

prevents the adverse effect of low night temperature (LNT) on reproductive development. Primarily this research was conducted to find if there is some negative effect on pollen quantity and quality followed by fruits along with post harvest quality with the increase in day temperature and decrease in night temperature. Here, maximum utilization of solar radiation and trying to save some energy in greenhouses used to grow tomatoes.

2. LITERATURE REVIEW

Depending on the developmental stage the optimum mean daily temperature of tomato is 21-24°C (Geisenberg & Stewart 1986).With the increase in temperature, morphology of flower as well as different components of pollen is changing which may alter pollen quality to the reverse direction. Not only the day and night temperature but also the average temperature had effective role in determining the quality of pollen quantity and quality. Tomato production is mostly limited by day temperature rather than night temperature (Moore and Thomas, 1952). Energy saving can be done by increasing day temperature by sunlight and lowering the night temperature. To maintain temperature upto higher set point more CO_2 can be used to manipulate the plant growth and development during the winter season(Ho 2001). The low fixed set points for relative humidity control also used in common practice (80–85% RH) counteract the positive effect of heating on energy consumption. Vents will open at lower temperatures than required for heating will decrease RH or both. This problem will be even more pronounced in highly insulated greenhouses. The effect of higher light also reduces the effect of higher temperature. Presence of adequate amount of light, the effect of higher temperature can be balanced (Atherton & Rudich 1986).

The same ambient temperature may affect, for instance, the physiological processes of different organs in a plant differentially, while the temperature of different organs of the same plant in the same ambient temperature may also be different. Therefore, the control of temperature in the glasshouse should be based on the temperature response of specific organs relevant to the yield or quality concerned, than the ambient temperature in the glasshouse (Langton et al. 2000). Temperature affects different process of the flower and fruit development including meiosis on pollen and ovule mother cells, position of stigma, pollen productivity, pollen germination, growth of ovule, fertilization as well as growth of the embryo and fruit set (Peet et al. 1997). It was very difficult to pollinate in tomato flowers because pollen has to move through small tube to reach stigma for fertilization. The distance between anther and stigma was also large which results in parthenocarpic fruit (Aloni et al. 1999).

Furthermore, higher leaf temperature also affect photosynthetic process, influencing stomatal conductance due to magnitude of air vapor pressure difference (Lloyd & Farquhar 2008). The relationship between photosynthetic activity and temperature variations was proportional and also rate of biochemical reactions catalyzed by different enzymes increases. Unlike this most of the enzymes above certain temperature threshold loss their function and comes results in heat stress (Farquhar et al. 1982).

2.1 POLLEN (QUANTITY AND VIABILITY)

Pollen grains, the haploid gametophyte which represents the whole male portion and it carries two male sperms from anther to the ovary was the carrier of male sperms to the female sac for fertilization (Borg et al. 2009). Pollen develops from anther which contains sporophytic as well as gametophytic genes. The tapetum layer of pollen contains sporophytic expression and the vegetative and generative nuclei bear the gametophytic gene expression (Taylor & Hepler 1997). Endothecium, epidermis and stomium of pollen are damaged in case of high temperature treatment. If the plants were transferred from the high temperature before anthesis then the disruption was not observed (Sato et al. 2002). After anthesis pollen dehydration was a crucial factor for pollen germination and tube growth. High temperature dehydrates pollen in range of 6-60%. The viability of pollen could be recovered if the structural changes reversed after rehydration (Taylor and Hepler, 1997). Under high temperature conditions the stigma shows a reduced elongation in length as well as the anther which was called anther shortening (Sato *et al.*, 2006).

Pollen quality and quantity depends on the amount of carbohydrate and soluble solid content in pollen. With the increase in temperature (32/26˚C) the amount of starch content in pollen grains was significantly lower than the control (28/22˚C) pollen grains (anther walls and inner fluid) (Pressman et al. 2002).

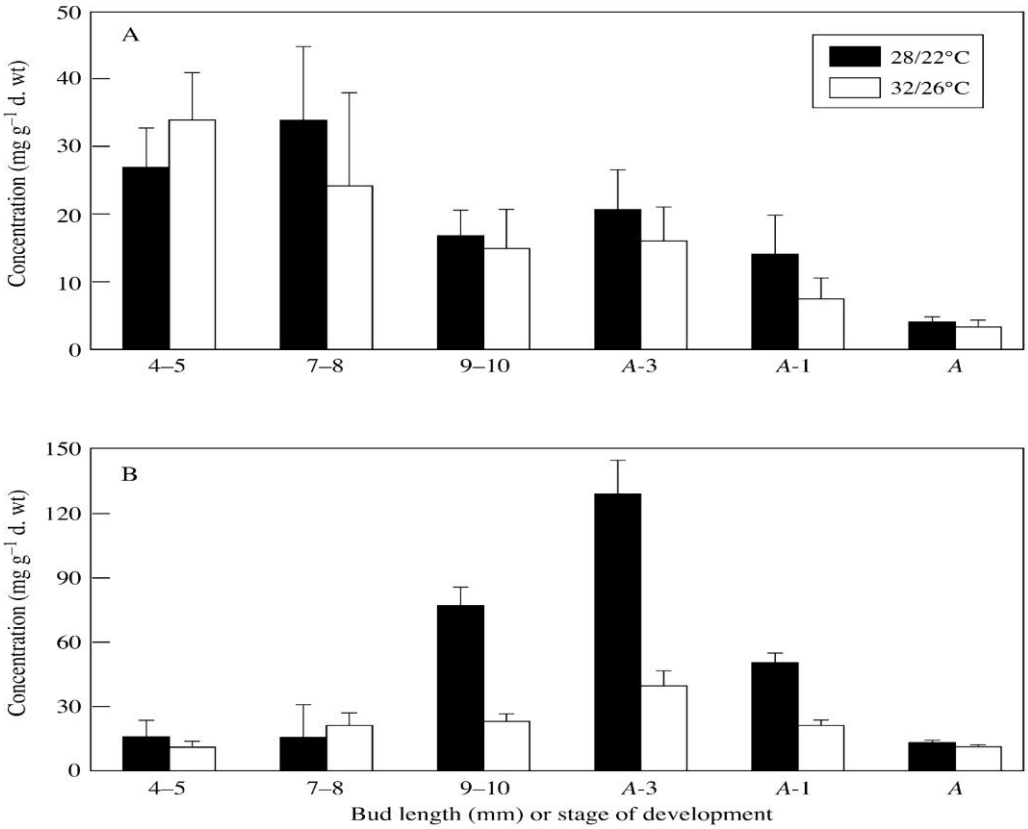

Figure 1: Effect of day and night temperature on carbohydrate content on: A. Anther wall and B. Pollen grains on different development stages of anther in two growing conditions (Pressman et al. 2002).

The amount of carbohydrate content in heat tolerant varieties didn't reduce before anthesis but in heat sensitive varieties was reduced in huge amount 3 days before the anthesis (Firon et al. 2006). Heat tolerant varieties had certain mechanisms to control the loss of carbohydrates. Pollen of heat tolerant varieties have high amount of glucose rather than sucrose and fructose and it can also retain high amount of carbohydrates (Firon et al. 2006).

2.1.1. Pollen production

The number of pollen production increases with increase in day temperature with constant low night temperature (12˚C) (Pressman et al. 2006). Whereas, the number of pollen grains released by the flower of tomato was mostly affected if day temperature was increased more or less than the certain range (22°C to 24°C) (Sato et al. 2006). The number of pollen grains was higher in the lower temperatures (28/22°C) than the higher temperatures (32/26°C). Some research also claimed that, pollen productivity was not significantly affected by the day temperature to some

limit 28 to 34°C (Peet et al. 1998). The least difference in some varieties was due to tolerance of the varieties to the higher temperature (Sato et al. 2000).

The reduction of pollen grains in tomato flowers was related to reduction of starch content in pollen grains before anthesis and the reduction of total soluble solids in mature pollen grains (Pressman et al. 2002). Scientist claimed that decrease in the number of pollen with increasing temperature. At higher day and night temperature the amount non viable pollens was higher compared to the control (Pressman et al. 2002) (Figure 2).

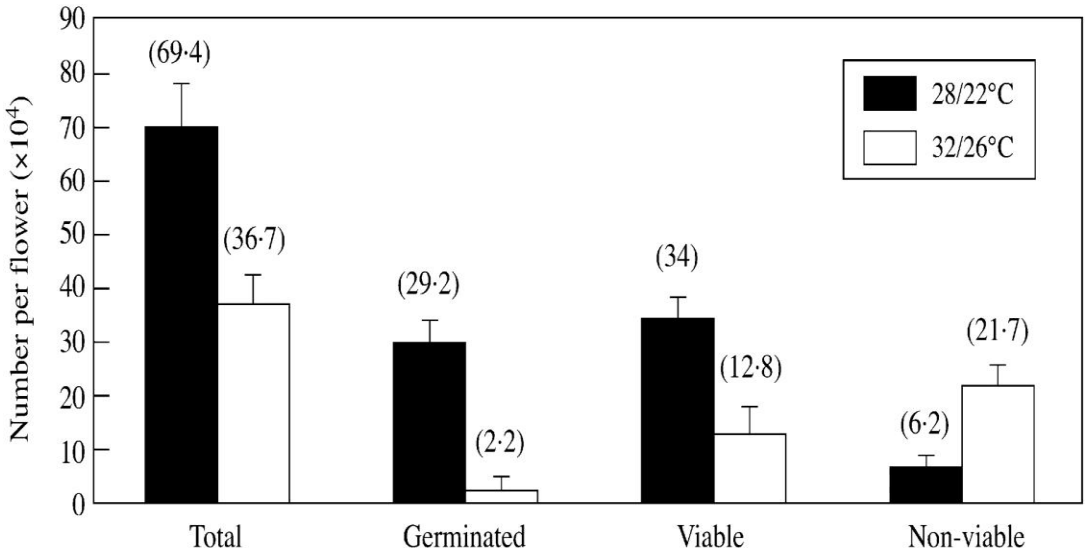

Figure 2: Effect of high day and night temperature (white columns) compare to control conditions (black columns) on the total amount of pollen, the amount of germinated pollen, and the amount of viable and non-viable pollen; Numbers in brackets indicating the amount, and the bars indicating standard deviation/ standard error (Pressman et al. 2002).

The amount of sugar content was different in different stages of flower development. In some stages in low night temperature treatment higher amount of sugar content was observed which was the main reason to reduce the number of pollen in lowering night temperatures (Shaked et al. 2004). Among the night temperature from 18, 20, 22 °C and 26 °C the pollen number is highest in 18°C and lowest in 26 °C night temperature (Peet & Bartholemew 1996).

2.1.2. Pollen germination

Pollen germination was decreased with increasing temperature due to high reduction in the carbohydrate content in the pollen locules and tapetum (Firon et al. 2006). Pollen germination

was decreased with increase in temperature above 34°C along with the pollen tube growth (Song et al. 2002). Among the night temperature from 18, 20, 22 °C and 26 °C the pollen germination was highest in 26 °C and lowest in 18 °C night temperature (Peet & Bartholemew 1996). With increasing temperature, the amount of proline content in pollen was decreased which reduces the pollen germination (Kuo et al. 1986). Pollen germination was affected by the day and night temperature as it is shown in graph as grey bars with temperature 28/22°C and black bars with 32/26°C (Sato et al. 2000).

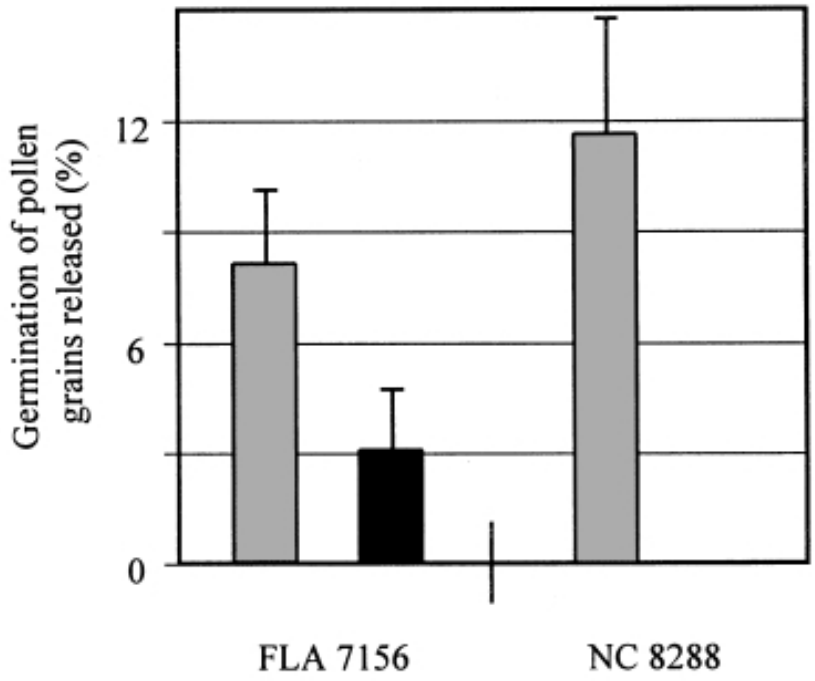

Figure 3: Effect of higher day and night temperature (black bars: 32/26°C) and lower day and night temperature (brown: 28/22°C) pollen grains germination of different varieties of tomato bars indicating standard error (Sato et al. 2000).

Fertility of tomato pollen was found to be decreased under high temperatures for longer periods. Heat tolerant varieties could tolerate high temperatures stress for longer periods than the sensitive ones (Dane et al. 1991). Pollen germination was reduced if the temperature lowered in case of in vitro culture of pollen. The reduction in the germination of pollen was due to the genetic effect transferred from its parent as well as growing conditions. In tomato, the genetic effects also transfers to its gametophytic and sporophytic growth of pollen which could be seen in generations (Zamir et al. 1981). Different polyamines and polybasic aliphatic amines were involved in the process of pollen germination and pollen tube growth. With increasing temperature amines like SAMDC (s-adenosyl methionine decarboxylase) and ADC (arginine

decarboxylase) were reduced which reduced the pollen germination and pollen tube growth (Song et al. 2001). The lower content of SAMDC was due to impaired protein synthesis or impaired enzyme activity (Song et al. 2002). Reduction in pollen germination was observed when crops grown under lower night temperature (Shaked et al. 2004). During lower night temperature pollen was shrinked and resulting decrease in pollen viability (Mercado et al. 1997).

2.2. TOMATO QUALITY

Tomato fruit is a living part; it continues to respire through its life which results in degradation of the quality towards senescence. Tomato quality is affected by pre harvest factors followed by post harvest factors. The best way to obtain good quality is to optimize growth condition and to preserve the quality by proper storage conditions(Aguayo et al. 2004).

Preharvest factors have an important role in determining post harvest quality of tomato. Different climatic conditions like temperature, light conditions, relative humidity, carbon dioxide helps in affecting different attributes of quality of fruit. Temperature during growth and post harvest temperature both has significant effect in determining and preserving quality of tomato. Appropriate or optimum temperature condition was required during growth for proper eating quality and harvesting quality .Temperature along with light have positive impact on optimum plant productivity and harvest index (Kays 1999).

Excessive preharvest temperatures also lead to quality losses, e.g., alterations in color, shape and texture of tomato fruits (Zipelevish et al. 2000). Direct effects of high temperature stress include damage to cellular membranes, proteins, and nucleic acids (Kays 1999). High day and night temperature differences or wide fluctuations in temperature can induce cracking of tomato fruits (Peet 1992). According to Dorais et al. (2004), fruit cracking in tomato was positively and linearly correlated with the averages of the day, night, and daily (24-hr) temperatures, as well as the average of the day/night temperature differential.

2.2.1. Preharvest temperature

Preharvest temperature was found to have major influence in determining the firmness of tomato fruits. Firmness was found to be higher in tomatoes grown at lower temperature (Carl E 1999). Temperature along with ripeness stage affect firmness of tomatoes (Lana et al. 2005). Pink stage tomato are considered as best tomato for storage for the good quality of tomato after storage (Biggs et al. 1988). According to Bouwkamp et al. (1978), an increase in soluble solid content is found in tomatoes grown at higher temperature compared to tomatoes grown at lower temperature. The dry weight ratio was found to be less in the fruits grown at higher temperature (32±1˚C) than in the fruits grown in control temperature (27±1˚C) (Kang et al. 2002). Some researchers also explains there is not much more effect of temperature in dry matter partitioning (Heuvelink & Buiskool 1995). But some researchers claim that there is less dry matter in fruits grown at higher temperature (Adams et al. 2001; Heuvelink & Marcelis 1989).

The final temperature before harvest had significant effect on the soluble solids content in tomatoes. Higher temperature during harvest increases the soluble solid content in tomatoes (Bouwkamp et al. 1978). A temperature increase from 26 to 30˚C also increases the amount of soluble solids, it is due to carbohydrate biosynthetic enzyme activity (Beckles 2012). With the increase in temperature, soluble solids was found to be increased but with concern about sink competition soluble solids may decrease with increase in respiration (Gautier et al. 2005).Citric acid and malic acid are predominant acid found in tomato fruit. Citric acid is found to be increased from maturation to end of post harvest life and malic acid is found to be decreased from maturation to end of post harvest life (Oms-Oliu et al. 2011).The amount of acid content in tomato fruit was found to be increased with the increase in temperature during growth (Weerakkody 2003). As we know, pH is inversely related with acid content. Along with titrable acids there are some other organic acids (ascorbic acid, dehydroascorbic acid, citramalic, shikimic, fumaric, isocitric, succinic, lactic, malic, saccharic, gluconic, gulonic andtartaric acids) which contribute to pH content of the fruit (Oms-Oliu et al. 2011). So with the increase in temperature pH of the fruit content is lower (Weerakkody 2003).

Varietal difference was found in firmness (Moraru et al. 2004), dry matter (Anza et al. 2006; Moraru et al. 2004), soluble solids (Baldwin et al. 1991; Gómez et al. 2001; Moraru et al. 2004), titrable acidity (Baldwin et al. 1991; Gómez et al. 2001; Moraru et al. 2004) and pH content(Gómez et al. 2001; Moraru et al. 2004).

2.2.2. Post harvest of tomatoes

Temperature is an important management factor to extend the shelf life and quality of the fresh tomatoes. For the extension of shelf life, the respiration should be slowed down by low temperature during storage (Kalt, et al. 1999). The more the interval between harvesting and storing the more the water is lost from the berry ultimately results more decaying of tomato which directly influence on nutritional quality (Kader and Morris, 1978). Tomato stored below 13°C has been reported to have significant effect on flavor of tomato, without having of lesions and cracking. The metabolic activity of tomato continues even after detachments of fruit from plant when fruits have reached their red stage. The ripening process continues until it become valueless by deterioration (Toor & Savage 2006).

High temperature inhibits the production of ethylene which results in inhibiting ripening process, including color changes, fruit softening and aroma development(Lu et al. 2010). The tomato fruit which is kept at 20°C have maximum amount of ethylene production. There is substantial reduction in amount of ethylene production above 20°C, in case of tomatoes harvested at pink stage (Atta-Aly 1992). Temperature along with ripeness stage affect in one of the quality parameter, firmness of tomato (Lana et al. 2005).

With the increase in storing days firmness was found to be decreased and firmness values are significantly different (Artés et al. 1999). Additionally, storing days had no significant difference in dry matter (Lisiewska & Kmiecik 2000) and soluble solids (Artés et al. 1999) of tomatoes. Furthermore, in case of titrable acid content, it was found to be decreased with increase in storing days (Artés et al. 1999). Increase in pH was also observed with increase in storing days and are significantly different (Artés et al. 1999).

3. METHODOLOGY

The experiment was conducted in greenhouses at SKP (Senter for Klimaregulert Planteforskning) and Fruit Laboratory of Norwegian University of Life Sciences (UMB), Norway. For this research project, seeds of the tomato cultivars Capricia, Mecano and Cederico were seeded in December 2010. The temperature was maintained at 20 degree Celsius (°C) while the plants were rising. The light provided during plant rising was 100µmol/m2/s with 20 h of day length with high pressure sodium (HPS) lamps.

3.1. GREENHOUSE COMPARTMENTS

Three greenhouse compartments each 10.2 m^2 of size were used. The compartments of greenhouse were in row in linear order. Greenhouse temperature was increased by sunlight and supplemented by the heating pipes inside the greenhouse. The recordings of the different climate parameters are done by automatic sensor system named Priva (Zijlweg, The Netherlands) which use connext operating system where the recordings are recorded in the computer. If the temperature goes higher than wanted the vents were opened. All the compartments were enriched with pure carbon dioxide (CO_2) at 700 parts per million (ppm) during the light period or day period. Carbon dioxide enrichment was turned off when the vents were opened. Relative humidity was maintained to 75-80%. Sulphur was applied by heating sulfur (2h/day) during night at 22:00 pm.

There was no use of supplementary light after placing the plant in the different compartments. From start of experiment, the temperature of greenhouse was maintained as 12/12 hours of day and night. Day temperature was maintained as minimum 20°C with the temperature to increase naturally with the sun in relation to plane. The night temperature was also allowed to decrease naturally as described in the plane.

3.2. EXPERIMENTAL SETUP

The three rooms were maintained with three different day and night temperatures as shown in table 1.

Table 1: Table showing three different day and night temperature treatments.

Temperature (^{0}C)	**Treatment 1**	**Treatment 2**	**Treatment 3**
Day	24^0C	27^0C	30^0C
Night	17^0C	14^0C	11^0C

3.3. CROP HANDLING

The crops were planted in second week of February in the bigger pots with one plant in each pot. The temperature treatment started at 23.02.2012. Plants were grown in 30 litres pot with peat mixed with 30% perlite. Fertilization was done by drip irrigation. The conductivity of watering water was 2.5 mS/cm, and the salinity of growing medium was maintained around 4-5

milli Siemens/centimetre (mS/cm), measured with SSE (Soil saturated extract) methods. The plants was stopped growing after formation of 7 clusters.

Plants had already started to produce initial flowers from first clusters during transferring to temperature treatments. So the first cluster of all the plants was removed. While performing the research, the first cluster counted for pollen is explained as first cluster for pollen experiment and second and third clusters leaving one cluster for fruit in between. In similar way, the cluster which are taken to analyse the fruit alternately were also explained as first, second and third cluster for fruit quality experiments. After finishing the experiments, the clusters are removed from the plants.

3.4. POLLEN ANALYSIS

First, third and fifth inflorescence in each plant grown under different temperature conditions were used to assess the pollen productivity and quality (figure 4). First and second flowers in this inflorescence were assessed for pollen productivity and germinability, respectively one day after flower opening. Third and fourth flowers in these inflorescences were assessed for similar variables (pollen production and germinability) at four days after flower opening.

For pollen production assessment, flower in the above mentioned developmental stages were removed and placed in 50 ml centrifuge tubes; filled with 5 ml of distilled water containing tween 20 (Sigma-Aldrich Chemie GmbH, Steinheim, Germany) of 20 $\mu l l^{-1}$ (one flower/ 5 ml of distilled water). Tubes were shaken by hand for forty times and flower in each tube was removed. The number of pollen present in one ml of water was calculated by using the pollen count obtained by haemocytometer (HYCOR, Hycor biomedical inc. California, USA) under light microscope (LM) at X 100. Pollen with diameter less than 20 micrometer (µm) and shrinked pollen were considered as under sized or abnormal pollen.

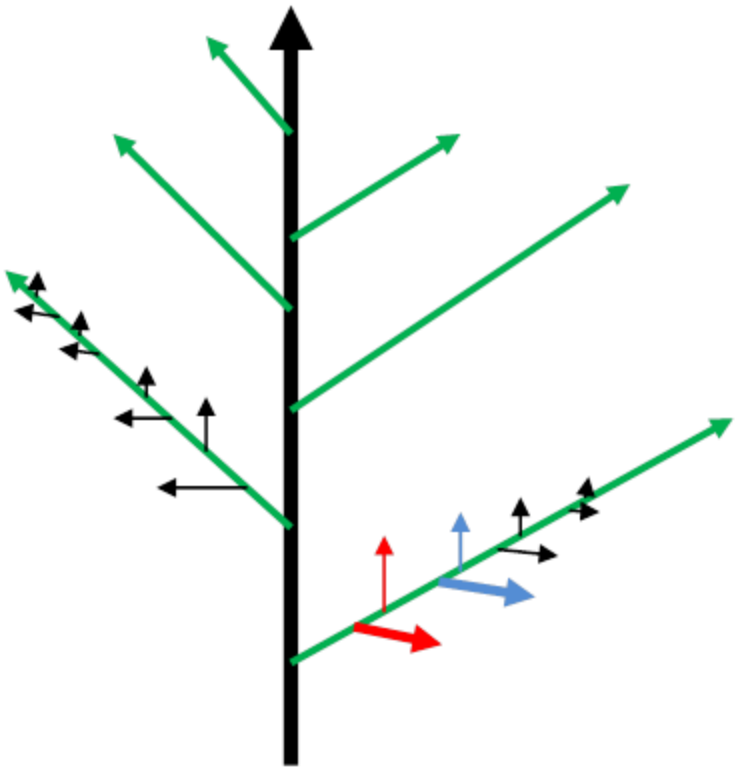

Figure 4: Diagram of tomato plant with six inflorescences. Main stem (Thick black line), six inflorescences developed under treatment conditions (Green lines). First and second flowers in inflorescences of 1st, 3rd and 5th were assed for pollen production (Red thick arrow line) and germinability (Red thin arrow line) at 1 day after flower opening. Third and fourth flowers were assessed for pollen production (Blue thick arrow line) and germinability (Blue thin arrow line) at 4 day after flower opening. Fifth and sixth flowers were assessed for pollen germination at 1 and 4 days after flower opening under similar greenhouse conditions.

For pollen germination, selected flowers were picked with their pedicle and held 2 cm above the open petridishes of 5 cm in diameter that contained pollen growth media (Brewbaker & Kwack 1963). Electric tooth brush was placed on the flower pedicle and vibrated for 5 seconds. Petri dishes were then sealed and incubated in growth chamber for 24 h for germination. The conditions in the growth chamber were 20 °C, 70 % relative humidity and 14 h of light. Photosynthetic active radiation of 130 ± 10 µmol $m^{-2}s^{-1}$ was supplied by mercury lamps (Powerstar HQI-BT 400 W/D day light, OSRAM GmbH, Augsburg, Germany). Piece of agar was placed on microscopic glass slide; added with drops of water; covered with cover slips. Prepared samples were then assessed under LM for pollen germination. Pollens containing germ tubes with length of at least half of the diameter of the pollen were considered germinated. First 100 pollens were assessed and percentage of pollen germination was calculated.

Pollens produced in 5th and 6th flowers were assessed for pollen germination at 1 and 4 days after flower opening respectively for second and third pollen analysis cluster. The methods of pollen collection and assessment were similar as explained above. But pollen collected in these flowers was incubated in the similar greenhouse environmental conditions where they developed

3.5. TOMATO ANALYSIS

3.5.1. Plant material

45 tomatoes from each cultivar and treatment were harvested at commercial ripening. The tomatoes were harvested at ripening 6-9 according the colour chart (Ctifl, Code Couleur Tomate, France) (figure 5A) of tomato. The weights of individual tomatoes were recorded at harvest. The tomatoes were without visible symptoms of any kind. At harvest (day 0) 15 tomatoes were selected randomly among the 45 tomatoes. The 15 tomatoes were then divided into 3 replicates containing 5 tomatoes each. Then weight, colour and firmness were measured. Weight was measured by digital balance and colour was measured by comparing with colour chart (Ctifl, Code Couleur Tomate, France). Firmness was measured by using digital firmness tester (DUROFEL DFT 100, France) (figure 5B) by pressing the tip of the digital firmness tester in surface of tomatoes, done in three points in each tomato. The durofel instrument measures the elasticity of the outer flesh of the fruit. The range is from 100 (no elasticity) to 0 (no resistance). As this is not directly correlated to a force or distance, firmness is given as DUROFEL-units.The analysed tomatoes were frozen at -20°C for further analysis. The remaining 30 tomatoes were stored in darkness at 13°C and 85% RH.

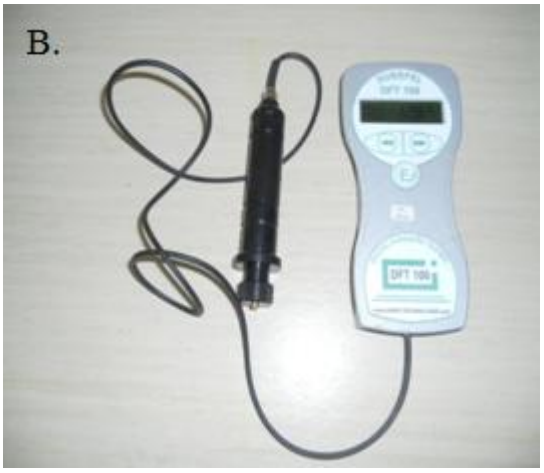

Figure 5: A: Colour chart of tomatoes (Ctifl, Code Couleur Tomate, France); B: Digital firmness tester (DUROFEL DFT 100, France)

After 7 and 15 days of storage respectively, 15 tomatoes were selected randomly and were analysed according to day 0 and frozen at -20°C for further analysis. The frozen tomato samples were thawed overnight at room temperature. The tomato samples were then homogenized using a food processor and then analysed for dry matter, soluble solids, titrable acidity and pH content.

3.5.2. Dry matter and sample preparation

Approximately 6 grams of the homogenized sample were dried for 24 h at 104^0 C. . After drying for 24 hours the weight of sample was recorded. The dry matter percentage is calculated as follow:

$$\% \text{ Dry matter} = \frac{[(\text{Dry weight of sample} + \text{cup}) - \text{weight of cup})]}{\text{Fresh weight of sample}} * 100$$

The homogenized samples were filtered using filter funnel and filter paper (Whatman Gmbn, Germany). The filtrate/juice was collected in conical flasks. The filtrate was used for further analysis.

3.5.3. Soluble Solids

For this measurement, digital refractrometer was used (Atago Palett PR-100, Japan). The refractrometer was calibrated using distilled water. 2-3 drops tomato juice was placed on the sensor of the refractrometer and the content of soluble solids recorded.

3.5.4. Titratable acids

The acidity was measured by titration. 10 ml of filtrate was diluted with 50 ml of distilled water and sodium hydroxide (0,1N) was added until a pH of 8.1 was obtained. Automatic titrator (figure 6)was used which works on the basis of neutralization point of acid and base.

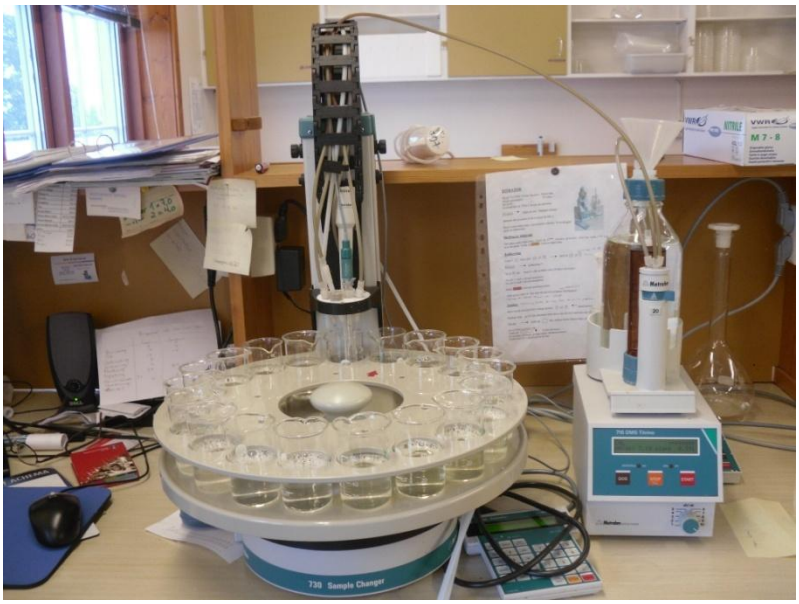

Figure 6: Automatic Titrator (Methrom 716 DMS Titrino and 730 Sample changer, Herisau, Switzerland)

3.5.5. PH content

The measurement of pH was done using a pH meter (691 PH Meter, Metrohm, Swiss). The pH meter was calibrated by using Titrisol (Puffer-Konzentrat) with pH value of 4.

4. DATA ANALYSIS

Minitab (version 16) was used to conduct analysis of variance (GLM procedure). Comparisions of means were performed with Tukey`s pairwise comparison test at p=0.05 and p=0.01. For graphical presentation sigma plot was used.

5. RESULTS

The set points of temperature are 24/17°C, 27/14°C and 30/11°C as day and night temperatures. The temperatures observed from the experiments were not up to the set points in initial readings in first cluster. Temperature of one week before flower opening was observed for pollen experiment and four weeks before for fruit harvesting. For easiness to explain the results the set point temperature was considered in explaining the results. The temperatures on the table in appendix are highest average day, lowest average night and average daily temperature shown in table 3 and 5 in appendixes. For other climatic factors average daily climatic parameters are considered during evaluation of the experimental results shown in table 4 and 6 in appendixes.

Temperature data during fruit analysis were shown in table 8 in appendix. The average results the pollen analysis was shown in table 2 and fruit quality and storability analysis results on table 7 in appendixes.

5.1. POLLEN ANALYSIS

Comparisons of the three varieties (Capricia, Mecano and Cederico) related to pollen number and germination percentage was not significantly different because of taking mean comparison.

The light level was about half under production of pollen on cluster one compared on cluster one compared on cluster two and three (Table 4 and 6). The day temperature differences when production of pollen on cluster one was 2-3˚C, while it was 5-6˚C on mainly related to difference in night temperature. The CO_2 level was about 50 ppm higher with a high day temperature (30˚C) than for the treatment with low day temperature (24˚C). The production of pollen on cluster one is 10-20 x 10^3 per milliliter on each flower while it on cluster two and three are 30-50 X 10^3 per milliliter per flower.

5.1.1. First cluster

5.1.1.1. One day after opening

One day after flower opening, the number of pollen was significantly ($p<0.05$) related to different day and night temperatures. High day and low night temperature treatment (30/11°C) had a higher number of normal pollen with decreasing in number with decrease in temperature difference to 27/14°C and further decrease to temperature 24/17°C. In case of abnormal pollen, there was also significant ($p<0.05$) difference in day and night temperature treatments with 30/11°C day and night temperature having higher number of abnormal pollen with decreasing in number with decrease in temperature differences to 27/14°C and 24/17°C (figure 7A). Moreover, there was significant difference ($p<0.05$) in pollen germination with increase in temperature difference from 24/17°C with the best germination in highest temperature difference (30°C/11°C) (figure 8A).

5.1.1.2. Four days after opening

Four days after flower opening, 30/11°C and 27/14°C day and night temperatures had significantly higher ($p<0.05$) number of normal pollen than 24/17°C. In case of abnormal pollen,

there was significant ($p<0.05$) difference in day and night temperature treatments. Higher temperature difference (30/11°C) had higher number of abnormal pollen followed by 27/14°C and 24/17°C in descending order (figure 10A). Further analysis on percentage of pollen germination, significant ($p<0.05$) difference was found in between different day and night temperature regimes with 30/11°C having higher percentage of pollen germination. There was decrease in pollen germination with decrease in temperature difference to 27/14 ˚C and 24/17°C respectively (figure 11A).

5.1.2. Second cluster

5.1.2.1. One day after opening

No significant difference but positive increment in number of normal pollen and abnormal pollen was found between different day and night temperature treatments in second cluster when observed one day after flower opening. Whereas, linear increment in pollen number was observed with increase in temperature differences (figure 7B). Additionally, pollen germination was significantly ($p<0.05$) higher with increase in temperature difference from 24/17°C to 30/11°C. But there is no difference in pollen germination percentage between 27/14°C and 30/11°C (figure 8B). In case of pollen germination in growing room, there was significant difference ($p<0.05$) in pollen germination between different day and night temperatures. 30/11°C has higher pollen germination followed by 27/14°C and 24/17°C with less percentage of pollen germination respectively (figure 9A).

5.1.2.2. Four days after opening

Significantly higher number of normal and abnormal pollen was observed ($p<0.05$) in higher temperature difference (30/11°C) than lower temperature difference (24/17°C).Whereas, 27/14˚C had no significant difference in number of normal and abnormal pollen with 24/17˚C and 30/11˚C (figure 10B). Moreover experiments on pollen germination showed significantly ($p<0.05$) higher percentage in higher temperature difference (30/11°C) than lower temperature difference (24/17˚C and 27/14˚C). No significant difference was observed between 27/14°C and 24/17°C (figure 13B). Experiment on pollen germination in growing room also showed significantly ($p<0.05$) different results. The result showed 30/11°C had higher percentage of pollen germination with decreasing in percentage along with temperature differences 27/14°C and 24/17°C respectively (figure 12A).

5.1.3. Third cluster

5.1.3.1. One day after opening

Pollen observed one day after flower opening in third cluster also showed that higher temperature difference (30/11°C) had significantly ($p<0.05$) higher number of normal pollen than lowest temperature difference (24/17°C). It also showed 27/14˚C had no significant difference in pollen number with 24/17˚C and 30/11˚C. There was also significant difference in abnormal pollen between day and night temperature treatments with higher number in higher temperature difference (30/11°C) than lower temperature differences (24/17˚C and 27/14˚C). Moreover there was no significant difference in number of abnormal pollen between 24/17°C to 27/14°C (figure 7C). Similarly, pollen germination percentage if observed in growth chamber (figure 8C) and growing room (figure 9B), significant ($p<0.05$) difference results was observed. 30/11°C day and night temperature had higher percentage of pollen germination with decreasing in percentage with decrease in temperature difference to 27/14°C and further decrease in 24/17°C.

5.1.3.2. Four days after opening

After four days of flower opening when pollen was observed, 30/11°C and 27/14°C day and night temperature regimes had significantly ($p<0.05$) higher number of normal pollen than 24/17°C. In case of abnormal pollen, there was also significant difference in number of in between different day and night temperature regimes. It showed higher temperature difference (30/11°C) had higher number of abnormal pollen with decreasing in number along with decrease in temperature difference to 27/14°C and 24/17°C respectively (figure 10C). Experiments on pollen germination percentage if observed in growth chamber (figure 11C) and growing room (figure 12B), significant ($p<0.05$) difference results was observed. 30/11°C day and night temperature had higher percentage of pollen germination with decreasing in percentage with decrease in temperature difference to 27/14°C and further decrease in 24/17°C.

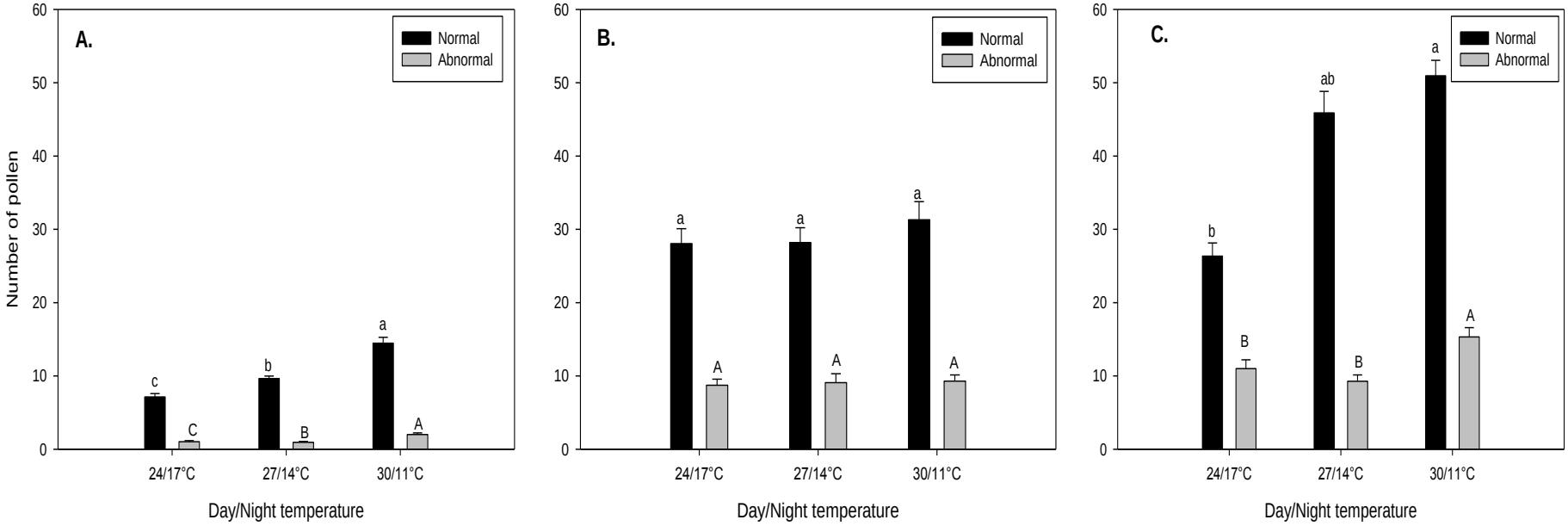

Figure 7: Effect of day and night temperature regimes on number of normal and abnormal pollen (X 10^3 per milliliter) in different clusters counted one day after flower opening A. cluster 1 B. cluster 2 C. cluster 3; X-axis shows number of pollen (X 10^3 per milliliter); error bars shows the standard error of mean; text represents the significant difference values.

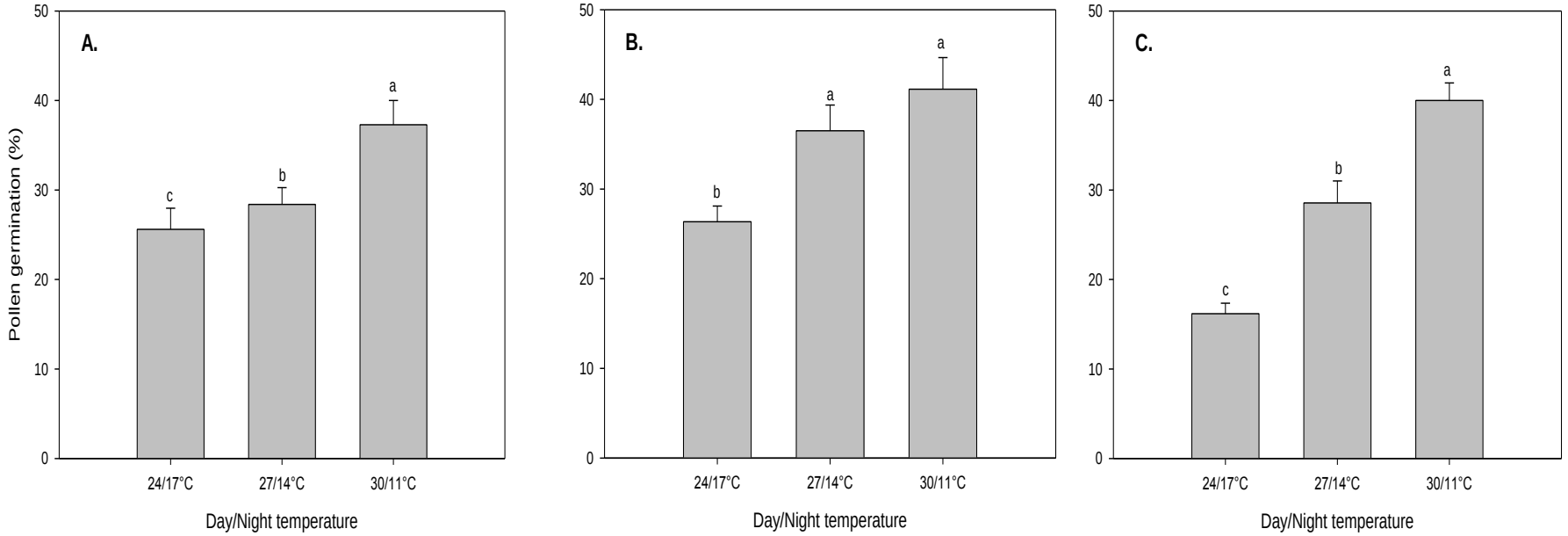

Figure 8: Effect of day and night temperature regimes on pollen germination percentage in different clusters counted one day after flower opening A. cluster 1 B. cluster 2 C. cluster 3; X-axis shows number of pollen germination percentage; error bars shows the standard error of mean; text represents the significant difference values.

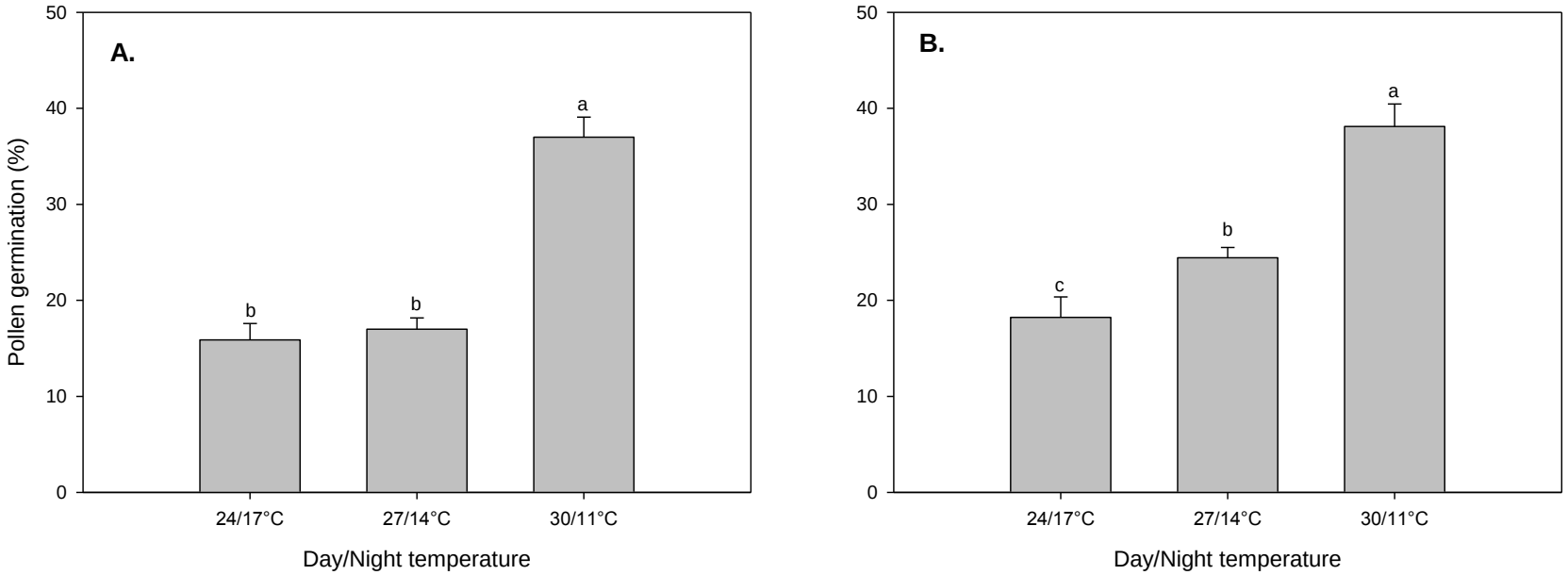

Figure 9: Effect of day and night temperature regimes on pollen germination percentage in growth conditions in different clusters counted one day after flower opening A. cluster 2 B. cluster 3; X-axis shows number of pollen germination percentage; error bars shows the standard error of mean; text represents the significant difference values.

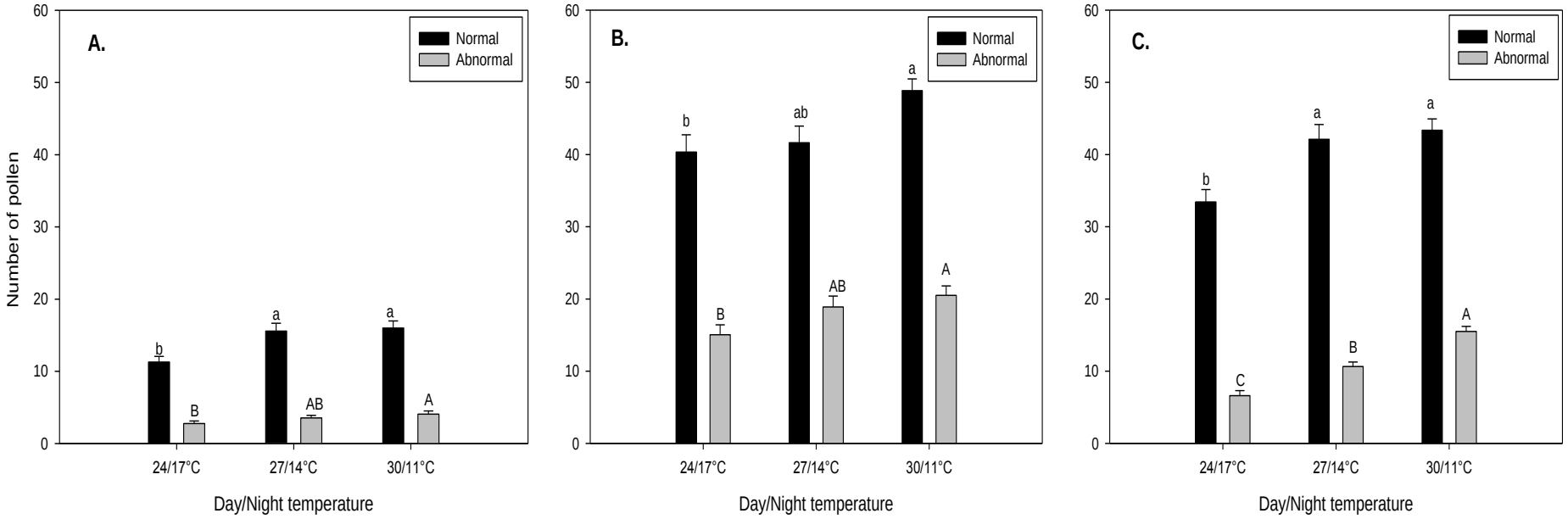

Figure 10: Effect of day and night temperature regimes on number of normal and abnormal pollen (X 10^3 per milliliter) in different clusters counted four days after flower opening A. cluster 1 B. cluster 2 C. cluster 3; X-axis shows number of pollen (X 10^3 per milliliter); error bars shows the standard error of mean; text represents the significant difference values.

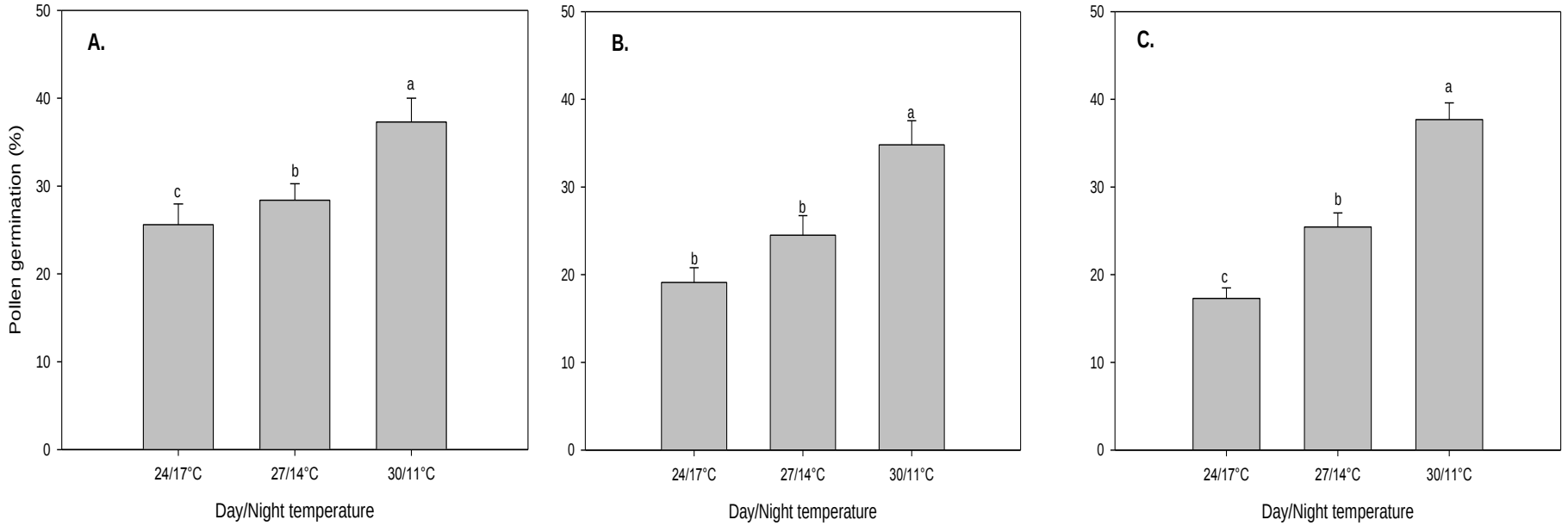

Figure 11: Effect of day and night temperature regimes on pollen germination percentage in different clusters counted four days after flower opening A. cluster 1 B. cluster 2 C. cluster 3; X-axis shows number of pollen germination percentage; error bars shows the standard error of mean; text represents the significant difference values.

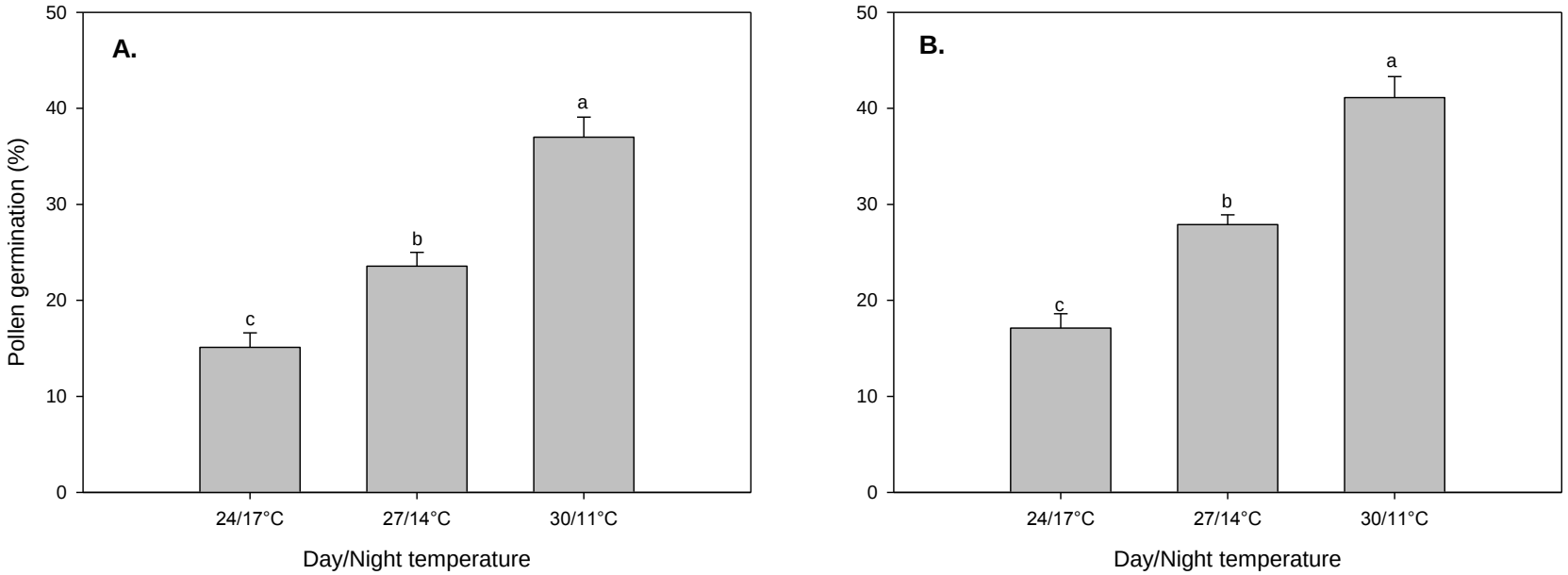

Figure 12: Effect of day and night temperature regimes on pollen germination percentage in growth conditions in different clusters counted four days after flower opening A. cluster 2 B. cluster 3; X-axis shows number of pollen germination percentage; error bars shows the standard error of mean; text represents the significant difference values.

5.2. TOMATO FRUIT QUALITY AND STORABILITY

5.2.1. Firmness:

In this experiment, significant difference ($p<0.05$) of firmness between different temperature regimes, varieties and storing days was observed. In temperature regimes, 27/14°C had significantly higher firmness than 24/17°C and 30/11°C. Followed by this, there was no significant difference between 24/17°C and 30/11°C (figure 13A). In case of varieties Capricia had significantly ($p<0.05$) higher firmness value followed by Mecano and Cederico respectively in decreasing order (figure 13B). Cederico had lowest firmness than other two varieties. Finally in storing days, 0 days firmness was significantly higher than 7 days and then 7 days firmness is higher than 14 days (figure 13C).

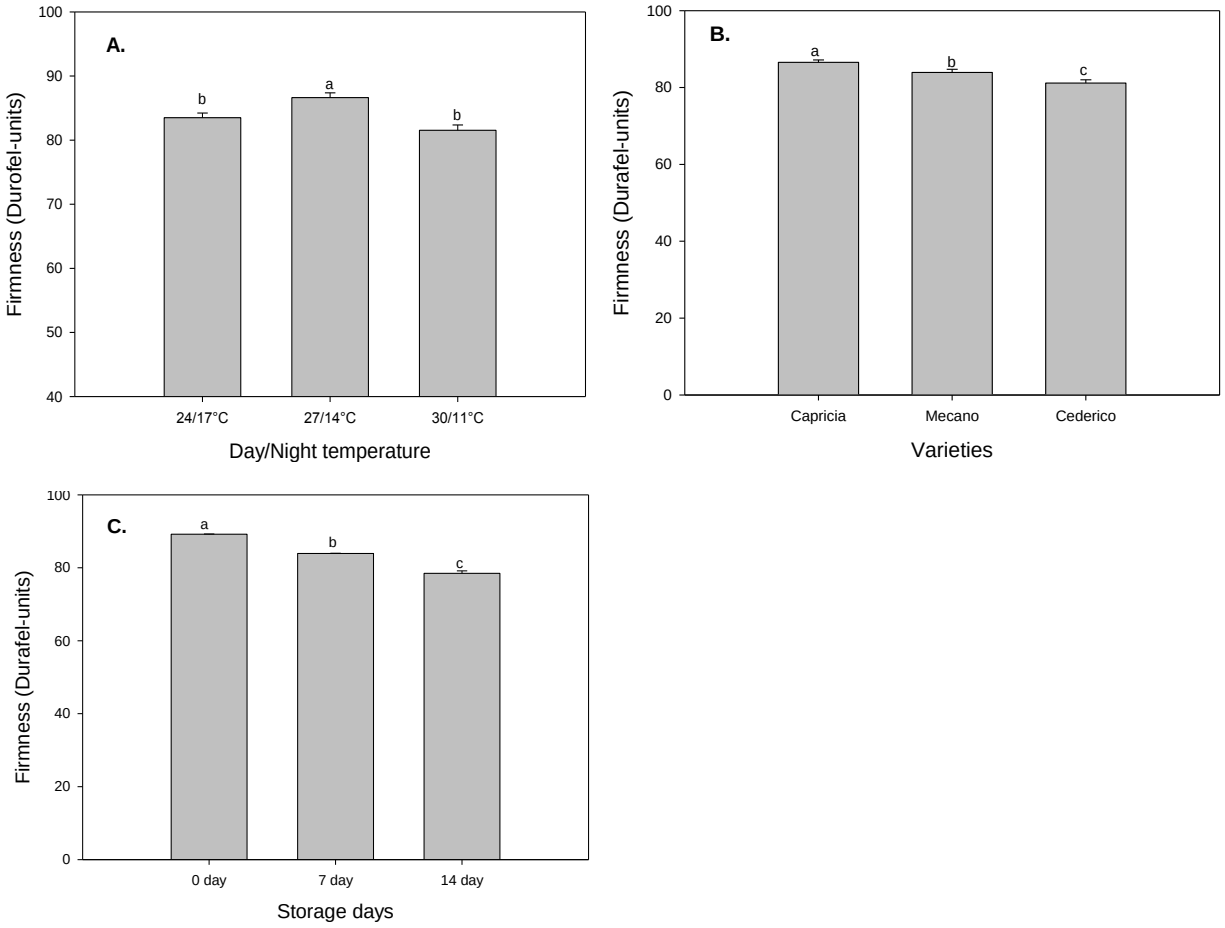

Figure 13: Firmness in different A. Temperature regimes B. Varieties C. storing days; error bar shows standard error of mean; text value shows the result of tukey comparison test.

5.2.2. Dry Matter percentage

The percentage of dry matter content of 24/17°C was significantly ($p<0.01$) higher than 27/14°C and 30/11°C temperature regimes. Furthermore, there was no significant difference in percentage of dry matter content between 27/14°C and 30/11°C (figure 14A). Moreover, the dry matter percentage between the three different varieties was also significantly different ($p<0.05$). Capricia variety had higher dry matter than Cederico. Mecano had not significantly different dry matter percentage with Capricia and Cederico (figure 14B).

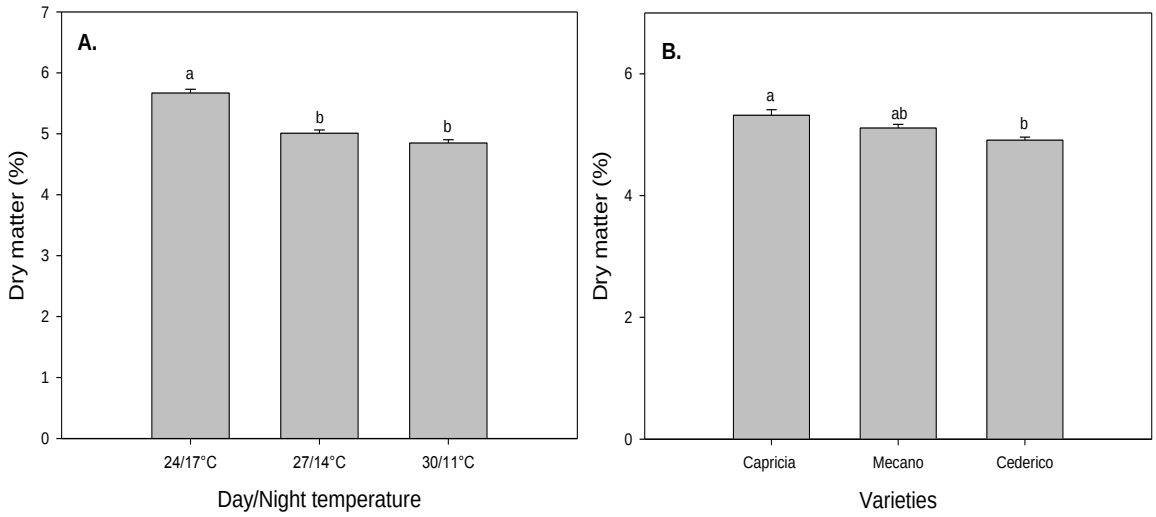

Figure 14: Dry matter in percentage in different A. Temperature regimes B. Varieties; error bar showing the standard error of mean; text value shows the result of tukey comparison test.

5.2.3. Soluble solids

The probability value of the soluble solids percentage is less than 0.01 which show that the soluble solids in tomatoes grown at the different day and night temperature regimes were significantly different. The highest soluble solids percentage value is in temperature with 24/17°C. However, no significant difference was observed between 30/11°C and 27/14°C treatments (figure 15A). The soluble solids percentage between the three different varieties was also significantly different ($p<0.01$). Mecano and Capricia variety has higher soluble solids percentage than Cederico (figure 15B). There was no significant difference in soluble solids during storage for the different varieties.

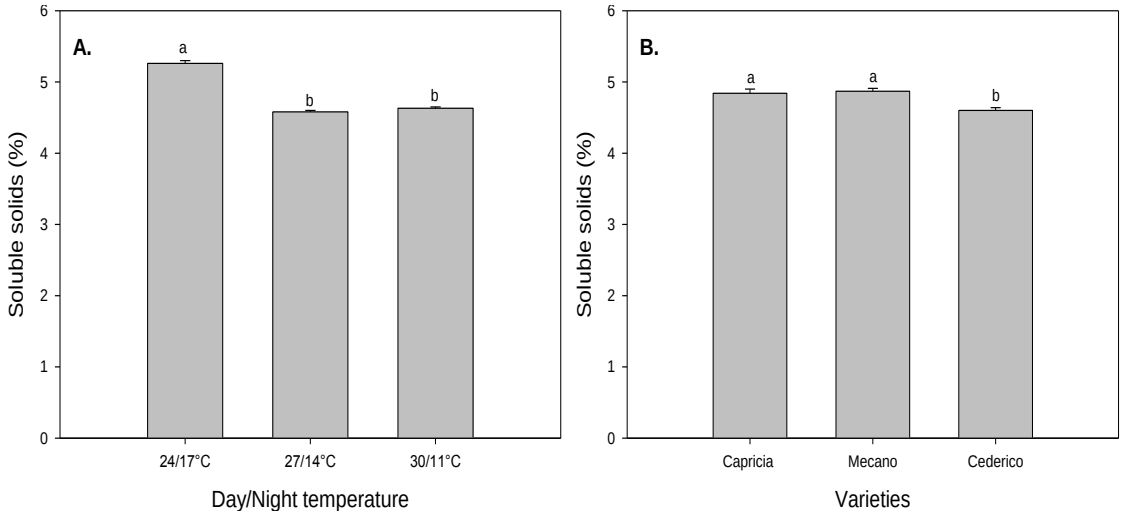

Figure 15: Soluble solids (%) in different A. Temperature regimes B. Varieties; error bar shows standard error of mean; text value shows the result of tukey comparison test.

5.2.4. Titrable acid

The titrable acid percentage of 24/17°C was significantly ($p<0.05$) higher than of 27/14°C and 30°C/11°C. Moreover, titrable acid percentage in 27/14°C had no significant difference with 27/14°C (figure 16A). There was also significant difference ($p<0.05$) in titrable acid between the different varieties. The titrable acid value of Capricia is higher than of Mecano and Cederico. But Mecano has no significant difference with Cederico (figure 16B). There was no significant change in content of titrable acidity during storage.

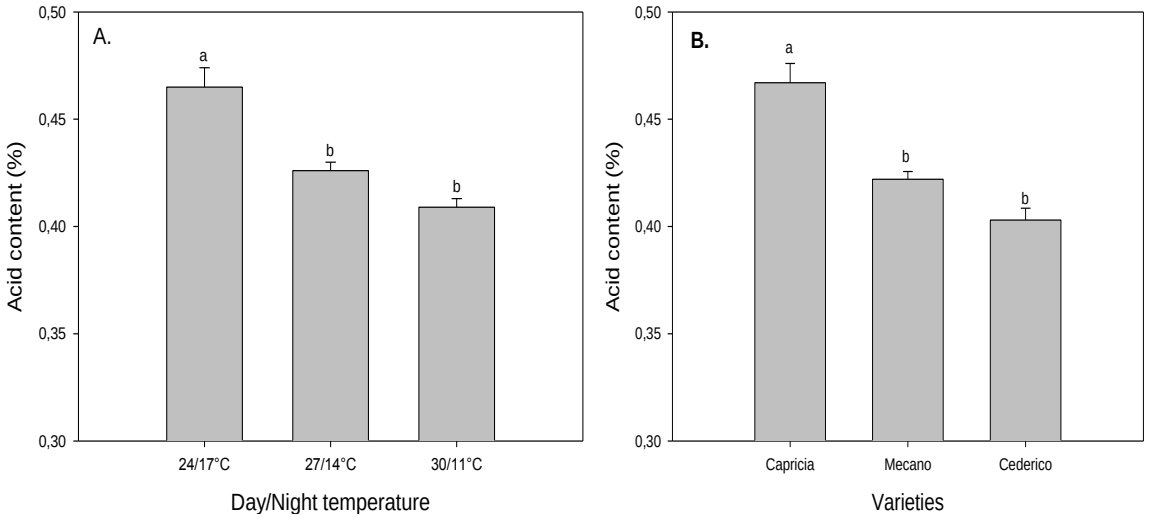

Figure 16: Titrable acid (%) acid in different A. Temperature regimes B. Varieties; error bar shows standard error of mean; text value shows the result of tukey comparison test.

5.2.5. PH content

In the experiment, pH content of 24/17°C and 27/14°C were significantly ($p<0.01$) lower compared to tomatoes grown at 30/11°C. But there is no significant difference in pH between 27/14°C and 30/11°C (figure 17A). Along with this, the pH content of Mecano and Cederico were also significantly ($p<0.01$) higher compared to the pH value of Capricia. Mecano and Cederico were significantly different from Capricia. There was no significant difference in pH between Mecano and Cederico (figure 17B). Moreover, there was no significant difference in pH values between the different storage days.

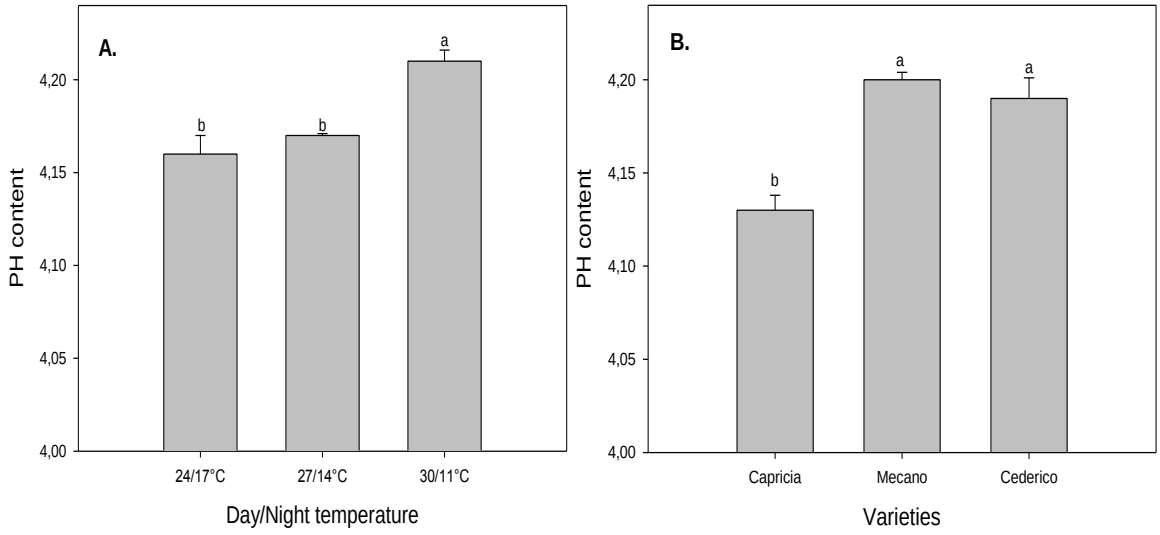

Figure 17: PH content in different A. Temperature regimes B. Varieties C. Storage days; error bar shows standard error of mean; text value shows the result of tukey comparison test.

6. DISCUSSION

6.1. POLLEN QUANTITY AND VIABILITY

Lower night temperatures affect generative phase by reduction in number of pollen grains and markedly impaired their functioning (Shaked et al. 2004). The results of present study shows that negative effect of low night temperature treatments on reproductive development could be prevented by increasing daytime temperatures. The most supportive improvements in high temperature difference treated plants compared to low temperature difference is much larger number of pollen grains produced per flower and also higher percentage of germinating pollen grains and lower percentage of non viable pollen. Our result also showed that an increasing difference in day and night temperature increases the productivity and viability of the pollen.

Overall the effect of different day and night temperature regimes on pollen production and pollen germination is not negative at higher day temperatures as shown in other literatures (Sato et al. 2000; Sato et al. 2006). However, tomatoes grown in this experiment are not only the higher day temperature but also in lower night temperature while the average daily temperature is almost constant.

As we have seen in case of higher temperature difference vents will be closed for longer period of time than the plants grown at lower temperature regimes. This also shows that plants grown at higher temperature regimes have higher amount of CO_2 available than plants grown at lower temperature regimes. Higher temperature negative effects can be minimized by increasing enrichment of CO_2 (Taub et al. 2000). So photosynthesis is also higher in the plants grown at higher day temperature followed by higher CO_2. In higher light condition also photosynthesis will be higher. This will results in more production of photosynthates. In the presence of light during day plant can do more photosynthesis in higher temperature than in the lower temperature (Pastenes & Horton 1996). In the present result, first cluster day temperature is lower than other two clusters so night temperature might have more effect on pollen quantity and quality. Furthermore, irradiance is also low compared to second and third cluster. This might be the reason of lower number of pollen observed in first cluster than second and third cluster. Both the climatic conditions favor the increment in photosynthates or energy reserves in anther.

The higher production of photosynthates might be the reason of higher number of pollen production in plants grown at higher temperature difference because of longer time with high CO_2 (Mortensen & Gislerod 2005). This can also be explained by supporting some climate data observed. In higher light and temperature conditions there are higher number of pollen than in lower light and lower temperature difference. This might be the effect of higher light which reduces the effect of higher day temperature (Atherton & Rudich 1986). Mature pollen grains contain genes products (enzymes and mRNA), inorganic nutrients and energy reserves (starch and lipids). Lower night temperature interferes in starch accumulation before anthesis by decreasing the concentration of soluble sugar in mature pollen grains (Shaked et al. 2004). Whereas, when plants grown at high day temperature along with low night temperature, there will be 50% reduction in enzyme activities of pollen cell wall and soluble acid invertase that catalyze the hydrolysis of sucrose (Pressman et al. 2006).

Lower night temperature have some negative effects on pollen germination (Mercado et al. 1997) as depicted by earlier research. Energy reserves seem prominent factor determining the pollen viability (Firon et al. 2006). There is clear and significant increment in percentage of pollen germination in the plants grown at increasing difference in day and night in the present experiment. Since day temperature difference between different clusters is lower in first cluster than in second and third cluster, pollen germination percentage is similar in three clusters. This depicts that, the effect of night temperature had higher effect in pollen germination percentage than day temperature. When pollen germinated in growing room, germination percentage is also increased with increase in temperature difference between day and night. Since in this case pollen germination percentage was only observed in second and third cluster, both day and night temperature effect could be seen. Our result might appear contradict to earlier studies in which pollen germination is lower at higher growing temperature conditions where day and night temperatures are higher (Sato et al. 2006). In earlier research day temperatures regimes pollen germination was observed highest in higher day temperature (34˚C) which supports our results (Song et al. 2002). Higher photosynthates and varietal affinity towards higher temperature might be the supportive condition resulting in higher pollen germination in higher temperature regimes.

6.2. FRUIT QUALITY AND STORABILITY

Our results shows significantly different relationship between the temperature regimes tested along with varieties and storage days. In case of different varieties there is significant difference in physical characteristics (firmness, dry matter, soluble solids, percentage of acid and pH content).Varietal difference is also supported by earlier research for firmness (Moraru et al. 2004), dry matter(Anza et al. 2006), soluble solids, titrable acidity and pH (Baldwin et al. 1991; Gómez et al. 2001) which might be due to genetic difference. Capricia had shown better quality than Mecano and Cederico in firmness and titrable acidity. Capricia and Mecano had shown higher dry matter and soluble solids compared to Cederico. Tomato firmness is significantly affected in different preharvest temperature regimes. Firmness is increasing to certain temperature range (27/14˚C) and further increase in difference between day and night (30/11˚C) results in decrease in firmness value. As we know polysaccharides and cell wall enzymes have significant role in firmness, it might be that till certain temperature the activity of polysaccharides and cell wall enzymes is activated positively. After attaining optimal temperature further increase in temperature may results in deactivation of enzymes (galactosyl

and arabinosyl), and accumulation of polyuronides (Mitcham & McDonald 1992). Decrease in tomato firmness might be due to changes in cell wall number, cell turgor properties and cell wall composition(Woolf et al. 1999).

The dry matter content is found significantly lower in tomato fruits grown at higher temperature regimes. It might be due to decrease in the content of carbohydrates with increase in day temperature which is supported by previous research (Kang et al. 2002). This might be due to higher amount of water content in the fruits grown at higher temperature regimes. Moreover, this result contrast with some research which claims that there is no significant difference in dry matter content in different temperatures (Adams et al. 2001; Heuvelink & Buiskool 1995). The result of soluble solid content is significantly lower in higher temperature regimes than lowest one (24/17˚C). The soluble solids content is found to be decreased with increase in temperature regimes which supports the earlier research (Wang & Camp 2000). This might be due to higher content of glucose, fructose and total carbohydrates highest in fruits grown at lower temperature regimes. This contrasts with some earlier research which claims increase in soluble solids with increase in temperature (Beckles 2012; Gautier et al. 2005).

Titratable acidity of tomato fruits is found to be significantly different with the highest concentration in lowest temperature regimes. In support of some literatures higher percentage of titrable acid is found in fruits grown at lower night temperature (12˚C) (Wang & Camp 2000). Our results on soluble solids might be due to the amount of organic acid is found to be decreased with increase in temperature regimes during growing. Increase in day temperature and decrease in night temperature might have negative effect on organic acid content in tomato. In contrast some literature also claim that there is increase in amount of titrable acidity with increase in temperature (Weerakkody 2003). PH content is almost reverse of acid content. So, there is significantly higher pH content in highest temperature regimes (30/11˚C). Some literature also claim contrasting results with higher pH content in lower growing temperatures (Weerakkody 2003). Decrease in pH might be the reason that the amount of organic acid is higher in lower temperature regimes.

Study done to test post harvest quality explained that, firmness value decreased with increase in storing days which supports previous research (Artés et al. 1999). This might also be due to increase in ripening of tomatoes with results in accumulation of polyuronides and decrease in some enzymes like galactosyl and arabinosyl in the cell wall (Mitcham & McDonald 1992). Storing tomatoes for longer period had no significant effect on dry matter content as described

in other research (Lisiewska & Kmiecik 2000) which might be due to storing tomatoes in controlled climatic condition prevent water loss from fruit which results in similar dry matter content. Storing tomatoes for longer period had no significant effect on soluble solids content as supported by other research (Artés et al. 1999). This shows no photosynthetic effect on tomato fruits after harvesting. Storing tomatoes for longer period had no significant effect on titrable acid and pH which contrast the results found by other research (Artés et al. 1999). No effect on titrable acidity and pH might be due to no change in organic acids content with the ripening during the storing days.

7. CONCLUSION

Tomato plants grown at lower night temperature along with higher day temperature had positive effect on pollen production and viability (germination). Fruit quality is reduced to certain extent but not as expected. So conclusively tomatoes could be grown at higher temperature regimes during flowering phase and regimes could be decreased to some extent during fruiting without negative effect on fruit quality. The results indicate that growing temperature at 27/14˚C day and night temperature is considered better than other day and night temperature treatments. This also indicates growers could save some energy while growing tomatoes in greenhouses by reducing night temperature and utilizing higher day temperatures. In future more research can be done by testing smaller temperature range with alternating day and night temperatures along with evaluation of seeds and nutritional quality of tomatoes.

8. REFERENCES

Adams, S., Cockshull, K. & Cave, C. (2001). Effect of temperature on the growth and development of tomato fruits. *Annals of Botany*, 88 (5): 869.

Aguayo, and, E. & Artes. (2004). Quality of fresh-cut tomato as affected by type of cut, packaging, temperature and storage time. *European Food Research and Technology*, 219 (5): 492-499.

Aloni, B., Pressman, E. & Karni, L. (1999). The effect of fruit load, defoliation and night temperature on the morphology of pepper flowers and on fruit shape. *Annals of Botany*, 83 (5): 529-534.

Anza, M., Riga, P. & Garbisu, C. (2006). Effects of variety and growth season on the organoleptic and nutritional quality of hydroponically grown tomato. *Journal of food quality*, 29 (1): 16-37.

Artés, F., Conesa, M. A., Hernández, S. & Gil, M. I. (1999). Keeping quality of fresh-cut tomato. *Postharvest Biology and Technology*, 17 (3): 153-162.

Atherton, J. G. & Rudich, J. (1986). *The tomato crop: a scientific basis for improvement*: Springer.

Atta-Aly, M. A. (1992). Effect of high temperature on ethylene biosynthesis by tomato fruit. *Postharvest Biology and Technology*, 2 (1): 19-24.

Bailey, B. & Seginer, I. (1988). Optimum control of greenhouse heating. *Engineering and Economic Aspects of Energy Saving in Protected Cultivation 245*: 512-518.

Baldwin, E. A., Nisperoscarriedo, M. O., Baker, R. & Scott, J. W. (1991). Quantitative-analysis of flavor parameters in 6 florida tomato cultivars (Lycopersicon-esculentum mill). *Journal of agricultural and food chemistry*, 39 (6): 1135-1140.

Beckles, D. M. (2012). Factors affecting the postharvest soluble solids and sugar content of tomato (Solanum lycopersicum L.) fruit. *Postharvest Biology and Technology*, 63 (1): 129-140.

Biggs, M. S., Woodson, W. R. & Handa, A. K. (1988). Biochemical basis of high temperature inhibition of ethylene biosynthesis in ripening tomato fruits. *Physiologia Plantarum*, 72 (3): 572-578.

Borg, M., Brownfield, L. & Twell, D. (2009). Male gametophyte development: a molecular perspective. *Journal of Experimental Botany*, 60 (5): 1465.

Bot, G. (2001). Developments in indoor sustainable plant production with emphasis on energy saving. *Computers and electronics in agriculture*, 30 (1-3): 151-165.

Bouwkamp, J. C., Angell, F. F. & Schales, F. D. (1978). Effects of weather conditions on soluble solids of muskmelon. *Scientia Horticulturae*, 8 (3): 265-271.

Brewbaker, J. L. & Kwack, B. H. (1963). The essential role of calcium ion in pollen germination and pollen tube growth. *American Journal of Botany*: 859-865.

Carl E, S. (1999). Preharvest factors affecting postharvest texture. *Postharvest Biology and Technology*, 15 (3): 249-254.

Dane, F., Hunter, A. G. & Chambliss, O. L. (1991). Fruit-set, pollen fertility, and combining ability of selected tomato genotypes under high-temperature field conditions. *Journal of the American Society for Horticultural Science*, 116 (5): 906-910.

E.Heuvelink. (2005). Tomatoes. 13.

Farquhar, G. D., O'leary, M. & Berry, J. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Functional Plant Biology*, 9 (2): 121-137.

Firon, N., Shaked, R., Peet, M., Pharr, D., Zamski, E., Rosenfeld, K., Althan, L. & Pressman, E. (2006). Pollen grains of heat tolerant tomato cultivars retain higher carbohydrate concentration under heat stress conditions. *Scientia Horticulturae*, 109 (3): 212-217.

Gautier, H., Rocci, A., Buret, M., Grasselly, D. & Causse, M. (2005). Fruit load or fruit position alters response to temperature and subsequently cherry tomato quality. *Journal of the Science of Food and Agriculture*, 85 (6): 1009-1016.

Geisenberg, C. & Stewart, K. (1986). Field crop management. *The Tomato Crop. A Scientific Basis for Improvement. JG Atherton, J Rudich (eds). Chapman and Hall. New York, USA. pp*: 511-557.

Gómez, R., Costa, J., Amo, M., Alvarruiz, A., Picazo, M. & Pardo, J. E. (2001). Physicochemical and colorimetric evaluation of local varieties of tomato grown in SE Spain. *Journal of the Science of Food and Agriculture*, 81 (11): 1101-1105.

Heuvelink, E. & Marcelis, L. (1989). *Dry matter distribution in tomato and cucumber*. 149-180 pp.

Heuvelink, E. & Buiskool, R. (1995). Influence of sink-source interaction on dry matter production in tomato. *Annals of Botany*, 75 (4): 381.

Ho, L. (2001). *Manipulation of physiological processes for better yield and quality in crop plants in control environment*. 273-279 pp.

Kang, H. M., Park, K. W. & Saltveit, M. E. (2002). Elevated growing temperatures during the day improve the postharvest chilling tolerance of greenhouse-grown cucumber (Cucumis sativus) fruit. *Postharvest Biology and Technology*, 24 (1): 49-57.

Kays, S. J. (1999). Preharvest factors affecting appearance. *Postharvest Biology and Technology*, 15 (3): 233-247.

Kuo, C., Chen, H. & Ma, L. (1986). Effect of high temperature on proline content in tomato floral buds and leaves. *J. Amer. Soc. Hort. Sci*, 111 (5): 746-750.

Lana, M. M., Tijskens, L. M. M. a. & Kooten, O. v. (2005). Effects of storage temperature and fruit ripening on firmness of fresh cut tomatoes. *Postharvest Biology and Technology*, 35 (1): 87-95.

Langton, F., Horridge, J. & Hamer, P. (2000). *Effects of the glasshouse environment on leaf temperature of pot chrysanthemum and dieffenbachia*. 75-84 pp.

Lisiewska, Z. & Kmiecik, W. (2000). Effect of storage period and temperature on the chemical composition and organoleptic quality of frozen tomato cubes. *Food Chemistry*, 70 (2): 167-173.

Lloyd, J. & Farquhar, G. D. (2008). Effects of rising temperatures and [CO2] on the physiology of tropical forest trees. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363 (1498): 1811.

Lu, J., Charles, M. T., Vigneault, C., Goyette, B. a. & Raghavan, G. S. V. (2010). Effect of heat treatment uniformity on tomato ripening and chilling injury. *Postharvest Biology and Technology*, 56 (2): 155-162.

Mercado, J., Trigo, M. M., Reid, M., Valpuesta, V. & Quesada, M. (1997). Effects of low temperature on pepper pollen morphology and fertility: evidence of cold induced exine alterations. *Journal of horticultural science*, 72 (2): 317-326.

Mitcham, E. J. & McDonald, R. E. (1992). Effect of high temperature on cell wall modifications associated with tomato fruit ripening. *Postharvest Biology and Technology*, 1 (3): 257-264.

Moraru, C., Logendra, L., Lee, T.-C. & Janes, H. (2004). Characteristics of 10 processing tomato cultivars grown hydroponically for the NASA Advanced Life Support (ALS) Program. *Journal of Food Composition and Analysis*, 17 (2): 141-154.

Mortensen, L. & Gislerod, H. (2005). *The Influence of Carbon Dioxide Concentration during High-temperature Periods on Net Photosynthesis of Cut Roses*. 89-96 pp.

Ohio Vegetable Production Guide. (2010). Greenhouse Tomatoes. 672-10: 5 (accessed: 16/02/2012).

Oms-Oliu, G., Hertog, M. L. A. T. M., Van de Poel, B., Ampofo-Asiama, J., Geeraerd, A. H. & Nicolaï, B. M. (2011). Metabolic characterization of tomato fruit during preharvest development, ripening, and postharvest shelf-life. *Postharvest Biology and Technology*, 62 (1): 7-16.

Pastenes, C. & Horton, P. (1996). Effect of high temperature on photosynthesis in beans (I. Oxygen evolution and chlorophyll fluorescence). *Plant Physiology*, 112 (3): 1245-1251.

Peet, M. (1992). Fruit cracking in tomato. *HortTechnology*, 2 (2): 216-223.

Peet, M., Sato, S. & Gardner, R. (1998). Comparing heat stress effects on male fertile and male sterile tomatoes. *Plant, Cell & Environment*, 21 (2): 225-231.

Peet, M. M. & Bartholemew, M. (1996). Effect of night temperature on pollen characteristics, growth, and fruit set in tomato. *American Society for Horticultural Science (USA)*.

Peet, M. M., Willits, D. & Gardner, R. (1997). Response of ovule development and post-pollen production processes in male-sterile tomatoes to chronic, sub-acute high temperature stress. *Journal of Experimental Botany*, 48 (1): 101.

Picken, A. (1984). A review of pollination and fruit set in the tomato (Lycopersicon esculentum Mill.). *Journal of horticultural science*, 59 (1): 1-13.

Pressman, E., Peet, M. M. & Pharr, D. (2002). The effect of heat stress on tomato pollen characteristics is associated with changes in carbohydrate concentration in the developing anthers. *Annals of Botany*, 90 (5): 631.

Pressman, E., Shaked, R. & Firon, N. (2006). Exposing pepper plants to high day temperatures prevents the adverse low night temperature symptoms. *Physiologia Plantarum*, 126 (4): 618-626.

Sakata, T., Takahashi, H., Nishiyama, I. & Higashitani, A. (2000). Effects of High Temperature on the Development of Pollen Mother Cells and Microspores in Barley Hordeum vulgare L. *Journal of Plant Research*, 113 (4): 395-402.

Sato, S., Peet, M. & Thomas, J. (2000). Physiological factors limit fruit set of tomato (Lycopersicon esculentum Mill.) under chronic, mild heat stress. *Plant, Cell & Environment*, 23 (7): 719-726.

Sato, S., Peet, M. M. & Thomas, J. F. (2002). Determining critical pre and post anthesis periods and physiological processes in Lycopersicon esculentum Mill. exposed to moderately elevated temperatures. *Journal of Experimental Botany*, 53 (371): 1187.

Sato, S., Kamiyama, M., Iwata, T., Makita, N., Furukawa, H. & Ikeda, H. (2006). Moderate increase of mean daily temperature adversely affects fruit set of Lycopersicon esculentum

by disrupting specific physiological processes in male reproductive development. *Annals of Botany*, 97 (5): 731.

Shaked, R., Rosenfeld, K. & Pressman, E. (2004). The effect of low night temperatures on carbohydrates metabolism in developing pollen grains of pepper in relation to their number and functioning. *Scientia Horticulturae*, 102 (1): 29-36.

Song, J., Nada, K. & Tachibana, S. (2001). The early increase of S-adenosylmethionine decarboxylase activity is essential for the normal germination and tube growth in tomato (Lycopersicon esculentum Mill.) pollen. *Plant Science*, 161 (3): 507-515.

Song, J., Nada, K. & Tachibana, S. (2002). Suppression of S-adenosylmethionine decarboxylase activity is a major cause for high-temperature inhibition of pollen germination and tube growth in tomato (Lycopersicon esculentum Mill.). *Plant and cell physiology*, 43 (6): 619.

Taub, D. R., Seemann, J. R. & Coleman, J. S. (2000). Growth in elevated CO2 protects photosynthesis against high-temperature damage. *Plant, Cell & Environment*, 23 (6): 649-656.

Taylor, L. P. & Hepler, P. K. (1997). Pollen germination and tube growth. *Annual Review of Plant Biology*, 48 (1): 461-491.

Toor, R. K. & Savage, G. P. (2006). Changes in major antioxidant components of tomatoes during post-harvest storage. *Food Chemistry*, 99 (4): 724-727.

Wang, S. Y. & Camp, M. J. (2000). Temperatures after bloom affect plant growth and fruit quality of strawberry. *Scientia Horticulturae*, 85 (3): 183-199.

Weerakkody, W. (2003). *Nutritional value of fresh leafy vegetables as affected by pre-harvest factors*. 511-515 pp.

Woolf, A. B., Bowen, J. H. & Ferguson, I. B. (1999). Preharvest exposure to the sun influences postharvest responses of 'Hass' avocado fruit. *Postharvest Biology and Technology*, 15 (2): 143-153.

Zamir, D., Tanksley, S. & Jones, R. (1981). Low temperature effect on selective fertilization by pollen mixtures of wild and cultivated tomato species. *TAG Theoretical and Applied Genetics*, 59 (4): 235-238.

Zipelevish, E., Grinberge, A., Amar, S., Gilbo, Y. & Kafkafi, U. (2000). Eggplant dry matter composition fruit yield and quality as affected by phosphate and total salinity caused by potassium fertilizers in the irrigation solution. *Journal of plant nutrition*, 23 (4): 431-442.

9. APPENDIXES

Table 2: The table shows number of normal pollen and abnormal pollen (in 10^3 per milliliter); and pollen germination in percentage in different temperature regimes and clusters. Text represents the significant difference value.

		One day after opening			Four days after opening		
Cluster	Day/Night temperature	Normal pollen	Abnormal pollen	Pollen germination	Normal pollen	Abnormal pollen	Pollen germination
First	24/17°C	7.13 c	1.02 b	22.44 b	11.29 b	2.77 b	25.61 c
	27/14°C	9.64 b	0.94 b	23.27 b	15.58 a	2.99 ab	28.39 b
	30/11°C	14.47 a	2.01 a	32.06 a	15.98 a	3.66 a	37.29 a
		**	**	**	**	**	**
Second	24/17°C	40.34 b	15.04 b	19.11 b	40.34 b	15.04 b	19.11 b
	27/14°C	41.64 ab	18.89 ab	24.50 b	41.64 ab	18.89 ab	24.50 b
	30/11°C	48.84 a	20.5 a	34.81 a	48.84 a	20.5 a	34.81 a
		**	**	**	**	**	**
Third	24/17°C	40.34 b	11.34 ab	16.18 c	33.44 b	6.66 c	17.29 c
	27/14°C	41.64 ab	12.71 a	28.56 b	42.10 a	10.63 b	25.44 b
	30/11°C	48.84 a	10.42 b	40.00 a	43.36 a	15.50 a	37.69 a
		**	**	**	**	**	**

** indicates values are significantly different and NS indicates no significant difference at 95% confidence interval.

One day after flower opening:

Table 3: Average maximum day, minimum night temperature and daily temperature; 7 days before flower opening at different temperature regimes.

Day/Night temperature(˚C)	Cluster	Day temperature(˚C)	Night temperature(˚C)	Average temperature(˚C)
24/17	1	21.2±1.5	16.5±0.1	18.4
27/14	1	22.4±2	13.6±0.1	17.1
30/11	1	23.0±2	10.9±0.1	16.5
24/17	2	23.7±1	16.4±0.1	19.1
27/14	2	26.0±1	13.9±0.1	18.2
30/11	2	28.7±2	11.4±0.2	17.5
24/17	3	22.3±2	16.5±0.1	18.9
27/14	3	26.2±2	13.9±0.1	18.4
30/11	3	29.5±2	11.1±0.2	18.1

Table 4: Average light, CO2 and relative humidity (high/low); 7 days before flower opening at different temperature regimes.

Day/Night temperature(˚C)	Cluster	Light (Watt/m^2)	CO_2 (ppm)	Relative humidity in % (High/Low)
24/17	1	50±35	506±111	75±1 (77/74)
27/14	1	50±35	523±107	75±1 (76/74)
30/11	1	50±35	559±90	77±2 (79/75)
24/17	2	119±44	481±86	76±2 (79/73)
27/14	2	119±44	512±83	77±2 (77/74)
30/11	2	119±44	554±88	79±3 (82/75)
24/17	3	102±60	477±80	78±4 (81/75)
27/14	3	102±60	484±100	78±4 (82/76)
30/11	3	102±60	525±110	85±6 (90/79)

Four days after flower opening:

Table 5: Average maximum day, minimum night temperature and daily temperature; 7 days before flower opening at different temperature regimes.

Day/Night temperature(˚C)	Cluster	Day temperature(˚C)	Night temperature(˚C)	Average temperature(˚C)
24/17	1	22.6±2	16.5±0.1	18.7
27/14	1	24.5±2	13.8±0.1	17.7
30/11	1	26.5±3	11.3±0.1	16.9
24/17	2	23.9±1	16.3±0.1	19.2
27/14	2	26.4±1	13.8±0.1	18.4
30/11	2	29.1±2	11.1±0.2	17.7
24/17	3	23.5±2	16.6±0.1	19.3
27/14	3	26.4±2	14.1±0.1	18.9
30/11	3	29.3±2	12.0±0.7	18.5

Table 6: Average light, CO_2 and relative humidity (high/low); 7 days before flower opening at different temperature regimes.

Day/Night temperature(˚C)	Cluster	Light (Watt/m^2)	CO_2 (ppm)	Relative humidity in % (High/Low)
24/17	1	83±43	503±92	75±2 (76/74)
27/14	1	83±43	519±83	76±1 (77/74)
30/11	1	83±43	555±70	77±2 (79/75)
24/17	2	137±44	434±76	75±2 (78/73)
27/14	2	137±44	456±81	76±2 (79/72)
30/11	2	137±44	473±74	79±3 (84/73)
24/17	3	137±70	430±119	78±3 (82/73)
27/14	3	137±70	467±125	78±3 (82/73)
30/11	3	137±70	525±119	82±6 (88/77)

Table 7: The results showing mean values of soluble solids, dry matter (%), pH, titrable acids (%) and firmness along with significance level; text represents the significant difference values.

Treatments		Soluble solids (%)	Dry matter (%)	pH	Titrable acid (%)	Firmness
Day/Night temperature	24/17°C	5.26 a	5.67 a	4.16 b	0.465 a	83.49 b
	27/14°C	4.60 c	5.01 b	4.17 b	0.426 b	86.63 a
	30/11°C	4.71 b	4.85 b	4.21 a	0.409 b	81.53 b
		**	**	**	**	**
Varieties	Capricia	4.84 a	5.32 a	4.13 b	0.467 a	86.56 a
	Mecano	4.87 a	5.11 ab	4.20 a	0.422 b	83.94 b
	Cederico	4.60 b	4.91 b	4.19 a	0.403 b	81.17 c
		**	*	*	**	**
Storing days	0 day	4.85 a	5.16 a	4.19 a	0.431 a	89.20 a
	7 days	4.83 a	5.21 a	4.16 a	0.441 a	83.93 b
	14 days	4.77 a	5.02 a	4.29 a	0.420 a	78.48 c
		NS	NS	NS	NS	**

** shows the values are significant in 99% confidence interval; * shows the values are significant in 95% confidence interval and NS indicates the values are not significant.

Table 8: Average maximum day and minimum night temperature during harvesting of tomato fruits of different temperature regimes and clusters; data recorded four weeks before tomato harvesting.

Day/Night temperature (˚C)	Cluster	Day temperature (˚C)	Night temperature (˚C)	Average temperature (˚C)
24/17˚C	1	25±2	15±1	19.6
	2	25±2	15±1	19.7
	3	25±2	15±1	20.0
27/14˚C	1	27±1	14±0,5	19.3
	2	27±1	14±0,5	19.4
	3	27±1	14±0,5	19.8
30/11˚C	1	30±2	11±0,5	19.4
	2	30±2	11±0,5	19.6
	3	30±2	11±0,5	20.3