Effect of shading and cultivation inside greenhouse on some flowering and fruit characteristics of brinjal (*Solanum melongena* L.).

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ABSTRACT: *High ambient temperature is the greatest problem faced by tropical greenhouse producing vegetables. Temperature affects the productivity and growth of a plant, therefore using shades to alleviate this effect could increase the yield of plants grown in greenhouses. This study intends to investigate the effect of shading and greenhouse conditions on brinjal flowering and traits, and subsequently compare them to open field cultivation of brinjal.*

The experiment was carried out at the Institute of Sustainable Agrotechnology field, University Malaysia Perlis (UniMAP), Padang Besar, Perlis, Malaysia. The brinjal used in the experiment was of the purple and long variety type (F1hybrid). The experimental treatments were designated T1 (shading outside greenhouse), T2 [control outside greenhouse (without shading)], T3 [(control inside greenhouse (without shading)],T4 [shading inside greenhouse for first plant growth stage only (from transplanting until 50% of bloom)], T5 (shading throughout plant growth) and T6 [shading inside greenhouse for last plant growth stage only(from 50% of bloom until end of plant life)].

The results indicated that greenhouse conditions increased the interval between transplanting to flowering, and between flowers blooming and fruit setting, while also reducing the percentage of fruit setting and fruit quality in terms of its weight, length diameter, and sugar content. Regarding shading, the brinjal were almost unaffected, with the notable exception of its flower number, which increased when the plants were shaded during the last stages of growth. However, a negative correlation was observed between the number of flowers and the percentage of fruit set. The results indicated that the greenhouse condition is unsuitable for Brinjal productivity, particularly when shading is used during the last stage of plant growth due to the adverse effect on flower initiation and some fruit traits.

KEYWORDS**:** *Shading, Greenhouse, Open field, Brinjal, Flowering.*

I. INTRODUCTION

Most studies involving greenhouses were done in countries in the northern hemisphere and although some were conducted in the Mediterranean, arid and tropical climates, they are by no means comprehensive. Solanaceous crop (tomato, pepper and brinjal) constitute ~60% of greenhouse-cultivated area. Among these crops, tomatoes are the most researched, followed by pepper, and finally brinjal. Plant growth in a greenhouse is a complex process, as it is governed by the interaction between the plant's genetic properties and its environmental condition [1].

The increasing market demand for high quality yield has led to more and more horticultural crop production systems in protected environments for the purpose of improving production. Brinjal ranks among the top 10 in terms of its antioxidant content [2].

High temperatures increase the growth of the brinjal, but very high temperatures are unsuitable for the formation of flower buds, which will inevitably result in pollen sterility [3]. Evaporative cooling system in hot and humid areas may not be as efficient, so shading is necessary to mitigate the temperature increase in a greenhouse. The screen house structures are much cheaper than greenhouses, and under certain climatic conditions, could adequately protect the crops [4].[5]reported that the intensity of solar radiation during daytime increased the temperature inside the greenhouse, which could decrease plant production. In screen houses or net-houses, the crop is covered by a porous screen, which prevents excess heat and subsequent solar damage. [6] noted that the yield per plant was higher in the shade net house compared to an open field. Hence, growing tomato, brinjal, chilli, cucumber, radish, amaranthus and coriander under shaded house conditions is more profitable, regardless of the season.[7]pointed out that the appearance of the first flower of brinjal could be controlled via light and temperature in greenhouses.

[8] observed that Malaysian greenhouse infrastructure and control systems are mostly imported from Australia and the Netherlands, which operates using the evaporative cooling systems (misting or high-pressure fog and pad-and-fan) without proper modifications for the environment, where the RH is as high as 90% in some days, at ambient temperatures between 38 - 41°C. They found that the evaporative methods, either by means of pad-and-fan, misting or swamp cooling, is inefficient in decreasing the air temperature at specific times, especially when maximum cooling load is required. They concluded that high temperature, RH and their interaction with crop growth micro-environments, on top of inappropriate deployment of resource management are some of the major factors that decrease the production potential of lowland greenhouses in Malaysia.

This work investigates the usage of shade net under greenhouse conditions and the effect of greenhouse condition and shade on flowering and fruit traits, compared to open field cultivation of brinjal.

II. MATERIAL AND METHODS

The experiment was carried out at the Institute of Sustainable Agrotechnology field, University Malaysia Perlis (UniMAP), Padang Besar, Perlis, Malaysia. Brinjal (*Solanum melongena* L.) used in the experiment was purple, long variety (F1 Hybrid) from Green World Company, Malaysia.

The experimental treatments were as follow:

- T1: Shading outside greenhouse
- T2: Control outside greenhouse (no shade)
- T3: Control inside greenhouse (no shade)
- T4: Shading inside greenhouse, from transplanting until 50% bloom.
- T5: Shading throughout plant growth.
- T6: Shading inside greenhouse, from 50% bloom until harvest.

The treatments were arranged in a factorial experiment with randomized complete block design in six replicates. Duncan’s test was used to evaluate differences among the means. Significance was reported at $P < 0.05$ when using SAS version 9.2 [9]. The greenhouse measures 6 by 18 meters. Three shading treatments (three plant growth stages) and the control treatment (no shade) were distributed inside the greenhouse that was divided into four compartments. Each compartment was 2 m high, 2 m wide and 4 m long. Two treatments were outside the greenhouse, control treatment (no shade) and shade treatment. The shades outside the greenhouse were constructed using an iron structure, measuring 2 m high, 2 m wide and 4 m long, covered with shading nets.

A drip irrigation system was used in the experiment, 30 cm between the drippers and 60 cm between the plants. The amount of water used throughout experiment was 106 L/plant. The seedlings were transplanted in white plastic bags (size 20 L) and arranged alternately along the drip tube. The characteristics of the soils used in the experiment are shown in Table 1.

Table 1 Soil characteristics used in the experiment.

Total N (%)	Ava .P(ppm)	K(me %)	Ca(me%)	Mg(me %)	O.M (%)	O.C (%)	pH	C.E.C(me%)	Clay (%)	Silt (%)	Fine Sand (%)	Coarse Sand (%)	Soil Texture	N/C Ratio	EC µs/cm
0.22	38	2.6	35	4.9	5.9	1.9	5.6	61	9.6	9.8	54.7	20	Loamy sand	11/95	720

The temperature and relative humidity were recorded using a data logger, where four sensors were fixed inside and outside the greenhouse during the experiment. In addition, mercury thermometer was used to measure the temperature under shading treatment during sunshine hours, and the average was taken. The air speed was measured using the airspeed, temperature, volume flow telescoping AS-201Hotwire probe, procured from Ireland (Table 2).

Table 2 The measurements of some environmental conditions for the shading treatments.

Treatments	Temperature (°C)	Relative humidity (%)	Air speed (m/s)	Light intensity (W/m^2)
Shading outside	30.52	84.51	1.10	356.50
Control outside	30.66	78.15	2.63	639.06
Control inside	31.94	81.77	0.88	632.81
Shading inside	31.95	81.40	0.33	338.28

<u>Plant measurements recorded were:</u>

1. Number of days from transplanting until flowering
   The measurement was conducted by counting the number of days between transplanting to flowering. Six plants were taken as replicates, where five flowers were used for each replicate. The reported values were then averaged.
2. Number of days between flower bloom and fruit set
   Five flowers were used for each plant to determine the number of days that passed between the flowers blooming and fruit set, which was then averaged for six replicate plants.
3. Number of days to harvest after fruit set
   Six replicate plants were used to count the days between fruits setting and harvest. Five flowers were used for each replicate and then averaged.
4. Percentage of fruit set
   The total number of flowers that blossom and fruit set was counted throughout plant growth until the end of the experiment and then using the following equation:

$$\text{Percentage of fruit set} = \frac{\text{Number of fruit set}}{\text{Total flower number}} \times 100$$

5. Number of flowers
   The number of flowers was counted for the six plant replicates throughout plant growth up till the end of the experiment.
6. Individual fruit weight
   Average of fruit weight for six plants as replicates was calculated using the following equation:
   $\text{Individual fruit weight} = \frac{\text{Fruit yield (g)}}{\text{Fruit number}}$
7. Fruit length
   A measuring tape was used to measure the length of five fruits for each replicate, and then the values were averaged.
8. Fruit diameter
   A digital Vernier calliper was used to measure the fruit diameter, which was then averaged.

9. Total sugar
   The samples were gently boiled in 100 mL of water then filtered. Ten mL of the solution was filtrated with hydrochloric acid then titrated with 200 mL against Fehling's solution (Lane and Eynon's method). A known inverted sugar solution was prepared and used to standardize the Fehling's solution [10].
10. Vitamin A
    Four samples were extracted with dimethyl sulfoxide and hexane and shaken for 45 minutes in a water bath at 60 ^{o}C. The solution was then centrifuged at 3000 rpm for 10 minutes then the hexane layer was removed via pipetting into a 100 ml beaker. The extraction process was then repeated using three additional protein of hexane. The hexane layerwas filtered using 0.45 µm membrane filter prior to being injected for HPLC analysis (Agilent technologies 1200 Series with diode array detector). The isocratic elute used for vitamin A analysis contained hexane and isopropyl alcohol (99:1), with the elution flow rate of 1 ml/min. The standard was analysed on a separate chromatogram and the quantification was based on the comparison between peak area of the sample and the reference standard [11].

III. RESULTS AND DISCUSSION

The results showed that the yield differed significantly as a response to the treatments shown in the following:

3.1. Number of days from transplanting until flowering

The results in Figure 1 indicated that the plant that grew outside the greenhouse under control treatment(T2) flowered early (34.66 days) compared to the other treatments, whether inside a greenhouse or under shade treatments (41.33, 42.25, 42.38, 42.22, and 42.8 days, respectively) for shade outside greenhouse (T1) treatment, control inside greenhouse (T3) treatment, shading for first plant growth stage (T4) treatment, shading throughout plant growth (T5) treatment and shading for last plant growth stage (T6) treatment inside the greenhouse. There were no significant differences among these treatments on their effect on this trait.

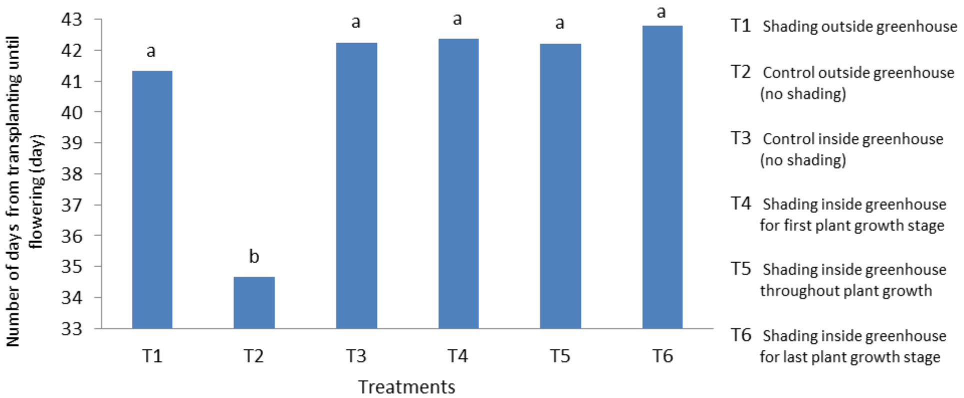

Fig.1. Number of days from transplanting until flowering as affected by different shading treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05).

These results could be ascribed to the high temperature in a greenhouse, which raised 2 ^{o}C on average (Table 2) compared to outside, and some time the difference could reached up to 5 ^{o}C during full sunshine at midday. This high temperature especially when accompanied by low light intensity could be the cause of the increase of the interval. This condition encourages vertical plant growth, as per [12], especially under shade treatments, which increases the internode length of the plant and the number of nodes culminating in vegetation growth and delayed flowering. This is consistent with [7], who found that the number of leaves formed before the first fruit of aubergine linearly decreased with decreasing temperature, particularly at the lowest daily mean light integral. However, this disagrees with [13], who pointed out that the increasing temperature led to the decreasing number of days to flowering for tomatoes.

3.2. Number of days between flower bloom and fruit set

The interval between flower blooming and fruit setting outside the greenhouse (3.26 days) for control (T2) treatment was significantly shorter compared to the control plants inside the greenhouse (4.24 days) (T3) treatment. The intervals under shade treatments were significantly longer compared to its no shade counterparts, regardless of whether it was inside (4.5 and 4.83 days, respectively) for shading throughout plant growth (T5) treatment and shading for last plant growth stage (T6) treatment or outside the greenhouse (4.04 days) for shade (T1) treatment (Figure 2). This is in line with [7], who attributed this to the shade treatment effect, especially under greenhouse, which resulted in an increased vegetative growth that would delay fruit settings [12, 4].

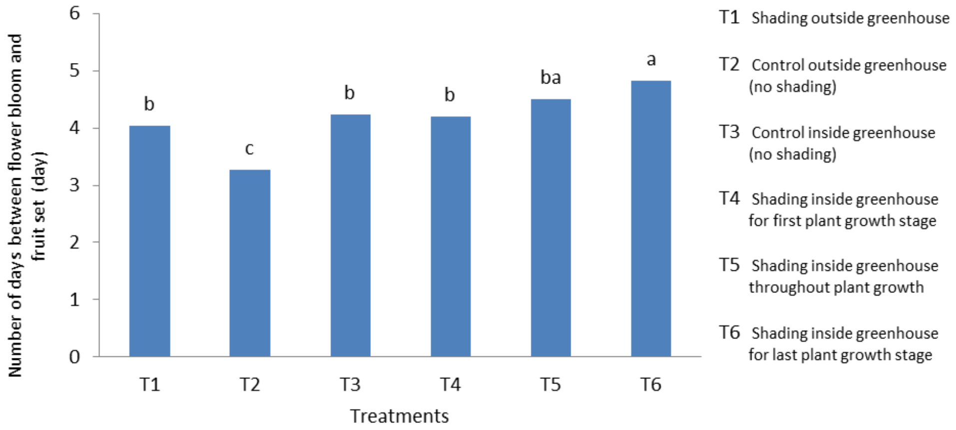

Fig.2. Number of days between flower bloom and fruit set as affected by different shading treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05).

3.3. Number of days to harvest after fruit set

Figure 3 shows that despite the lack of significant differences between the effect of being inside/outside of a greenhouse in the context of interval between fruit set and harvest, stages of shade treatments resulted in a significant difference in intervals. The shortest interval was 12.36 days for shading of first plant growth stage (T4) treatment inside the greenhouse while the longest interval was13.88 days for shading at the last plant growth stage (T6) treatment. This could be attributed to the fact that fruits mature under shade a lot slower compared to unshaded fruits, due to the micro-climatic conditions under shades being more comfortable. This is consistent with [14] who stated that the fruit growth period decreased with increasing light and temperature.[15]pointed out that increasing temperature resulted in decreasing time between flowering till harvest.

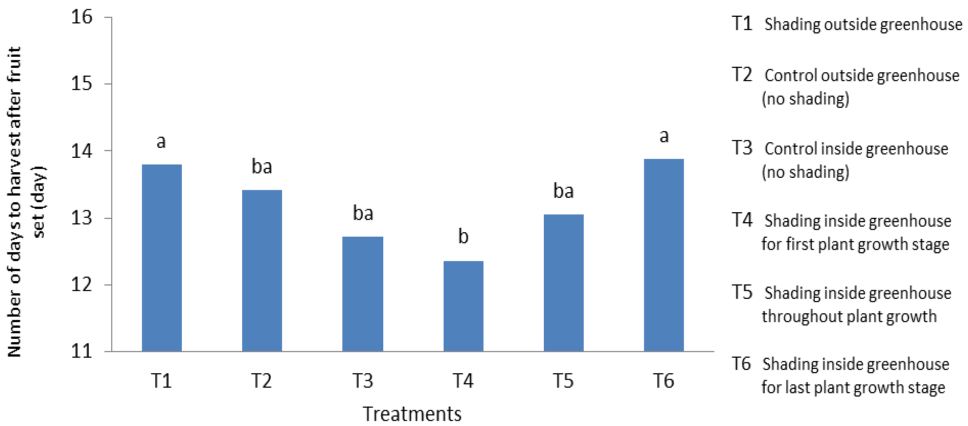

Fig.3. Number of days to harvest after fruit set as affected by different shading treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05).

3.4. Percentage of fruit set

The percentage of fruit setting outside greenhouse treatments was significantly higher than those inside the greenhouse (Figure 4), where it was 41.73% and 40.37% for shade (T1) treatment and control (T2) treatment outside greenhouse, respectively, which were significantly higher compared to inside greenhouse treatments. The lowest percentage of fruit setting was reported by the last stage plant growth shading (T6) treatment (13.73%) inside a greenhouse. This showed that fruit setting was hampered by the pollen grains losing their viability due to the high temperature inside the greenhouse, as shown in the Table2, which could result in pollen sterility, thereby reducing fruit setting inside the greenhouse to levels higher than those outside, especially under shade treatment at the last stages of plant growth [3, 16].

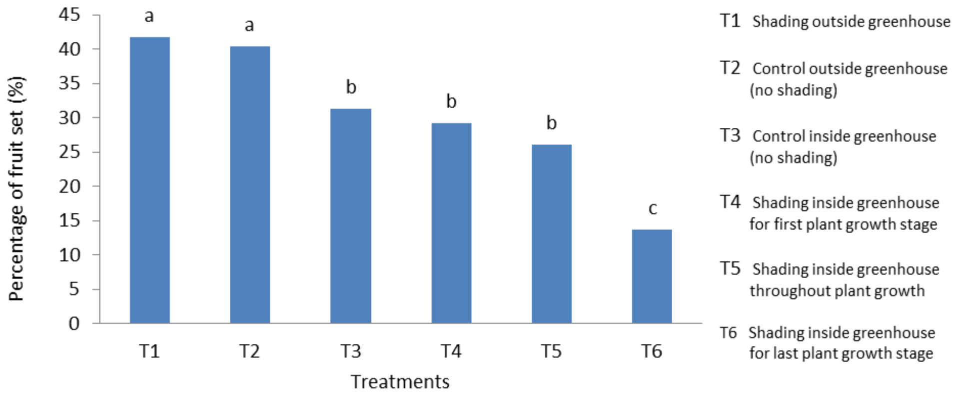

Fig.4. Percentage of fruit set as affected by different shading treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05).

3.5. Number of flowers

The number of flowers remain unaffected in most of the treatments, except for the shaded plants on the last stage of plant growth (T6) treatment, which increased the number of flowers significantly (40.33 flowers/plant), as per Figure5. This due to the decrease of fruit setting, especially under shade at the last stage of plant growth under greenhouse, prompting the formation of new flowers, as confirmed by the negative correlation between the number of fruit and fruit set (correlation coefficient = -0.787).

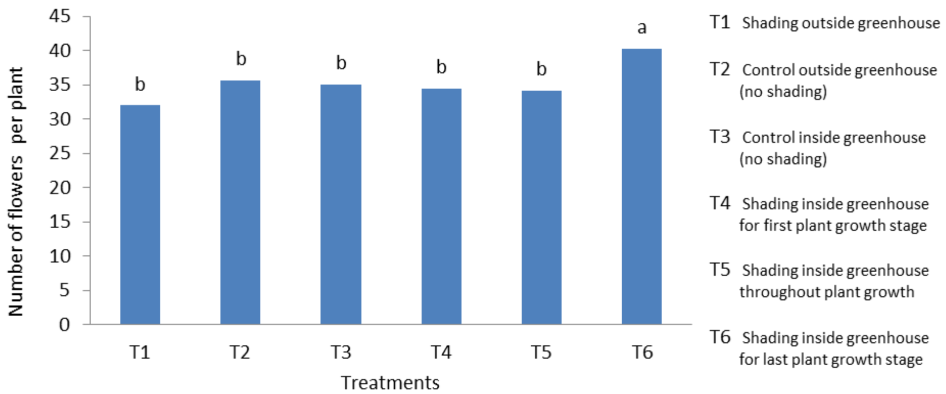

Fig.5. Number of flowers as affected by different shading treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05

3.6. Individual fruit weight

Figure 6shows that the individual fruit weight increased significantly under outside greenhouse treatments (96.54 and 103.97 g/fruit) for shade (T1) and control (T2) outside greenhouse treatments, respectively, compared with those treated inside the greenhouse (51.56, 54.79, 55.30 and 67.47 g/fruit) for control (T3), shading for first plant growth stage (T4), shading throughout plant growth (T5), and shading for last plant growth stage (T6) inside greenhouse treatments, respectively. There was a positive correlation between the increment of fruit weight and total sugar content in fruit, as per correlation coefficient = 0.96. These values could be attributed to the increasing transpiration rate under greenhouse being higher in the open field due to the high temperature, which increased to more than 2 ^{o}C on average, as per Table 2, under greenhouse and sometimes, the difference reached 5 ^{o}C during midday compared to the plants outside, resulting in fruit development being inferior compared to outside conditions.[17]explained that low temperature is crucial towards the accumulation of sugar to prevent its loss from high respiration induced by high temperatures. These results are consistent with [3] who pointed out that the high temperature during the summer is unsuitable for brinjal production. [16] reported that temperature affects productivity and growth of a plant.[14]mentioned that fruit weight increased in tandem with temperature up to a certain point, after which it decreased, while the fruit growth rate was influenced by temperature via the rates of respiration and starch synthesis in the fruit. Also this result agreed with [18] who found that fruit fresh weight of cherry tomato was reduced by high temperature because it increased leaf and fruit temperature and therefore increased water loss by transpiration. Moreover, the reduction of brinjal yield in a greenhouse could be attributed to the water deficit from the reduction of relative water content in the plant via increasing heat[19]. Reduction in leaf water content results in poor yield, as per [20] who mentioned that the reduction of relative water content in plants by 5% results in reduced photosynthetic efficiency by 40 - 60 %.

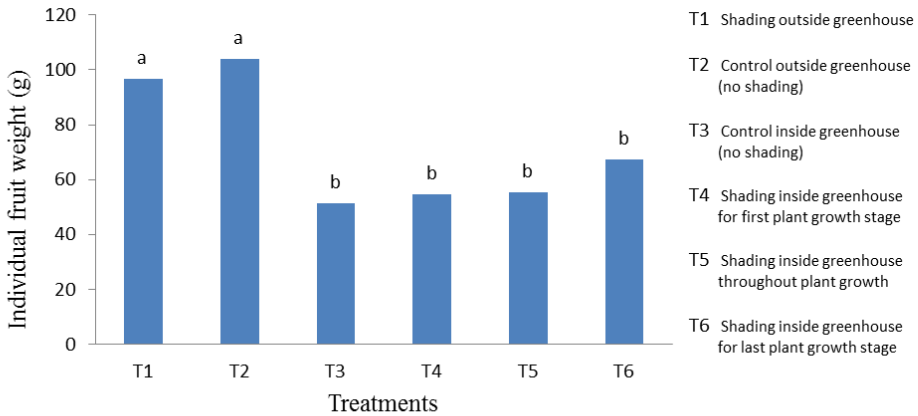

Fig.6. Individual fruit weight as affected by different shading treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05).

3.7. Fruit length

Figure 7 shows that the fruit length significantly decreased in greenhouse condition, as opposed to those outside, where the fruit length was 14.47 cm for control (T3) treatment inside the greenhouse compared to 18.25 cm for the control (T2) treatment outside. However, the effect of shade treatment upon fruit length was almost negligible, excepting the fruit length was 15.7 cm for last plant growth stage (T6) treatment, which was the longest fruit inside the greenhouse compared to 14.47 cm for the control (T3) treatment. The increment in fruit length was the result of increase in the average fruit weight, which was confirmed by the positive correlation coefficient between the average fruit weight and fruit length, at 0.97.

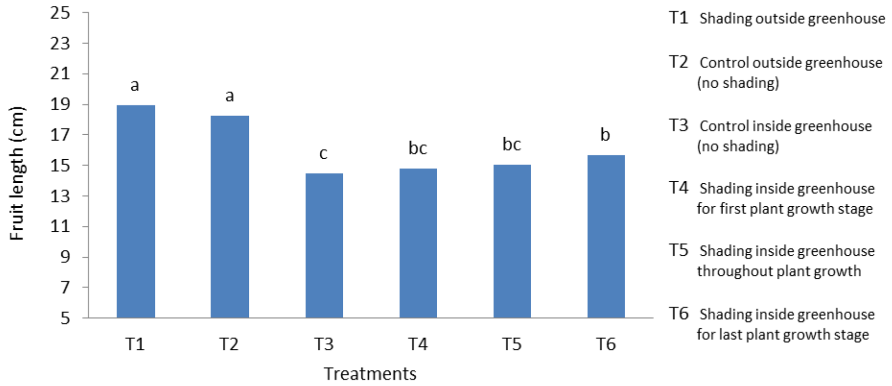

Fig.7. Fruit length as affected by different shading treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05).

This could be attributed to the effect of high temperature under greenhouse in reducing brinjal productivity, as per[3, 16 and 14], who all reported decreased brinjal yield due to increased temperatures. This could also be attributed to the decreasing leaf water content in the greenhouse from the high temperature, as per [19].

3.8. Fruit diameter

The diameter of the fruit decreased significantly under the greenhouse condition compared to the plants growing outside (Figure 8), at 44.51 and 43.87 mm, respectively for shade (T1) and control (T2) outside the greenhouse treatments, which were thicker compared with inside greenhouse treatments (37.9, 38.38, 38.64, and 37.43 mm, respectively) for control (T3), shading for the first plant growth stage (T4), shading throughout plant growth (T5), and shading for the last plant growth stage (T6) inside greenhouse treatments. There was also a slight effect due to the shade treatment on this trait, which increased the fruit diameter, especially outside the greenhouse. The positive correlation between average fruit weight and fruit diameter (0.929) indicated that the fruit diameter was directly proportional to fruit weight [3, 16, 14 and 19].

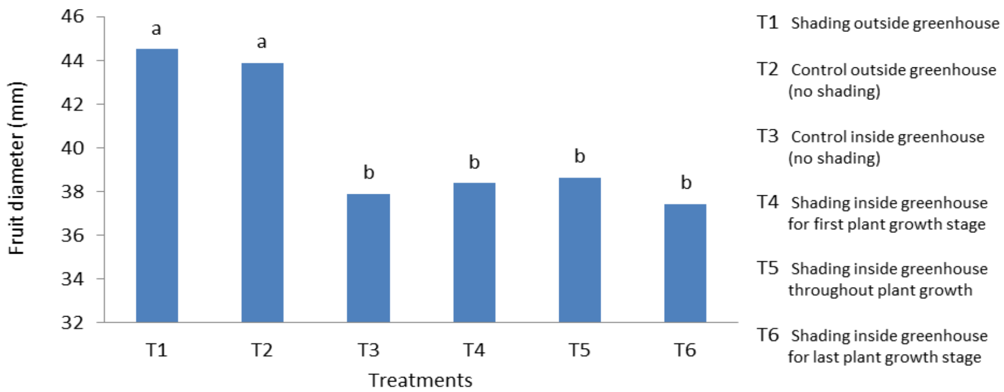

Fig.8. Fruit diameter as affected by different treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05).

3.9. Total sugar

The results show that the total sugar content in brinjal decreased significantly under greenhouse condition, at 36.97 % for control (T3) treatment compared to those outside the greenhouse for shade (T1) and control (T2) treatments (40.6 % and 40.52 %, respectively). However, the highest value of total sugar content under greenhouse was 39.2 5% of shading for last plant growth stage (T6) treatment, which was significantly higher than the other treatments under greenhouse, especially the control treatment, which was lowest (Figure 9).

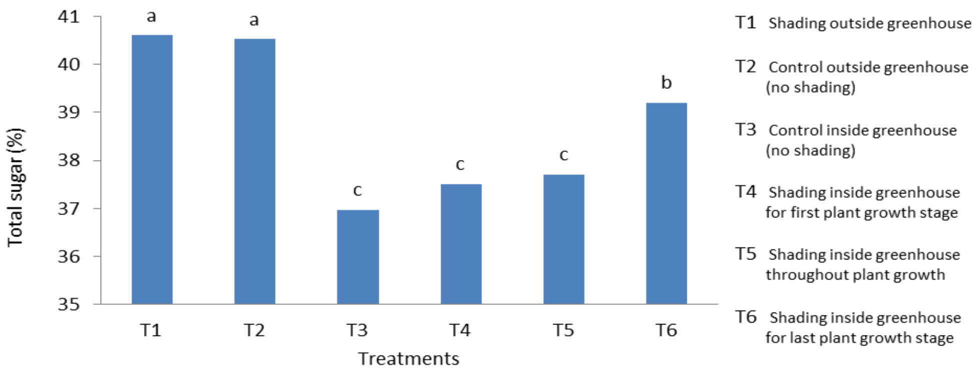

Fig.9. Total sugar as affected by different shading treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05).

This result could be attributed to the photosynthesis process exceeding the respiration rate due to the micro-climate outside being better than the ones inside. Therefore, manufactured products such as sugar or carbohydrate via photosynthesis of plants growing outside the greenhouse exceeded that of the ones growing inside the greenhouse. There was a positive correlation between fruit development period and total sugar content (correlation coefficient = 0.805), which agrees with [16, 18, and 17],whom explained that low temperature is very important to the accumulation of sugar and preventing its loss from high respiration.

3.10. Vitamin A

Based on the results, vitamin A responded differently to the experimental treatments (Figure 10), where it increased significantly under the greenhouse condition. The control treatment (T3) reported the highest value in the greenhouse. The shade treatment reported the highest value outside the greenhouse, whereas the shade treatments inside greenhouse reported the lowest value. This indicated that vitamin A, despite increasing when under the shade outside the greenhouse, decreases when the temperature increases inside the greenhouse.

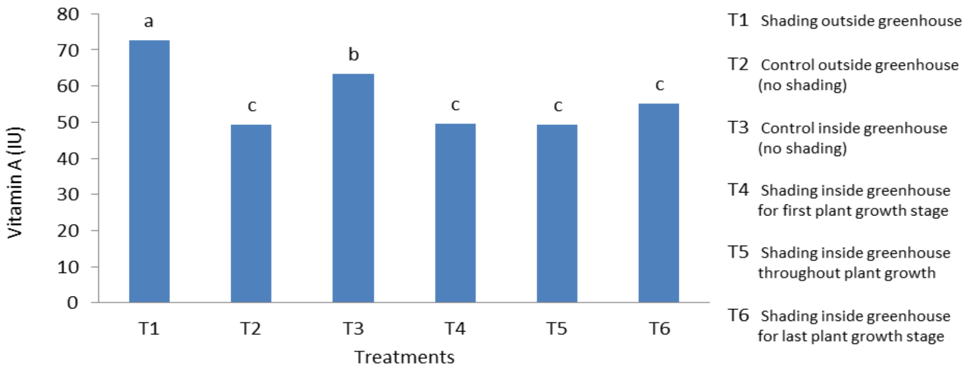

Fig.10. Vitamin A as affected by different shading treatments.
(Treatments which have the same letter are not significantly different according to Duncan test at P≤0.05).

IV. Conclusion

The results showed that flowering traits of brinjal, such as the interval between transplanting and flowering and between flower blooming and fruit setting increased in a greenhouse condition, especially under shade treatments. However, the number of flowers increased under the greenhouse conditions, especially under shading at the last stage of plant growth but the percentage of fruit setting significantly decreased. There was a negative correlation between the number of flowers and the percentage of fruit set. The fruit weight decreased inside the greenhouse condition compared to the outside condition and it was concluded that there is a positive correlation between fruit weight, fruit length, fruit diameter, and total sugar content.

These values indicated that the greenhouse condition was unsuitable for brinjal cultivation due to its adverse effect on flowering, especially the percentage of fruit set and fruit quality in the context of weight, length, diameter and sugar content. In terms of shading treatment, there was an almost negligible effect on the brinjal, except in the case of vitamin A content, which increased under shade treatment outside the greenhouse while it decreased inside the greenhouse under shade treatment compared to the control sample (no shade).It also seems that the last stage of plant growth is the critical period for shade treatment where fruit setting decreased significantly due to shading treatment.

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