

**INFLUENCE OF TEMPERATURE ON THE
YIELD AND QUALITY OF THREE
STRAWBERRY (*Fragaria * anannasa* Duch)
CULTIVARS**

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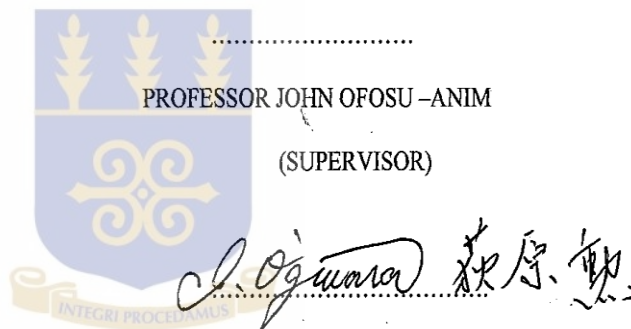
DECLARATION

I hereby declare that except references to the works of other researchers which have been duly cited, this work is the result of my own original research and this dissertation has neither in whole nor in part been presented for another degree elsewhere.

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ABSTRACT

The influence of temperature on yield and quality of three Japanese strawberry (*Fragaria x ananassa* Duch) cultivars ('Sachinoka', 'Benihoppe' and 'Tochiotome') were studied between March and August, 2011 in a screen house at Tokyo University of Agriculture and Technology, Japan. Completely Randomised Design was used with eight (8) replications each of the cultivars. One set of treatment comprising of the three cultivars were set as control and the other treatment was set under a thin film of shade. Yield parameters taken included fruit length, fruit weight, fruit width and number of fruit harvested per plant. Quality parameters taken were fruit colour and fruit firmness. Few vegetative growth parameters were also recorded and these included leaf length and leaf area. The optimum day/ night temperature for fruit development, fruit length, fruit width and fruit weight was 26/14 °C, which occurred in the month May. However, the above parameters reduced as temperature increased throughout the study period. Further, fruit firmness decreased as the temperature increased throughout the study period. Fruit surface colour L, which indicates 'lightness of colour' became darker and greater in pigment intensity as temperature increased to 34/23 °C in July. Increasing growth temperatures resulted in smaller leaf area whiles leaf length increased. Chlorophyll content of leaves and light interception by plants in screen house also increased as the

growth temperature increased. Increasing growth temperatures of the environment resulted in decreased fruit quality including soluble solids. However, sugar-acid ratio, titratable acids and pH varied among the cultivars indicating that these qualities may be heritable traits as they were less influenced by the environment.



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DEDICATION

I dedicate this thesis to my parents who always supported me both financially and spiritually and helped me to climb up the academic ladder.

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LIST OF ACRONYMS

SYMBOL	MEANING
°C	Degree Celsius
μ	Micro
mol	Mole
$m^{-2}s^{-1}$	per meter square per second
PAR	Photo synthetically Active Radiation
mls	Milli litres
%	Percentage
TSS	Total Soluble Solids
Kg	Kilogram
mm	Millimeter
cm	Centimeter
cm ²	Centimeter squared
S.A.S	Statistical Analysis System
g	gram
SPAD	Single Photoelectric Analysing Diode
N	Newton

CHAPTER ONE

1.0 INTRODUCTION

Strawberry (*Fragaria x ananassa* Duch.) belongs to the *Rosaceae* family. It is cultivated in at least 63 countries worldwide. The total world production and acreage are estimated at 2,700,000 MT and 200,000 ha, respectively. The United States is the largest strawberry producing country with almost 28% of total world production (FAO, 1997).

The cultivated strawberry, *Fragaria x ananassa*, fruits form a regular part of the diets of millions of people. Strawberries have been shown to be a rich source of phenolic compounds with antioxidant and anti-proliferation activities (Wang *et al.*, 1996). The strawberry is widely considered as a high value crop because of the high demand. The fruits are rich in vitamin C, iron, potassium and fibre. Strawberries have also been credited with cancer-fighting compounds (Stoner *et al.*, 1999). For hundreds of years homeopathic practitioners have incorporated strawberry plants and fruits in the treatment of anaemia, diabetes, rheumatic gout, kidney and liver complaints. Fresh strawberry removes tartar and teeth stains, soothes sunburn and lightens freckles. Strawberry preserves and jellies are widely used worldwide (Broom *et al.*, 1987).

Wang *et al.* (1996) and Eberhardt *et al.* (2000) have shown that the major antioxidant activity in fruits or vegetables may originate from the polyphenolic compounds and that total phenolic content (TPC) is the major contributor for their antioxidant activities.

Polyphenolic compounds display important functions in plant defence mechanisms and external stresses (Tao *et al.*, 2010) which helps in extending the shelf life and also enhancing the quality of preservation of fruits by delaying senescence induced by oxidative degradation (Connor *et al.*,2002).

Polyphenolic compounds also affect the quality, colour and taste of fruits (Robarbs *et al.*, 1999). Tao *et al.* (2010), Hebert *et al.* (2002) and Khanizadeh *et al.* (2008) also observed from their respective studies that Strawberry cultivars, rich in proanthocyanidins, are more resistant to fungal attacks by *Botrytis cinerea*, even though no strawberry cultivar is completely resistant to that fungus. Herbert *et al.* (2002) also suggested that proanthocyanidin content can be used as an indicator of grey mold resistance, in order to screen strawberry selections and cultivars for improving shelf life and quality.

Genetic factors affect strawberry plant growth and development as well as composition of the fruit. However, strawberry plants are also highly sensitive to variation in environmental conditions. Factors such as water availability, day and night time temperatures, and daylight intensities affect fruit size (Avigdori-Avidov, 1986).

Strawberry cultivars grown in specific areas are often adapted to the growing conditions of that area. Nevertheless, temperature stress is one of the challenges facing strawberry production in the world. Field grown plants are often subjected to fluctuating temperature that has a profound effect on the plant metabolism (Chaitanya *et al.*, 2001).

Reduction in plant growth by high temperatures is well established in horticultural crops such as tomato (*Solanum lycopersicum* L.) (Adams *et al.*, 2001), grape (*Vitis* spp) (Chaumont *et al.*, 1997), and strawberry (Renquist *et al.*, 1983). Generally, exposure to high temperature (35°C) results in reduced plant growth (Hellman and Travis, 1988) and lowers yields (Hellman and Travis, 1988).

High temperatures adversely affect vegetative growth and fruit quality of tomato (Adams *et al.*, 2001; Mulholland *et al.*, 2003) and reproductive systems of peanut (*Arachis hypogaea* L.) (Vara- Prasad *et al.*, 1999). There have been several reports on the responses of strawberry to various temperature regimes. It was observed by Zang *et al.* (1997) that strawberry cells subjected to 30°C grew slowly and failed to proliferate normally in suspension cultures. Strawberry vegetative growth (Hellman and Travis, 1998), root growth (Fukuda *et al.*, 1988), fruit set (Nishiyama *et al.*, 2003), pollen viability (Ledesma *et al.*, 2005), fruit weight (Mori, 1998) and fruit quality (Polito *et al.*, 2002) were all reported to be negatively affected by high temperatures. However, some strawberry plants resistant to high temperature have the ability to maintain high rate of photosynthesis, stabilize proteins and also synthesis new proteins (Gulen and Eris, 2004).

Inspite of the negative effects temperature has on strawberry growth and development, strawberries are cultivated in all arable regions of the globe from the Arctic to the Tropics (Hancock, 1998). Pipattanawong (1996) reported that the June-bearing ‘Tioga’ is adaptable to the high elevation environments in Thailand and produced appreciable marketable fruit sizes. Hellman and Travis (1998) established that the critical range of

strawberry growth inhibition is between 35 and 40 °C and also development of runners is reduced significantly by a three (3) day exposure to 40 °C of temperature. However, the mechanisms involved in heat stress as well as information related to strawberry varietal response to heat stress on the yield and quality of strawberry fruits is limited.

An annual temperature fluctuation occurs in Japan from late spring to the end of summer; a period characterized by high temperature and long exposure to day light that severely impact negatively on the growth and productivity of strawberry. High temperature is anticipated to become a limiting factor to strawberry growth in the future as well as many plant species, as global warming increases. Therefore, research on the mechanism of high temperature stress in strawberry has importance for future advances. The objective of this study was to determine the effect of high temperatures and shade on yield and quality of three Japanese strawberry cultivars.

CHAPTER TWO

2.0 LITERATURE REVIEW

Growth characteristics, origin and morphological description of Sachinoka, Tochiotome and Benihoppe strawberry cultivars.

2.1 Sachinoka

The cultivar 'Sachinoka' was registered as Strawberry Norin No. 20 in 1996 and was developed as a variety for fresh market in forcing culture. The plant is moderately prostrate and the peduncle is slightly longer. Thus intensive management including manual positioning of leaves to expose fruits to light and spraying of gibberellic acid to elongate the flower stalk is not necessary to accelerate fruit colouring. The flower bud of the terminal cluster becomes differentiated in the middle of September under natural conditions. Under forcing conditions, lateral fruit clusters are formed continuously and the plants do not tend to become dwarf even in mid-winter. Early and total fruit yield in normal forcing culture is almost the same as in 'Toyonoka'. The yield until late December is with night cooling and short day treatment in summer before transplanting is 50 to 100% that of 'Toyonoka', while the total yield until spring is almost the same. Average fruit size is slightly smaller but larger than that of 'Nhoyo', the leading variety in forcing culture in Eastern Japan. The fruit skin is shiny scarlet and the shape of the fruit is uniformly conical. Since the fruit firmness is about 20% than that of 'Toyonoka' and 'Nyoho', handling efficiency after harvest and transportability over long distances is higher. The fruit contains a large amount of sugar and ascorbic acid and the flesh texture is suitable for fresh consumption. Sachinoka is susceptible to antracnose, fulsarium wilt

and powdery mildew but symptom severity and spread of powdery mildew are apparently less severe than other strawberry cultivars. 'Sachinoka' is adapted to forcing culture which is especially useful for large scale growers who need labour-saving practices and for production areas rather far from the market where long distance transportation is required.

Source; Journal of the Japanese Society for Horticultural Science, 1994.

2.2 Tochiotome

'Tochiotome' is a new strawberry cultivar released in Japan in 1996. It was selected from hybrid seedlings of a cross between 'Kurume 49' (Toyonoka/Nyoho) and 'Tochinomine' (Kei511/Nyoho) crossed in 1990 to obtain high performance cultivar for forcing culture in Tochigi prefecture, Japan. Tochiotme is vigorous and produces runners well. The leaves are large and dark green and the degree of dormancy is similar to 'Nyoho', the most popular cultivar for forcing culture. The number of flowers per inflorescence is fifteen on the average. The yield is higher than 'Nhoho'. The fruits are conical in shape and have very shining scarlet colour. They have firm peel and flesh so the storage quality is very high. They have strong aroma, weak acidity and are also very juicy making the taste excellent. They are slightly resistant to powdery mildew.

Source; Journal of the Japanese Society for Horticultural Science, 1994.

2.3 Benihoppe

The cultivar 'Benihoppe' was obtained by crossing 'Akihime' and 'Sachinoka'. The time of flower bud initiation is later than 'Akihime' but the secondary and tertiary fruit

clusters are formed continuously. Plant growth is vigorous with successful runner production. The fruit texture is firm making it more suitable for transport and preservation. The fruits contain high sugar and moderate acid content corresponding to that of Sachinoka cultivar. These factors as well as its strong fragrance make the taste very excellent. Average fruit size is larger than other strawberry cultivars but the number of fruits per plant is very few as compared with the other cultivars. Benihoppe is susceptible to Antracnose and powdery mildew.

Source; Journal of the Japanese Society for Horticultural Science, 1994.

2.4 Light and temperature effects on the flower initiation and growth of strawberry

2.4.1 Photoperiod response of strawberry

Photoperiod is a primary environmental factor controlling the transition from vegetative to reproductive growth in strawberry. Commercial strawberry (*Fragaria x ananassa* Duch.) cultivars are classified as short-day or day-neutral, depending upon plant response to photoperiod for flower induction (Durner *et al.*, 1984). There is a third group of cultivars known as long-day or everbearing that had relative importance in the past, but is not currently produced commercially. As reviewed by Darnell and Hancock (1996), in general terms short day genotypes initiate flowers when photoperiod is shorter than 14 hours. On the other hand, day-neutral genotypes seem to be independent of day length in initiating flowers. For example, studies done by Durner *et al.* (1984) on the day-neutral types 'Hecker' and 'Tristar' showed that the numbers of inflorescences per plant were not significantly different under photoperiods of 9 hours (short-day) or 16 hours (long-day).

Optimum photoperiod and number of inductive cycles necessary for most plants to flower are temperature and cultivar dependent. However, as other cultivars have progressively been included in flowering studies, the photoperiodic range for flower induction became even wider suggesting that the response to photoperiod is cultivar related.

Temperature is another factor to be considered when studying photoperiodic responses in strawberry and will many times interact with photoperiod to induce the response. A third factor affecting photoperiodic response is the previous conditioning of the plant (i.e. chilling temperatures). Additionally, the age or size of the plant might condition the perception of light and temperature when photoperiods and/or temperatures are not optimum for flower induction. The older (or larger) the plant, the greater the sensitivity to photoperiod and temperature. Several literatures found that the exposure of only one leaf to light is enough to induce developmental responses in a plant grown under optimum floral inductive conditions. Generally, success in conditioning plants requires plants actively growing during the inductive treatment, as suggested by Nishizawa *et al.* (1997).

2.4.2 Light intensity and quality

Manipulation of flowering in strawberry by different light intensities and quality has been broadly reported in literature. In Belgium, when light from mercury lamps with an intensity of $300 \mu\text{molm}^{-2}\text{s}^{-1}$ was added to the natural winter light (to improve light efficiency in the PAR region) a gain in earliness (10-15 days) of fruit production was achieved in *Fragaria x ananassa* Duch. 'Primella' (Ceulemans *et al.*, 1986). Truss length,

petiole length, and leaf area were also increased under this light treatment. Under high light intensity ($650 \mu\text{mol m}^{-2}\text{s}^{-1}$) provided by incandescent, improved mercury vapour and sodium vapour lamps, the wild strawberry *Fragaria vesca* produced significantly more flowers per plant than at lower light intensities (22 or $150 \mu\text{mol m}^{-2}\text{s}^{-1}$) (Chabot, 1978).

Dennis *et al.* (1970) reported that an intensity of $\sim 430 \mu\text{mol m}^{-2}\text{s}^{-1}$ fluorescent + incandescent light almost doubled the number of flower stalks per plant compared to $\sim 220 \mu\text{mol m}^{-2}\text{s}^{-1}$ in 'Geneva,' a day neutral strawberry, under long photoperiod or continuous light, and at $24^{\circ}/21^{\circ}\text{C}$. In the UK, Wright and Sandrang (1995) observed a reduction in crown number in 'Hapil' strawberries when the percentage of shading on the plant was increased from 0 to 70%. Although flowering and fruiting were not evaluated in that experiment, which was conducted from May to Sept., the authors suggested a potential decrease in yield in plants grown under $>25\%$ shade as a consequence of decreased crown branching.

Flower initiation in short-day strawberries may be regulated by light quality and the phytochrome (P) may be involved in the flowering process (Collins, 1966; Vince-Prue and Guttridge, 1973). Vince-Prue and Guttridge (1973) exposed 'Cambridge Favourite' (short-day) plants to 8, 14, and 17 cycles of 8 hour photoperiod, and to $20\text{-}21^{\circ}/15\text{-}16^{\circ}\text{C}$ day/night temperatures. The 8-hour photoperiod was extended to 16.5 hours with red (fluorescent light), far red (incandescent light) or a 1:1 ratio of red and far red lights. After completion of the light treatments, the plants were grown under long day (24-h photoperiod) for 2 weeks. Then the plants were dissected in order to examine floral primordia formation. Eighty percent control plants (grown under an 8-h photoperiod without light extension) flowered after 14 short-day (8 h) cycles. Photoperiod extension

with far red retarded floral initiation (only 20% plants flowered after 17 short-day cycles). Photoperiod extension with red far red decreased floral initiation (40% plants flowered after 14 short-day cycles).

Photoperiod extension with red light did not delay floral initiation (60% plants flowered after 14 short-day cycles). According to Vince-Prue and Guttridge (1973), photoperiod extension or night-break with a high red/far red ratio (which increases Pfr or far-red absorbing form of the phytochrome), given during the long dark period required for flowering in short-day plants, suppressed flowering in short-day species such as *Perilla*, and *Xanthium*. On the contrary, photoperiod extension with a high red/far red ratio did not inhibit flowering in short-day strawberries. Therefore, they suggested that rather than the phytochrome reactions, other mechanism, such as the production of a flower inhibitor in the leaves, might prevent flowering in short- day strawberry plants grown under long photoperiod.

2.5 Temperature

Temperature is an important factor influencing seed germination, vegetative growth, flowering, fruit set and fruit ripening in horticultural crops (Sage and Kubien, 2007; Ledesma *et al.*, 2008; Kositsup *et al.*, 2009). Both high and low temperatures, be they temporary or constant, can induce morpho-anatomical, physiological and biochemical changes in plants, leading to profit reduction (Higuchi *et al.*, 1998; Wang *et al.*, 2003; Wahid *et al.*, 2007). Heat stress can be a concern in many regions of the tropics and subtropics, since high temperature can cause significant damage such as sunburns on

leaves, branches and stems, anticipated leaf senescence and abscission, shoot and root growth inhibition and fruit discoloration and damage (Yamada *et al.*, 1996; Higuchi *et al.*, 1998; Almeida and Valle, 2007; Wahid *et al.*, 2007).

Temperature conditions the response of *Fragaria* to photoperiod in short-day and day-neutral cultivars. Temperature is considered as important as photoperiod for flowering at high latitudes where long photoperiods prevail (Heide, 1977), and in tropical to equatorial latitudes, where photoperiod is short enough for flowering year round but where temperatures are too high. For this reason, in equatorial regions, strawberry can be commercially grown only in the highlands, where temperatures are lower. The development of cultivars adapted to both extremes of latitude has allowed the expansion of the cultivated species in these areas.

2.5.1 Temperature interaction with photoperiod

Series of experiment have led to the conclusion that short-day strawberry cultivars are temperature related. Consequently, these plants have been classified as short day-qualitative or absolute plants at high temperature, and short day quantitative or facultative at low temperature (Salisbury and Ross, 1992). Darrow (1966) exposed nine different strawberry cultivars to three photoperiods combined with three different temperature regimes. He found out that those photoperiods less than 14 hours combined with temperatures around 15°C produced the best flowering response. Thus, the longer the photoperiod, the lower the temperature needed to maximize flower number. Conversely,

environments with long photoperiod and relatively high temperature minimized flower induction and promoted vegetative growth.

Evidence supporting Darrow's results has been continuously produced by several scientists. Hartmann (1947a, b) exposed plants of several cultivars to two temperatures (15.5°C and 21°C) and two photoperiods (10 and 15 hours). All plants were induced to flower at 15.5°C, regardless of the photoperiod. Ito and Saito (1962) reported that 'Robinson' was induced to flower at temperatures between 9°C and 24°C, and 8 hour photoperiods. Jonkers (1965) obtained more flowers at 15°C than at 21°C in 'Talisman' in a short photoperiod, but failed to induce blossoms at 15°C. Heide (1977) compared the interactions of three temperatures (12°C, 18°C, and 24°C) and five photoperiods (10 hours, 12 hours, 14 hours, 16 hours and 24 hours) in five cultivars. At 12°C and 18°C, three cultivars flowered at all photoperiods, but they remained vegetative at 24°C under long photoperiod. In the other cultivars, critical temperatures were 12°C at 16 hours, 18°C at 14 hours, and 24°C at 13 hours photoperiod. Went (1957) exposed the short day cultivar 'Marshall' to four temperatures (6°C, 10°C, 14°C, and 20°C) and three photoperiods (8 hour, 16 hour, and 24 hours). Plants initiated flowers at all temperatures under an 8h photoperiod. Plants under a 16 hour photoperiod flowered only at 6°C or 10°C. Went therefore defined 'Marshall' as a short day cultivar at temperatures above 10°C and day neutral cultivar at lower temperature since they flowered even under a 24 hour photoperiod.

Sonsteby (1997) reported that at 9°C or 15°C, the short day cultivars ‘Bounty’ and Sengana’ flowered under both 8 hour and 24 hour photoperiods. It was concluded that flowering in plants grown under 9°C-15°C was photoperiodically insensitive. Collins and Barker (1964) induced ‘Sparkle’ to flower under relatively high temperatures (23° C /20°C) and continuous light, simply by changing light quality during the 20°C period. Thus, photoperiod/temperature interactions are likely to influence the flowering response at mid range temperatures (15°- 25°C), although the specific response is cultivar dependent (Sonsteby, 1997).

The minimum number of inductive cycles is a measure of the efficiency of the photoperiod and temperature interaction to bring about flower induction. At a 10 hour photoperiod and 21°C, ‘Missionary’ required 4 to 7 inductive cycles to start flowering, although this cultivar expressed maximum flowering with 21 cycles (Hartmann, 1947b). Went (1990) found that at 17° C to 23°C, 9 to 15 short day cycles were needed to induce flowering in ‘Marshall.’ Ito and Saito (1962) established that 10 cycles of 9°C with photoperiods between 8 hour and 12 hour brought about floral induction in a short day cultivar. ‘Sparkle’ was induced in 12 to 15 days under an 8-h photoperiod combined with 21° C /18°C day/night temperatures (Moore and Hough, 1962).

2.5.2 Thermoperiod and flower induction

Hartmann (1947a) showed that ‘Missionary’ plants conditioned with short photoperiods and fluctuating day (26.7°C) and night (15.6°C) temperatures had earlier fruit set and ripening than those grown at a constant temperature of 21°C. No differences in the total number of flowers were observed. Okimura and Igarashi (1997), found no difference

between 25°C/15°C (day/night) and 20°C constant in terms of flower induction the cultivar 'Selva' grown under a 16 hour photoperiod. Fluctuating temperatures have been used in experiments designed to promote flower induction in the cultivated and wild strawberries (Reichart, 1973; Bish *et al.*, 1997; Durner *et al.*, 1984; Chabot, 1978).

2.5.3 High temperature and flower induction

Durner and Poling (1988) revealed that flowering is inhibited by high temperature in short-day genotypes and these genotypes are more sensitive than day-neutral genotypes. Regardless of the photoperiod, constant high temperatures in the range of 28°C to 30°C inhibited flower induction in short day and day neutral cultivars of *F. x ananassa* Duch., and in *F. vesca* (Okimura and Igarashi, 1997). Heide (1977) found that flower number decreased considerably when plants of 'S. Sengana' and 'Abundance' were exposed to 24°C under short photoperiods, compared to 18°C. 'Sweet Charlie' plug transplants grown at a 25/15°C day/night temperature regime initiated flowers earlier and developed a more profuse root system than those held at 35/25°C under identical photoperiod and time of exposure (Bish *et al.*, 1996). Heide again stated that high temperature acts synergistically with long-days in promoting the biosynthesis of a flower inhibitor.

2.5.4 Low temperature and flower induction

Several reports have indicated that lower temperatures are very necessary for flower induction. Low temperature in strawberry is related to chilling; a variable period of

exposure to temperatures below 10°C that breaks bud dormancy. Darnell and Hancock, (1996) reported that chilling in strawberry plants was reported to promote both reproductive and vegetative responses, and was an important factor in balancing reproductive and vegetative growth. Chilling enhances vegetative growth, reduces flower induction, does not affect flower initiation, but augments floral differentiation (Durner and Poling, 1987). Increases in petiole length, leaf size, leaf number, leaf area, and runner formation occur as chilling increases (Kahangi *et al.*, 1992; Lieten, 1997). The chilling requirement is cultivar dependent in *F. x ananassa* Duch probably due to the contrasting sensitivity to chilling of their parents *F. virginiana* and *F. chiloensis*. The northern species, *F. virginiana*, has a longer chilling requirement than the southern species, *F. chiloensis*

Generally for strawberries, it is known that as chilling time increases, flower induction also decreases. Thus Durner and Polling (1988) pointed out that chilling preceding the optimum digging date at the nursery was advantageous for early fruit production in warm regions, while extra chilling after the optimum digging date had a negative effect on flowering. However, exposure of plants to night temperatures of about 15°C and short photoperiods (conditioning for flowering treatment) resulted in higher early yield, at least for ‘Sweet Charlie’ plug transplants in Florida (Bish *et al.*, 1996) and for ‘S. Sengana’ in Germany (Reichart, 1973). Plants exposed for two weeks to 15°C and 25°C during the dark and light periods, respectively, were more vigorous, and had improved stand establishment and capability to hold larger berries than plants grown at 35°C /25°C; however, there was no effect on flower induction. Lieten (1997) reported that chilled and

non-chilled plants of 'Elsanta' both produced flower trusses, but trusses of non-chilled plants were shorter. Additionally, early berry size was smaller and fruit quality was poorer in non-chilled versus chilled plants (Hamann and Poling, 1997).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Plant material and treatments used

Six month old Japanese strawberry cultivars ('Sachinoka', 'Tochiotome' and 'Benihoppe') were used in this experiment in a completely randomized design. A completely randomized design was used. The treatments were set as control and shade. Three strawberry cultivars were used with eight (8) replications per cultivar. Two different sets of treatments were used. One set of treatment consisting of 'Sachinoka', 'Tochiotome' and 'Benihoppe' were set as control and the same set of treatment were placed under shade in the screen house. The control had a total of twenty-four (24) plants and the shade treatment had a total of twenty-four (24) plants. The cultivars were propagated by runners in September, 2010 and were later transferred into plastic containers (14cm x 12 cm) containing a mixture of kanuma, vermiculite and peatmoss in the ratio 1:1:1 under plug fertigation system (N=7.2: P=2.0: K=3.3: Ca=3.2: Mg=1.2: EC=1.0). The strawberry plants were treated with 150 mls of fertigated water five (5) times a day during the winter and later increased to seven (7) times a day in the summer because of high temperatures. The experiment was set up from March to August.

Data collected during the period of the study included qualitative and qualitative parameters. The qualitative parameters included:

- Fruit firmness
- Fruit colour

- Titratable acidity
- Total soluble solids
- Percentage acidity
- Sugar-acid ratio
- pH

Other plant parameters recorded included:

- Number of fruits harvested
- Fruit weight
- Fruit length
- Fruit width
- Leaf area
- Leaf length

Environmental parameters were also recorded and these included:

- Light intensity
- Chlorophyll content
- Temperature
- Humidity



Figure 1: Control plants



Figure 2: Plants under shade treatment

3.2 Mean fruit length, mean fruit weight, fruit width, petiole length (Leaf height), leaf width and leaf area

The length (mm) of fruits was measured with a ruler from the tip of the fruit to the base of the pedicel. Fruit weight (kg) was measured using a weighing scale immediately after harvest. The diameter or width (mm) of fruits harvested was taken at the broadest part of the fruit with a venier caliper. Leaf height (cm), leaf area (cm²) and petiole length (cm) were all measured with a tape measure.

3.3 Relative Chlorophyll content

An indirect index of chlorophyll content was measured with a leaf chlorophyll meter. Three SPAD measurements from locations between the veins were averaged to represent one observation.



Figure 3: Chlorophyll meter (Model SPAD-502, Minolta, Japan) used for measuring leaf chlorophyll during the experimental period

3.4 Temperature, humidity and light intensity

Temperature and humidity were measured by use of data logger for the period of the experiment. Light intensity was measured at regular intervals with a photometer on a horizontal plane above the plant canopy.

3.5 QUALITY MEASUREMENT

3.5.1 Fruit Firmness

Fruit firmness was determined by using a universal testing machine (Fudoh Rheometer RT-3005D) and this was done immediately after harvesting. The machine was equipped with a load cell of 50 N for measuring the force that is required to push a cylindrical probe into the strawberries. The diameter of the plunger was 5 mm. The penetration depth was 5 mm and the speed at which the probe moved was 5 mms^{-1} . These properties are most appropriate for measuring the firmness of small fruit such as strawberries (Hietaranta and Linna, 1999). Refer to figure 4



Figure 4: Penetrometer (Fudoh Rheometer RT-3005D) used for measuring fruit firmness during the study

3.5.2 Colour measurement

The surface color of each fruit was measured with a hand-held tristimulus reflectance colorimeter (Minolta, Model CR-300, Osaka, Japan). Colour was recorded using the L^* , a^* , b^* uniform colour space (CIE Laboratories), where L^* indicates lightness, a^* indicates chromaticity on a green (–) to red (+) axis, and b^* indicates chromaticity on a blue (–) to yellow (+) axis. Numerical values of a^* and b^* were converted into hue angle ($Hue = \tan^{-1} b^* / a^*$) and chroma by the formula $[(a^{*2} + b^{*2})^{1/2}]^{33}$. (Refer to figure 5).



Figure 5: Colorimeter (Minolta, Model CR-300, Osaka, Japan) used for measuring fruit colour during the study

3.5.3 Preparation of samples for chemical measurement

After firmness and color measurements, samples were kept in a refrigerator at -31°C . Three fruits were chosen randomly from each month and chopped into small pieces with a knife. 1 g of sample was measured into 100ml/volume beaker and 4mls of distilled water was also added to the sample in the distilled water. The samples were then loaded into ependorf tubes and centrifuged at 13000rpm for 10 minutes (Figure 6- figure 8).



Figure 6: Fruit samples for chemical analysis

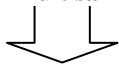


Figure 7: Ground fruit samples

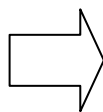


Figure 8: Centrifuge

3.5.4 Soluble solids (SSC), pH and Titratable acids (TA)

The soluble solid content (SSC) of the juice samples was determined with a hand held refractometer and was expressed in terms of percentage. The pH of the juice samples was determined using a pH meter that had previously been standardized to pH 4 and 7. For total titratable acidity (TTA) measurement, aliquots (6.00 g) of juice were diluted with 5ml of distilled water and the titratable acidity determined by titration with 0.1molL⁻¹ NaOH to an end point (that is when a pink colour was obtained). The results were converted to percentage acidity by the formula (Titre value * acid factor * 1.0283 * 0.25 * 100) / 1ml juice



Figure 9: pH meter (pH-526; WTW measurement systems, Wissenschaftlich-Technische Werkstätten GmbH, Wellhelm, Germany)

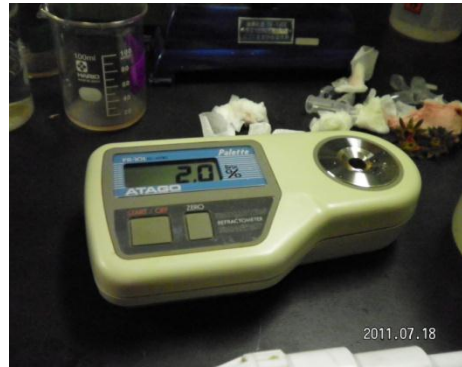


Figure 10: Refractometer (Palette 100 PR-100, AT AGO-Spectrum Technologies, Plainfield, IL) used for measuring brix during the experimental period

3.6 STATISTICAL ANALYSIS

The Statistical Analysis System computer package was used for the analysis. Data were analyzed by analysis of variance (ANOVA) and significant differences were detected by Tukey- Kramer test at $P < 0.05$.

CHAPTER FOUR

4.0 RESULTS

4.1 TOTAL NUMBER OF FRUITS HARVESTED DURING THE STUDY

Table 1: Total number of fruits harvested

CULTIVAR	MONTH		
	MAY	JUNE	JULY
A(CONTROL)			
SACHINOKA	7	27	6
TOCHIOTOME	13	17	13
BENIHOPPE	11	14	14
B (SHADED)			
SACHINOKA	15	16	2
TOCHIOTOME	22	7	11
BENIHOPPE	24	7	3

Total number of fruits (yield) harvested (Table 1) were different for all the cultivars. ‘Tochiotome’ recorded the highest number of fruits for the control plants followed by ‘Sachinoka’ and ‘Benihoppe’. For the shaded cultivars, ‘Tochiotome’ had the highest number of fruits followed by ‘Benihoppe’ and ‘Sachinoka’.

4.2 Fruit weight

Table 2: Effect of shade on mean fruit weight (g) of the three (3) strawberry cultivars

CULTIVAR	MONTHS			MEAN
	MAY	JUNE	JULY	
A (CONTROL)				
SACHINOKA	10.50	12.89	9.75	11.05
TOCHIOTOME	16.40	12.69	12.37	13.82
BENIHOPPE	17.70	16.52	9.79	14.67
	NS	NS	NS	
LSD (0.05)	0.120	0.050	0.460	
B (SHADED)				
SACHINOKA	15.10	11.04	9.20	11.78
TOCHIOTOME	18.09	12.60	10.00	13.56
BENIHOPPE	16.93	12.20	7.20	12.11
	NS	NS	NS	
LSD (0.05)	0.482	0.809	0.638	

For the control, the average weight/ plant (Table 2) showed no significant difference among the three cultivars. However, the highest mean weight was recorded for ‘Benihoppe’ (14.67g/plant) which is known to be a high yielding cultivar and the lowest was recorded for Sachinoka (11.05g/plant).

With the shaded treatment (Table 2), mean fruit weight decreased from May to July. However there were no significant differences observed. The highest mean fruit weight

was recorded in ‘Tohiotome’ (13.56g/plant) and the lowest for ‘Sachinoka’ (11.78g/plant).

4.3 Fruit length

Table 3: Effect of shade on mean fruit length (mm) of the three strawberry cultivars

CULTIVAR	MONTHS			MEAN
	MAY	JUNE	JULY	
A (CONTROL)				
SACHINOKA	32.30 a	34.31 a	30.68	32.43
TOCHIOTOME	38.60 a	33.55 a	31.21	51.68
BENIHOPPE	42.90 a	39.89 a	29.89	37.56
			NS	
LSD (0.05)	0.014	0.014	0.765	
B (SHADED)				
SACHINOKA	35.23	29.20	33.35	32.59
TOCHIOTOME	39.52	33.10	32.16	34.93
BENIHOPPE	38.55	34.70	26.80	33.35
	NS	NS	NS	
LSD (0.05)	0.170	0.112	0.098	

Means followed by the same letter are not significantly different

Fruit length (mm) decreased steadily from May to July in both treatments. There were no significant differences among the unshaded plants. The highest mean fruit length was

recorded from 'Tochiotome' (34.93mm) and the lowest was recorded from 'Sachinoka' (32.59mm). The shade plants showed significant differences in fruit length. In May after separation by Turkeys, the differences were not significant. The trend was similar in June. However, in July no significant differences were recorded among the cultivars. However, the highest mean fruit length was recorded from Tochiotome (51.67mm) and the lowest for Sachinoka (32.43mm).

4.4 Fruit width

Table 4: Effect of shade on mean fruit width (cm) of the strawberry cultivars

CULTIVAR	MONTHS			MEAN
	MAY	JUNE	JULY	
A (CONTROL)				
SACHINOKA	27.47	28.93	26.52	27.64
TOCHIOTOME	31.89	32.19	28.23	30.77
BENIHOPPE	32.34	28.95	26.59	29.29
	NS	NS	NS	
LSD (0.05)	0.134	0.087	0.572	
B(SHADED)				
SACHINOKA	31.17	27.44	27.70	28.77
TOCHIOTOME	32.21	29.53	26.48	29.41
BENIHOPPE	30.15	27.59	23.43	27.06
	NS	NS	NS	
LSD (0.05)	0.390	0.649	0.382	

Fruit width for unshaded plants (Table 4) increased steadily from May to July. Tochiotome recorded the highest mean fruit width (30.77) and the lowest for ‘Sachinoka’ (27.64). The differences which occurred were not significant. With the shaded plants, ‘Tochiotome’ recorded the highest mean fruit width (29.41) and the lowest mean fruit

width was recorded by 'Benihoppe' (27.06). However, there were no significant differences in the values obtained.

4.5 Leaf height

Table 5: Effect of shade the mean leaf height (cm) of the three strawberry cultivars

CULTIVAR	MONTHS			MEAN
	MAY	JUNE	JULY	
A (CONTROL)				
SACHINOKA	20.56 b	26.36	27.25	24.72
TOCHIOTOME	19.12bc	27.84	29.44	25.47
BENIHOPPE	28.06 a	28.19	29.62	28.62
		NS	NS	
LSD (0.05)	0.001	0.498	0.280	
B (SHADED)				
SACHINOKA	19.57bc	26.00	25.81bc	23.79
TOCHIOTOME	21.75b	27.74	28.25b	25.91
BENIHOPPE	30.56a	30.46	34.08a	31.70
		NS		
LSD (0.05)	0.001	0.088	0.001	

Means followed by the same letter are not significantly different

Table 5 shows the leaf area measurement for the three strawberry cultivars used in the study. Leaf height increased from May to July with increase in temperature. With the

unshaded plants, significant differences were observed in May. However, no significant differences were observed in June and July. ‘Benihoppe’ recorded the highest mean leaf height (28.62cm) and the lowest for ‘Sachinoka’ (24.72cm).

With the shaded cultivars, May and July recorded significant differences in the mean leaf area values obtained. However, ‘Benihoppe’ recorded the highest mean leaf height (31.70cm) and the lowest mean leaf height for ‘Sachinoka’ (23.79cm).

4.6 Leaf area

Table 6: Effect of shade on the mean leaf area (cm²) of the three strawberry cultivars

CULTIVAR	MONTHS			MEAN
	MAY	JUNE	JULY	
A (CONTROL)				
SACHINOKA	54.40 b	57.80c	52.40 c	54.87
TOCHIOTOME	190.90a	114.6 a	111.6 a	139.03
BENIHOPPE	97.50 a	84.20 b	76.60 b	129.15
LSD (0.05)	0.006	0.001	0.001	
B (SHADED)				
SACHINOKA	80.30 c	67.80 a	76.80	112.45
TOCHIOTOME	109.10b	104.9 a	92.60	102.2
BENIHOPPE	136.40a	87.90 a	89.60	104.63
			NS	
LSD (0.05)	0.001	0.012	0.345	

Means followed by the same letter are not significantly different

Leaf area (cm²) decreased steadily from May to July for both the control and shade plants. However with the control, significant differences were observed from May to July. However, Tochiotome recorded the highest mean leaf area (139.03 cm²) and the lowest leaf area was recorded from Sachinoka (54.87 cm²).

The shaded plants also showed a decline in leaf area from May to July. There were significant differences in the strawberry cultivars. However, the highest mean leaf area was recorded from Benihoppe (104.63 cm²) and the lowest leaf area was also recorded from Tochiotome (102.20 cm²).

4.7 Chlorophyll content

Table 7: Variation in Chlorophyll content of the three strawberry cultivars

CULTIVAR	MONTHS			MEAN
	MAY	JUNE	JULY	
A (CONTROL)				
SACHINOKA	38.40	40.10	42.80	40.43
TOCHIOTOME	39.08	41.20	49.90	43.39
BENIHOPPE	37.59	35.80	44.10	39.16
	NS	NS	NS	
LSD (0.05)	0.769	0.279	0.079	
B (SHADED)				
SACHINOKA	39.26	40.60	45.00	42.80
TOCHIOTOME	43.64	42.10	45.70	43.90
BENIHOPPE	38.51	38.00	34.60	36.30
	NS	NS	NS	
LSD (0.05)	0.026	0.292	0.178	

** Means followed by the same letter are not significantly different*

Relative chlorophyll content (Table 7) increased steadily from May to July for the control plants with Tochiotome recording the highest chlorophyll content followed by Sachinoka and then Benihoppe. However, the differences that occurred were not significant.

Relative chlorophyll content also showed an increased trend for the shaded plants from May to July with Tochiotome recording the highest chlorophyll content followed by

Sachinoka and then Benihoppe. In May significant differences was observed among the cultivars but the differences were not statistically significant.

4.8 Light intensity

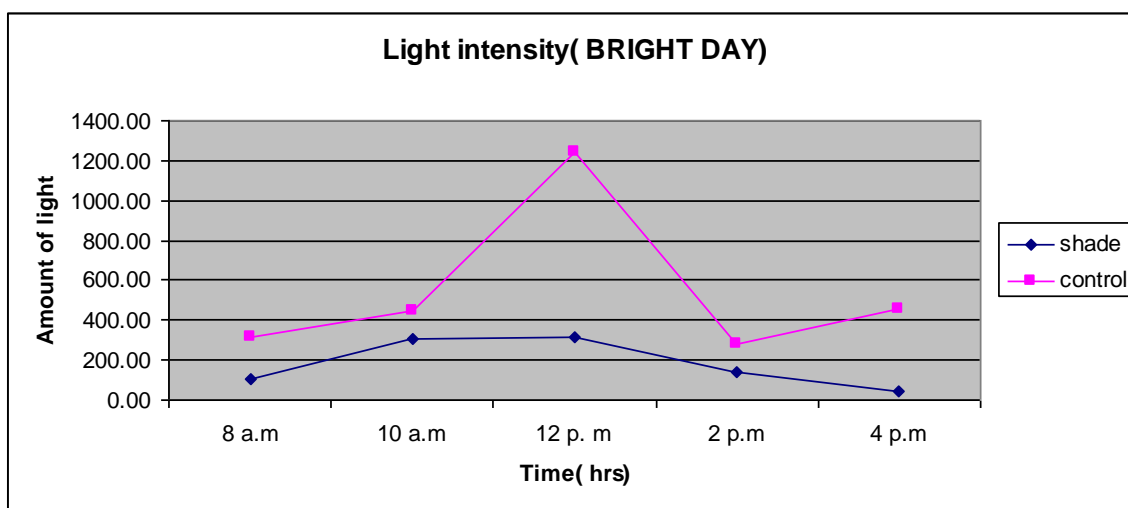


Figure 11: Light intensity variation measured during bright days at two hour interval

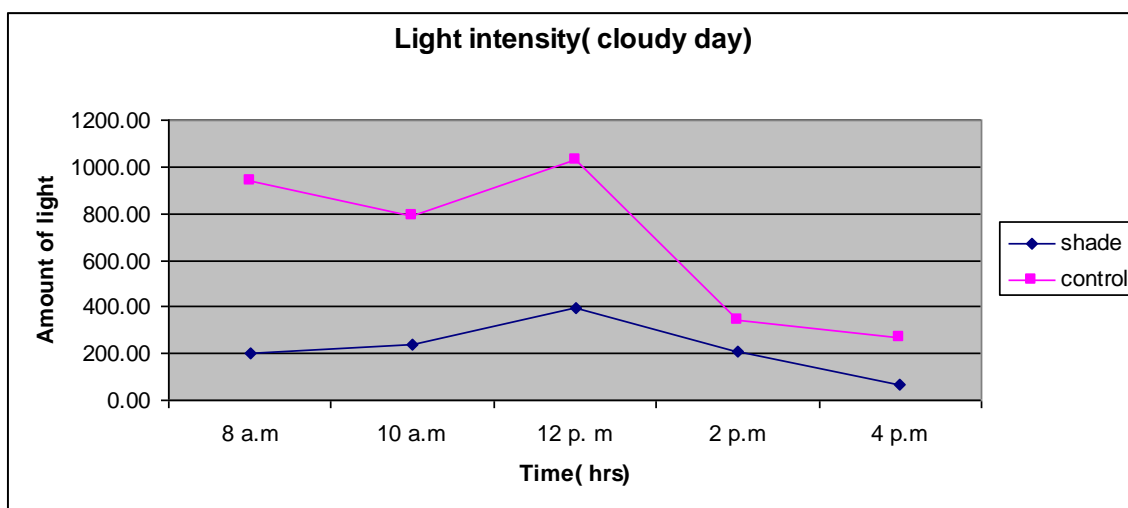


Figure 12: Light intensity variation measured on sunny days at two hour interval

Light intensity measured with a photometer on both sunny and bright day's showed similar trends. It was observed that the amount of light received by the strawberry cultivars was very low in the mornings. The highest light intensity was always recorded around mid-day and then declined steadily towards the evening.

4.9 Temperature

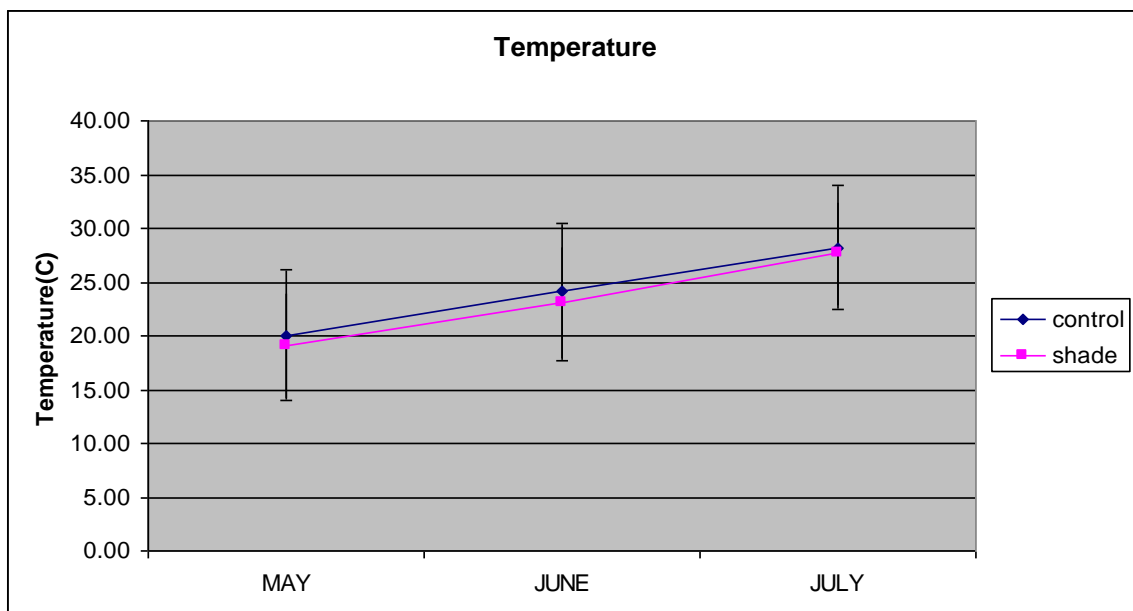


Figure 13: Temperature variation measurements during the experimental period

The highest temperature occurred in July with an average temperature of about 25°C. Maximum average temperature was 34 °C and minimum average was around 22 °C. In June, average temperature was around 24 °C with maximum and minimum averages of 31 °C and 17 °C respectively. The month May had the lowest average temperature of 20 °C with maximum and minimum average temperatures at 14 °C and 26 °C, respectively.

4.10 Humidity

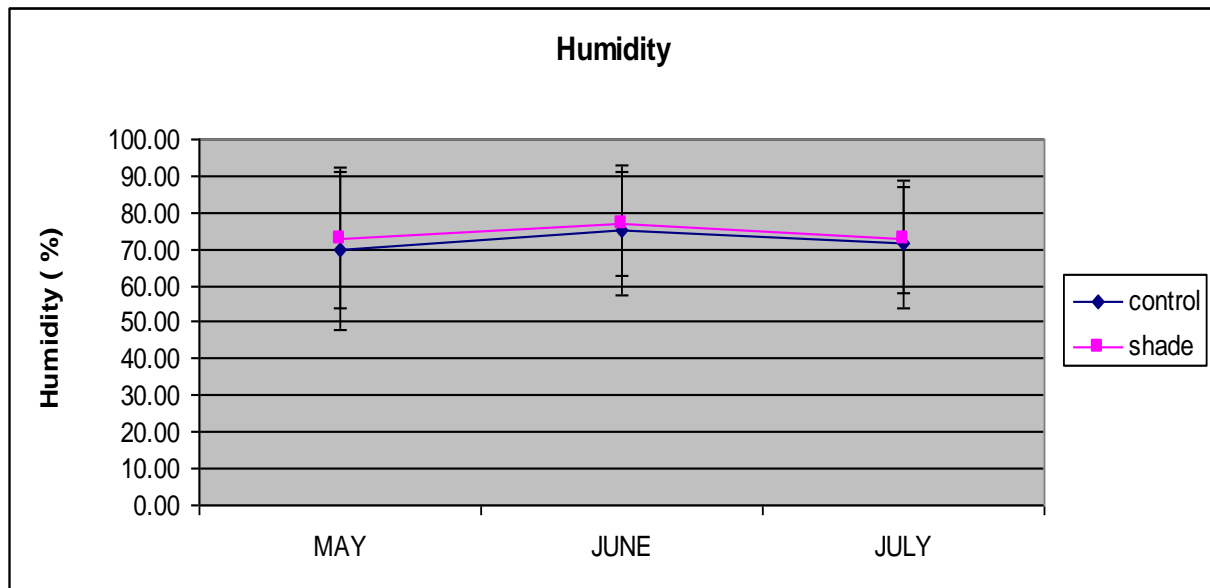


Figure 14: Humidity measurement during the experimental period

The highest average humidity occurred in June (78%) which was followed by May (71%) and then July recorded the least humidity of 70%.

4.11 QUALITY ANALYSIS

4.11.1 Fruit firmness

Table 8: Effect of shade on the mean fruit firmness (kg/N) of the strawberry cultivars

CULTIVAR	FRUIT FIRMNESS (Kg/N)			MEAN
	MONTHS			
	MAY	JUNE	JULY	
A(CONTROL)				
SACHINOKA	0.0459	0.0426	0.0379a	0.1264
TOCHIOTOME	0.048	0.0407	0.0282a	0.0389
BENIHOPPE	0.062	0.0427	0.0270a	0.0439
	NS	NS		
LSD (0.05)	0.567	0.900	0.016	
B (SHADED)				
SACHINOKA	0.0457	0.044	0.0404	0.04337
TOCHIOTOME	0.0478	0.037	0.0372	0.04067
BENIHOPPE	0.0384	0.0527	0.0440	0.04503
	NS	NS	NS	
LSD (0.05)	0.299	0.474	0.513	

Means followed by the same letter are not significantly different

Fruit firmness analysis (Table 8) showed no significant differences among the three strawberry cultivars used in this study in May and June for the control plants. However,

differences were observed in July among the cultivars but these were not statistically significant at $P < 0.05$.

4.11.2 Fruit colour

Table 9: Fruit colour measurement of the strawberry cultivars used in the study

CULTIVAR		FRUIT COLOUR								
		MAY			JUNE			JULY		
A(CONTROL)	L	Hue	Chroma	L	Hue	Chroma	L	Hue	Chroma	
Sachinoka	41.31	35.18	18.27	37.38	29.94	16.17	32.29	26.96	21.35	
	38.21	33.71	14.13	40.33	38.88	23.43	33.94	26.98	29.40	
Tochiotome	39.44	37.49	52.19	34.88	32.40	16.95	13.86	45.50	43.95	
	40.19	33.88	39.55	39.36	33.81	71.39	16.20	40.49	94.84	
Benihoppe	30.46	30.12	19.58	18.28	42.85	32.78	39.50	38.61	65.51	
	40.19	33.88	18.25	38.38	38.16	54.15	39.50	37.33	93.03	
B(SHADE)										
Sachinoka	30.00	27.00	16.30	27.30	19.90	20.20	20.20	12.00	28.00	
Tochiotome	29.20	16.50	17.60	26.40	15.10	21.70	20.80	12.50	25.60	
Benihoppe	24.00	12.00	25.50	22.50	13.00	25.50	36.80	14.90	38.70	

Table 9 shows the colour of fruits of the three strawberry cultivars used in the study. *L* indicates lightness, hue indicates chromaticity on a green (–) to red (+) axis, and chroma indicates chromaticity on a blue (–) to yellow (+) axis.

4.11.3 Soluble solid content

Table 10: Effect of shade on the total Soluble Solid Content (%) of the three strawberry cultivars

CULTIVAR	Soluble Solid Content (%)			
	MONTHS			
	MAY	JUNE	JULY	MEAN
A(CONTROL)				
Sachinoka	8.40	9.00	9.20	8.87
Tochiotome	4.80	7.00	8.40	6.73
Benihoppe	11.20	8.60	9.20	9.67
B(SHADED)				
Sachinoka	6.00	4.60	6.40	5.67
Tochiotome	14.40	8.00	7.20	9.87
Benihoppe	7.20	9.20	8.00	8.13

Soluble solid content (Table 10) increased in some of the cultivars towards July due to high temperature. Among the unshaded plants, Benihoppe recorded the highest mean soluble content, which was followed by Sachinoka and Tochiotome.

The shaded cultivars also showed differences in soluble solid content. All the three varieties showed a decline in soluble solid content from May to July with Tochiotome recording the highest soluble content followed by Benihoppe and then Sachinoka.

4.11.4 Titratable acidity**Table 11: Effect of shade on titratable acidity (mls) of the strawberry cultivars**

CULTIVAR	Titratable Acidity (mls)			
	MONTHS			
	MAY	JUNE	JULY	MEAN
A(CONTROL)				
Sachinoka	2.95	4.13	3.65	3.58
Tochiotome	3.00	3.18	3.93	3.37
Benihoppe	5.70	3.55	3.45	4.23
B(SHADED)				
Sachinoka	2.75	3.28	3.50	3.18
Tochiotome	4.00	2.90	3.88	3.59
Benihoppe	2.60	3.05	3.40	3.02

Acidity (Table 11) measurement for the unshaded cultivars showed that Benihoppe recorded the highest mean acidity followed by Sachinoka and then Tochiotome.

With the shaded plants, Tochiotome recorded the highest acidity followed by Sachinoka and then Benihoppe.

4.11.5 Sugar:acid ratio

Table 12: Effect of shade on Sugar:acid ratio of the three cultivars

CULTIVAR	Sugar:Acid ratio			
	MONTHS			
	MAY	JUNE	JULY	MEAN
A(CONTROL)				
Sachinoka	2.84	2.18	2.52	2.51
Tochiotome	1.60	2.20	2.14	1.98
Benihoppe	1.96	2.42	2.67	2.35
B(SHADE)				
Sachinoka	2.18	1.40	1.83	1.80
Tochiotome	3.60	2.76	1.86	2.74
Benihoppe	2.77	3.02	2.35	2.71

Sugar -acid ratio (Table 12) varied among the cultivars used in the study. For the unshaded plants, Sachinoka recorded the highest mean soluble content which was followed by Benihoppe and then Tochiotome. Under shade, Benihoppe recorded the highest mean soluble content followed by Tochiotome and Sachinoka.

4.11.6 Percentage acidity**Table 13: Effect of shade on the Percentage (%) acid content of the three strawberry cultivars**

CULTIVAR	Acid Content (%)			
	MONTHS			
	MAY	JUNE	JULY	MEAN
A(CONTROL)				
Sachinoka	0.4854	0.6795	0.6005	0.5885
Tochiotome	0.4936	0.5232	0.6466	0.5545
Benihoppe	0.9378	0.5841	0.5676	0.6965
B(SHADED)				
Sachinoka	0.4525	0.5397	0.5758	0.5227
Tochiotome	0.6581	0.4771	0.6384	0.5912
Benihoppe	0.4278	0.5018	0.5594	0.4963

Percentage acidity of fruits reduced in all the treatments both control and shade (Table 13). For the unshaded plants, Benihoppe recorded the highest mean percentage acid for the control cultivars followed by Sachinoka and Tochiotome. When plants were shaded, fruits of Tochiotome recorded the highest percentage acid followed by Sachinoka and then Benihoppe.

4.11.7 pH**Table 14: Effect of shade on pH of the strawberry cultivars used**

CULTIVAR	<u>MONTHS</u>			Fruit pH
	MAY	JUNE	JULY	MEAN
A(CONTROL)				
Sachinoka	3.70	3.70	3.70	3.70
Tochiotome	4.00	3.70	3.70	3.80
Benihoppe	3.70	3.70	3.50	3.63
B(SHADED)				
Sachinoka	3.70	3.70	3.50	3.63
Tochiotome	3.70	3.70	3.50	3.63
Benihoppe	3.80	3.70	3.70	3.73

pH values did not show much differences among the cultivars used in the study. With the unshaded plants, Tochiotome recorded the highest mean pH (3.80) followed by Sachinoka (3.70) and then Benihoppe (3.63). With the shaded plants, Benihoppe recorded the highest mean pH (3.73) but Sachinoka and Tochiotome had the same mean pH values (3.70).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of temperature on total number of fruits/ plant

The number of strawberry flowers and fruits are related to number and diameter of crowns, which can be used to predict plant yield potential (Hancock, 1999). Himelrick *et al.* (1990) reported that genetic and environmental variations are not the only factors that affect strawberry fruit production. Temperature and climatic factors like humidity could also influence strawberry fruit production. Temperature increased steadily throughout the study period. Temperature range for this study was between 20 to 34 °C. In this study, while temperature increased from May to July, fruit numbers reduced significantly. With the unshaded plants, Sachinoka recorded the highest fruit number (27.00) followed by Tochiotome (17.00) and then Benihoppe (14.00) which occurred in June with maximum and minimum temperature of 31/17 °C. However, the average temperature recorded in June was 24 °C. With the shaded plants, Tochiotome recorded the highest number of fruits (22.00) and this occurred in May with maximum and minimum temperature of 26/14 °C. However, average temperature recorded in May was 20 °C.

Burke (1990) observed that as maximum and minimum average temperatures increased, plant growth decreased which may have been due to the tendency for high temperature to enhance dark respiration, inhibit cellular metabolism and chloroplast biogenesis, reduce chloroplast photoreductive activity, and cause disruption of protein lipid interactions and decreased photosynthetic capacity. Hellman and Travis (1988) also showed that higher temperatures (35-40 °C) inhibited growth of June bearing strawberries. The least number

of fruits were produced in July which had the maximum and minimum temperature of 34/23 °C and average temperature of 26 °C. This study also revealed similar results. At higher growth temperatures of 34/23 °C which occurred in July, Benihoppe recorded a total of 14 fruits followed by Tochiotome with 13 fruits and Sachinoka with only 6 fruits for the control. With the shaded plants where temperature was higher, 'Tochiotome' recorded 11 fruits which were followed by 'Benihoppe' with 6 fruits and then 'Sachinoka' with 6 fruits.

5.2 Effect of temperature on fresh fruit weight, fruit length and fruit width

Fresh fruit weight, fruit width and fruit length are important factors in strawberry quality, which depend on water content in plant (Saied *et al.*, 2005). In addition, there are direct correlation between sugar concentration and nitrogen content of fruits (Lasertosa *et al.*, 1999). In this study, fresh fruit weight, fruit length and fruit width decreased as temperature increased from May to July. Fresh fruit weight measured during the study did not show any significant differences in both the control and the shaded plants. However, the heaviest fruit weight for the control was recorded from Benihoppe (17.70g) in May with maximum and minimum temperature of 26/14 °C and the lightest fruit weight was recorded for Sachinoka (9.75g) in July. For the shaded plants, the heaviest fruit weight was recorded from Tochiotome (18.09g) in May and the lightest fruit weight was recorded from Benihoppe (7.20g). Mori (1998) showed that yield and fresh fruit weight of strawberry were negatively affected by increase in temperature which was very evident in this experiment

Fruit length measured for the control plants showed no significant difference. However, the longest fruit length was recorded from Tochiotome (39.52mm) which occurred in May and the smallest fruit length was recorded from Benihoppe (26.80mm) in July. For the shade plants, significant differences were observed in May and June. However, the differences were not significant after separation. Benihoppe recorded both the longest and smallest fruit lengths. In May, Benihoppe recorded the longest fruit length (42.90mm) and also recorded the smallest fruit length (29.89mm) in July.

Fruit width did not show any significant differences among the cultivars. However for the control, Benihoppe recorded both the longest and smallest fruit widths. The longest width (32.34mm) was recorded in May and the smallest fruit width (26.59mm) was also recorded in July. For the shaded plants, Tochiotome recorded the longest fruit width (32.21mm) whereas Benihoppe recorded the smallest fruit width (23.43mm).

5.3 Effect of temperature on leaf area and leaf height of strawberry cultivars used in the study

The ability of the plant to photosynthesize leading to subsequent fruit production depends largely on the leaf area. The leaf surface serves as a point of interception of light and entry point of chlorophyll which are both important inputs for the growth and development of all plants. However, strawberry plants grown at higher temperatures have smaller leaf size and leaf area (Wang *et al.*, 2000). Le Mière *et al.* (1998) also found that the canopy development in strawberry was more limited at warmer temperatures leading to lower rate of photosynthesis and subsequent lower fruit yield. Plants exposed

to higher temperature regimes appear to develop faster vegetatively as compared to reproductive growth (Wahid *et al.*, 2007). In this study, leaf area also decreased as temperature increased, while petiole length increased. Jiao *et al.* (1998) reported that carbohydrate export rate of expanded leaves on the flowering shoot was reduced by 80% under high temperature (40°C) and suggested that temperature influences export and partitioning of assimilates. The unshaded plants recorded relatively smaller leaf areas and higher petiole lengths as compared to the shaded plants. Therefore at higher temperatures, more assimilates are directed towards the development of shoots as compared to fruit development (fruit weight, fruit width and fruit length). For this reason, leaf sizes and for that matter leaf area were compromised leading to increasing shoot system which was evident in this study.

5.4 Light intensity

Sunlight is not the only source of energy for photosynthesis, but also the most important factor affecting productivity in horticultural crops (Papadopoulos and Pararajasingham, 1997; Gregoriu *et al.*, 2007). Carbon exchange rate (CER) is strongly dependent on irradiance, absorption, and utilization of photon energy (Gregoriu *et al.*, 2007). Low irradiance, in as much as it determines insufficient light penetration into the canopy, influences CER directly by reducing photon energy utilization, thus decreasing productivity (Hampson *et al.*, 1996). Light intensity measurement in this study increased from the mornings to about 12 mid-day and then declined towards the evenings. Light intensity for both the unshaded and shaded cultivars recorded the same pattern. Relatively, the amount of light intensities received on bright and cloudy days was higher

for the shaded plants than the unshaded plants. This is because the shade material might have absorbed heat leading to the increase in temperature around fruits under the shade which negatively affected fruit production. At high light intensities, the rate of transpiration and chlorophyll uptake by leaves of plants tend to be higher. This is particularly important for horticultural crops like strawberry which are mostly cultivated in the temperate zones.

5.5 Chlorophyll

Gulen *et al.* (2003) suggested that longer exposure of strawberry plants to temperature increased chlorophyll content. It is known that at higher temperatures, the amount of chlorophyll also increases. Chlorophyll content is usually higher when the rate of transpiration is high and plant leaves are fully exposed. In this study there was an increase of chlorophyll content with increasing temperatures which was in agreement with an increase in chlorophyll content of grapevines grown in controlled environment (Fukuda *et al.*, 1988) and in mulberry (*Morus Spp.L.*) plants exposed to high temperature. In this study, there were no significant differences in the leaf chlorophyll of the control plants. Tochiotome recorded the highest chlorophyll content (49.90) in July and the lowest chlorophyll content (35.80) was recorded by Benihoppe in June. For the shade plants, significant differences were observed in May. Upon separation, the differences were not significant. However, the highest chlorophyll (45.70) content was recorded from Tochiotome in July and the lowest chlorophyll (38.00) content was recorded from Benihoppe in June. Gulen *et al.*,(2003) concluded that variations in the amount of

chlorophyll synthesised by plants could be attributed to the length of exposure and difference in plant species, prominence and source of stress (Dekov *et al.*, 2000) or an increase in leaf thickness which leads to concentration of higher chlorophyll content (Abdelrahman, 1984).

5.6 Fruit firmness

Strawberries show a continuous decrease of cell wall content during ripening (Perkins-Veazie, 1995; Rosli *et al.*, 2004). Moreover, there are multiple chemical changes that involve pectins and the cellulose-xyloglucan framework resulting in solubilization of polyuronides and hemicelluloses (Knee *et al.*, 1977) and loss of neutral sugars (Rosli *et al.*, 2004). Huber (1984) stated that strawberry softening may be caused by the action of several enzymes, and may be accompanied by a loss of calcium.

At higher temperatures, softening of strawberry fruit, either during ripening in the field or during storage is paramount and this is mainly due to loss of cell wall material, which is more pronounced in the cortical tissue (Koh and Melton, 2004). This study revealed that overall fruit firmness of strawberry fruits reduced as temperature increased from May to July. For the unshaded plants, significant differences were observed in July. However, differences were not statistically significant. The highest fruit firmness (0.0620 kg) was recorded from Benihoppe in May and the lowest fruit firmness (0.0282 kg) was recorded for Tochiotome in July. For the shaded plants, where temperatures were higher, Tochiotome recorded both the highest and lowest fruit firmness. The highest fruit

firmness (0.0478kg) was recorded in May and the lowest (0.0370kg) was also recorded in June. However, there were no significant differences observed.

Texture changes were more evident in the shaded plants than the unshaded plants. Soft texture would shorten the shelf- life since it will become prone to mechanical injury and mould contamination. The better firmness values recorded for the unshaded plants make them most suitable for cold storage and also handling since they are more resistant to physical injuries and abrasions.

5.7 Fruit colour

Among the different physical quality parameters of fruits, fruit colour is a special character which appeals the customer and is also one of the important maturity indices of fruits and vegetables. In the case of strawberries, two anthocyanidin glycosides, pelargonidin 3-glucoside and cyanidin 3-glucoside, are almost exclusively responsible for the red color of strawberries (Kalt et al., 1993; Gil et al., 1997).

The loss of a good characteristic colour in strawberries has been attributed to many factors including maturity, genotype or cultivar, methods of harvesting and handling, cultural practices, and environmental factors (Sistrunk and Morris, 1985). Many researches including Furney *et al.*, (1998) indicated that higher temperatures results in development of red colour in strawberry fruits. Similar observations were made in this study. In this study, when the day/ night temperature increased, the L*(Luminance) value and hue angle generally decreased while the chroma value generally increased. These indicated that as the day or night temperature became warmer, the fruit surface colour in

both the control and shaded plants became darker (L^* value decreased), redder (hue angle decreased), and greater in pigment intensity (chroma value increased) for the three cultivars.

5.8 Total soluble solids (TSS) and sugar: acid ratio

Soluble sugar content and sugar:acid ratio acidity may vary depending on the cultivar. Shaw (1990) showed that soluble solids content was more dependent on environmental conditions than genetic inheritance, while Kader (1991) found that fruit from summer-planted strawberries were higher in soluble solids and titratable acidity than those of winter-planted fruit. The results showed that changes in TSS during storage time vigorously depend on cultivar. The total soluble solid of mature strawberries has been reported to decrease under cold storage as a result of respiration (Garcia *et al.*, 1998). When the plants were not shaded, Sachinoka recorded the highest sugar content (9.20) in July and the lowest sugar content (4.40) was recorded for Tochiotome in May. With the shaded plants, Tochiotme recorded the highest soluble sugar content (14.40) in May and the lowest sugar content (6.00) was recorded from Sachinoka in May. Hellman and Travis (1988) found that when high temperature treatments (25/15, 30/20, 35/25, and 40/30 °C day/night temperature) were imposed on plants with approximately 50% of primary fruits just beginning to colour, soluble solid content of the fruit showed a significant negative relationship with temperature within the range of 25-40°C.

Sucrose is the primary source of glucose and fructose therefore, the increased amount of these monosaccharides could account for the decrease in sucrose level. However, the TSS increase indicates that sucrose synthesis had taken place during cold-storage.

5.9 Titratable acidity, percentage acidity and pH

Shaw (1990) concluded that titratable acidity and for that matter percentage acidity was a heritable trait, less influenced by environment than soluble solids content. However, application of nitrogen fertilizer or pre-harvest shading of strawberry fruit could decrease titratable acidity (Saxena and Locascio, 1968; Osman and Dodd, 1992). In this study, titratable acidity measurements also varied depending on the cultivar. For the unshaded plants, Benihoppe recorded the highest mean acidity (4.23mls) followed by Tochiotome (3.37mls). For the shaded cultivars, Tochiotome recorded the highest mean acidity (3.59mls) followed by Sachinoka (3.18mls) and then Benihoppe (3.02mls).

Percentage acidity increased throughout the study period. For the control plants, Benihoppe recorded the highest mean percentage acidity (0.6965) which was followed by Sachinoka (0.5885) and then Tochiotme (0.5545). The shaded cultivars also recorded the highest mean percentage acidity in Tochiotome (0.5912) which was followed by Sachinoka (0.5227) and then Benihoppe (0.4963).

Organic, non-volatile acids are the second most important component of strawberry flavour, after soluble sugars. The main compound accounting for titratable acid (TA) is citric acid, which is predominant (over 90%) in strawberry. These acids regulate the cellular pH and may influence the anthocyanin stability and, as a consequence, the colour of the fruit. However, there is little published information about changes of pH and TA content in strawberry fruit grown under high temperatures.

pH of both shaded and unshaded plants ranged between 3.50 and 4.00, values that are above the average for ripe strawberry, pH of 3.30 (Green, 1971). With the unshaded plants, Tochiotome recorded the highest mean pH (3.80) which was followed by Sachinoka (3.70) and then Benihoppe (3.62). However, Benihoppe recorded the highest mean pH (3.73) in the shaded cultivars which was followed by Tochiotome (3.63) and then Sachinoka (3.63).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

This study revealed that increase in temperature greatly reduced the total number of fruits harvested. The least number of fruits were produced in July with maximum and minimum temperature of 34/23 °C. Maximum fruit numbers were recorded by three cultivars used in the study in May with maximum and minimum temperatures of 26/14 °C. Therefore, this study revealed that the optimum temperatures for maximum development of strawberry fruits are 26/14 °C.

Fresh fruit weight, fruit length and fruit width reduced as temperature increased throughout the study. In spite of increasing temperatures, Benihoppe produced bigger fruits at higher temperatures. Sachinoka on the other hand, at higher temperatures, produced smaller fruits. However, under shade, Tochiotome produced appreciable fruit weight. Benihoppe produced the least fruit weight under shade. Tochiotome produced longer fruit length even under high temperatures whereas Benihoppe produced smaller fruit length under high temperatures when grown without shade. However, Benihoppe produced longer and wider fruits under shade treatment.

Increasing temperatures from May to July greatly reduced leaf area. On the contrary, leaf height increased with increasing temperatures. Tochiotome produced larger leaf area in

this study. Increased in temperature greatly reduced the leaf area of Sachinoka. Benihoppe showed an increased in leaf height as growth temperatures increased from May to July.

As temperature increased, the chlorophyll content also increased considerably. At higher temperatures, Tochiotome produced relatively higher chlorophyll content in leaves. However, Benihoppe produced low levels of chlorophyll in plant leaves which subsequently led to lower fruit production.

Increase in growth temperatures greatly reduced the firmness of the strawberry fruits used in this study. At high temperatures, Benihoppe produced firmer fruits for the control plants. However under shade treatment, Tochiotome produced relatively firm fruits than the other cultivars. Higher temperatures induced darker fruit colour in all the three cultivars used in this study.

As temperature increased, chemical composition of fruits also varied among the cultivars used in this study. Higher temperatures increased soluble solid content of cultivars used in the study. Sugar-acid ratio and acidity measurements also varied depending on the cultivar. pH values declined as temperature increased from May to July.

6.2 RECOMMENDATIONS

1. Further studies should be carried out in the open field under high temperatures for further analysis of yield and quality parameters of the three strawberry cultivars used in this study.
2. Similar experiment should also be carried out to confirm the results of this study.
3. Tochiotome and Benihoppe cultivars appear to be high yielding under high temperature and therefore further studies on these two cultivars should be done under tropical conditions to also determine the level of productivity and quality.
4. Similar experiments should be carried out using different growth media to observe the growth characteristics of the cultivars used in this study.

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APPENDIX**ANOVA USED FOR ANALYSIS****CHLOROPHYLL CONTENT**

Chlorophyll content for May

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	8.88	4.44	0.27	0.769
Residual	21	350.84	16.71		
Total	23	359.72			

Chlorophyll content for June

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	2	129.22	64.61	1.36	0.279
Residual	21	1000.12	47.62		
Total	23	1129.34			

Variate: Chlorophyll content July

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	230.03	115.02	2.87	0.079
Residual	21	840.12	40.01		
Total	23	1070.15			

Shade

Chlorophyll content for May

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	122.58	61.29	4.34	0.026
Residual	21	296.65	14.13		
Total	23	419.23			

Variate:Chlorophyll content june

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	69.61	34.81	1.31	0.292
Residual	21	559.60	26.65		
Total	23	629.21			

Variate:Chlorophyll content July

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	627.6	313.8	1.88	0.178
Residual	21	3512.3	167.3		
Total	23	4139.9			

Fruit width**Control**

Variate: Fruit width May

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	111.61	55.81	2.18	0.134
Residual	25	639.82	25.59		
Total	27	751.43			

Variate: Fruit width June

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	93.08	46.54	2.56	0.087
Residual	52	945.79	18.19		
Total	54	1038.87			

Variate: Fruit width July

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	21.88	10.94	0.57	0.572
Residual	30	576.35	19.21		
Total	32	598.24			

Shade

Variate:Fruit width May

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	48.70	24.35	0.96	0.390
Residual	58	1475.75	25.44		
Total	60	1524.45			

Variate: Fruit width June

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	22.57	11.29	0.44	0.649
Residual	27	694.36	25.72		
Total	29	716.93			

Variate: Fruit width July

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	28.03	14.02	1.04	0.382
Residual	13	175.46	13.50		
Total	15	203.50			

FRUIT WEIGHT**Control**

Variate: fruit weight May

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	238.84	119.42	2.31	0.118
Residual	28	1450.21	51.79		
Total	30	1689.05			

Variate: Fruit weight june

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	146.24	73.12	3.16	0.050
Residual	55	1273.69	23.16		
Total	57	1419.93			

variate: Weight july

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	47.07	23.54	0.70	0.505
Residual	29	974.59	33.61		
Total	31	1021.66			

Shade

Variate: Fruit weight may

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	79.83	39.91	0.74	0.482
Residual	58	3130.87	53.98		
Total	60	3210.70			

Variate:Fruit weight june

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	13.80	6.90	0.21	0.809
Residual	27	870.57	32.24		
Total	29	884.37			

Variate: Fruit weight july

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	18.77	9.38	0.46	0.638
Residual	13	262.46	20.19		
Total	15	281.23			

FRUIT LENGTH**Control**

Variate: Fruit length may

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	429.20	214.60	5.11	0.014
Residual	25	1050.93	42.04		
Total	27	1480.13			

variate: Fruit length june

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	310.00	155.00	4.67	0.014
Residual	52	1725.31	33.18		
Total	54	2035.31			

Variate: Fruit length july

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	11.77	5.89	0.28	0.756
Residual	30	625.87	20.86		
Total	32	637.64			

SHADE

Variate: Fruit length May

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
cultivar	2	172.26	86.13	1.83	0.170
Residual	58	2735.29	47.16		
Total	60	2907.55			

Variate: Fruit length june

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
cultivar	2	174.90	87.45	2.38	0.112
Residual	27	991.64	36.73		
Total	29	1166.55			

Variate: Fruit length july

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	75.51	37.75	2.80	0.098
Residual	13	175.53	13.50		
Total	15	251.04			

LEAF AREA**control**

Variate: Leaf area May

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	8608.5	4304.3	6.50	0.006
Residual	21	13897.3	661.8		
Total	23	22505.8			

Variate: Leaf area June

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	12931.3	6465.7	13.92	<.001
Residual	21	9754.9	464.5		
Total	23	22686.3			

Variate: Leaf area July

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	14196.3	7098.2	22.58	<.001
Residual	21	6601.6	314.4		
Total	23	20798.0			

shade

Variate: Leaf area may

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	12561.8	6280.9	22.83	<.001
Residual	21	5776.6	275.1		
Total	23	18338.4			

Variate: Leaf area June

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	5474.4	2737.2	5.53	0.012
Residual	20	9900.6	495.0		
Total	22	15375.0			

Variate: Leaf area july

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	1095.5	547.8	1.13	0.345
Residual	19	9235.6	486.1		
Total	21	10331.1			

LEAF HEIGHT**Control**

Variate: leaf height May

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	368.52	184.26	14.70	<.001
Residual	21	263.31	12.54		
Total	23	631.83			

Variate: leaf height June

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	15.01	7.51	0.72	0.498
Residual	21	218.51	10.41		
Total	23	233.52			

Variate: leaf height July

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	27.90	13.95	1.35	0.280
Residual	21	216.59	10.31		
Total	23	244.49			

Shade

Variate: leaf height May

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	541.64	270.82	26.04	<.001
Residual	21	218.37	10.40		
Total	23	760.02			

Variate: leaf height June

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	74.78	37.39	2.75	0.088
Residual	20	272.12	13.61		
Total	22	346.89			

Variate: leaf height July

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Cultivar	2	240.777	120.389	13.97	<.001
Residual	19	163.677	8.615		
Total	21	404.455			