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RESEARCH

Assessment of Growth and Yield Characteristics of a Greenhouse Hybrid and a Dual-Purpose Tomato Cultivar under Different Microclimatic Conditions

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ABSTRACT

Tomato (*Solanum lycopersicum* L., family Solanaceae) represents one of the most cultivated horticultural crops worldwide. It contains various nutrients, providing health benefits. For better crop management strategies, especially with global warming, it is crucial to investigate how varieties or cultivars bred for different purposes respond to the changing macro or microenvironmental conditions. This research aimed to assess the growth, reproductive development and selected quality parameters of two tomato varieties, 'Sylviana' (a greenhouse hybrid) and 'Bolseno' (a dual-purpose variety), under a greenhouse environment. The study was conducted in the mid-country wet zone of Sri Lanka where the intensive-control greenhouse (T1) maintained a favourable air temperature (<33°C) for crop growth compared to high daytime temperatures of semi-intensive (T2) and less-intensive (T3) greenhouses (up to 36°C). In 'Bolseno', vegetative growth parameters were significantly affected ($P<0.05$) by different environments but not in 'Sylviana' ($P>0.05$). T1 resulted in the highest mean fruit weight and mean fruit diameter in both varieties. Since 'Sylviana' performed well in all three growing environments, the fruit quality was assessed by measuring the antioxidant activity (AOX) and total phenolic content (TPC) using 1, 1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging assay and Folin–Ciocalteu method, respectively. Significantly higher AOX ($P<0.05$) was reported in T1 while T2 had a higher TPC. The results revealed that different tomato genotypes respond differently to changes in micro environmental conditions in terms of growth and some reproductive traits, and the same variety grown in different conditions had different TPC and AOX.

INTRODUCTION

Tomato (*Solanum lycopersicum* L., family Solanaceae) represents one of the most cultivated horticultural crops worldwide with over 5 million hectares of cultivated extent, and more than 182 million tons of tomato produced globally (Caruso et al., 2022). It is an economically important crop in terms of the farmers' livelihood, and creates more jobs per hectare (Cousins, 2013). Tomatoes and tomato-based products are rich sources of folate, vitamin C and potassium, while also rich in carotenoids like lycopene, beta-carotene, and gamma-carotene, which contribute to their strong antioxidant properties. Moreover, tomato offers a high provitamin A activity due to its carotenoid content. Tomato contains vitamin E, trace minerals, flavonoids, phytosterols, and water-soluble vitamins, all contributing to health benefits (Beecher, 1998). Hence, tomato is a nutritious vegetable with enormous food and economic value (Gereffi et al., 2009).

To forecast and choose future crop management strategies and patterns, especially in a changing climate, it is crucial to investigate how tomato crop respond to spatial and temporal variations in climatic conditions in its growing environment. Plant breeders around the world have bred different hybrids of tomato to satisfy the growing demand. For example, there are specific tomato hybrids such as Cobra, Anna F1, Aegean (Large Beef type), and Sylviana (small beef type) which were developed to achieve high quantity and quality of yield under tropical greenhouse conditions. Similarly, the dual-purpose varieties such as Shira, Anna, Angelina, Dominic, Mammoth, Latio, Top 2321 and Bolseno have been recommended to be cultivated both in the tropical greenhouses and open field conditions. When the conditions in the growing environment of a crop deviate heavily from the optimal that they are bred for, it can negatively affect the plant functions resulting in retarded growth, and development. These growth and developmental changes are recognizable in the form of morphological changes (Albrechtova, 2003). Shamshiri et al. (2013) reported that the high relative humidity and ambient temperature in tropical greenhouses, and their complicated dynamic interactions with the external environmental conditions, make the control of internal environment (microclimate) highly challenging. The semi-intensive greenhouses in most tropical countries are not fully environment-controlled (Erabadupitiya et al., 2022; Mawalagedera et al., 2012).

Sri Lanka imports greenhouse materials and dual-purpose hybrids varieties and cultivars as planting materials. Meanwhile, the majority of Sri Lanka's greenhouse vegetable cultivation utilizes complete mixtures of inorganic fertilizers in coco-peat-based hydroponic systems. Yet their average yields are low under tropical climatic conditions (Weerakkody et al., 2007). According to Dasgan et al. (2021), tomato is vulnerable to high temperatures (35 °C and above) during cultivation. Global warming may escalate the issue even in temperate countries and maintaining micro environmental conditions suitable for variety would be challenging (Beddington et al., 2010).

Tomato varieties may perform differently in changing environments (Shamshiri et al., 2018; Marsic et al., 2011). Further, the knowledge of the varietal performance in response to changing environmental conditions is important in planning future breeding programs to develop crops suitable for such changes. To the best of our knowledge, assessment of the performance of greenhouse hybrids and dual-purpose varieties of tomato in response to microclimatic conditions in greenhouses has not been carried out in detail. Therefore, this study was conducted to investigate the growth and yield response of a greenhouse hybrid 'Sylviana' and a dual-purpose variety 'Bolseno' to different greenhouse environments, where internal temperatures, relative humidity and light intensities are different to each other. Further, the total phenolic content, and the antioxidant activity of 'Sylviana' fruits were also analyzed to assess the quality of fruits grown under different greenhouse conditions.

METHODOLOGY

Experimental procedure

The experiment was conducted in the mid-country wet zone (WM_{2b}) in Sri Lanka as two different trials. Seeds of a dual-purpose tomato variety "Bolseno'' (Johnny's Seeds, Maine, USA), and an indeterminate greenhouse tomato hybrid 'Sylviana' (Agro-culture Trends (Pvt) Ltd, Sri Lanka) were used as the planting materials for two experiments: Trial 1 and Trial 2, respectively. Plug transplants were raised using wet coco pellets following standard protocols. Seedlings were watered regularly, and 1 g L^{-1} of Albert's solution was supplied daily and kept under controlled environmental conditions. Transplanting was done at 4 weeks stage to a coco peat (Jiffy Products, Mirigama, Sri Lanka) medium in drip-fertigated grow-bag culture. The bags were black in color and made of 300-gauge with a dimension of 35 cm x 40 cm. Plants were arranged in single rows under greenhouse conditions with a spacing of 0.9 m x 1.2 m. Irrigation/ fertigation and crop management were conducted following the recommendations made for commercial farmer practice (PAEA, 2010). Fertigation was practiced using Albert's fertilizer (UNIPOWER (PVT) LTD,), gradually increasing the dosage as illustrated in Table 1 (PAEA, 2010). A diluted solution (0.05 g L^{-1}) of calcium nitrate ($Ca(NO_3)_2$) was applied weekly as a foliar spray to prevent the physiological disorder 'Blossom-end rot (BER)' at the reproductive stage. Vertical support for crops were provided and standard pruning and training were conducted as canopy management practices, leading to maintaining a single stem. The first flower cluster was removed to further increase the vigour of the plant during vegetative growth. At the reproductive stage, fruit thinning was practiced to improve the fruit quality. The 2-3 leaves at the base of the plant were also removed after six weeks of transplanting (WAT) to facilitate dry matter partitioning to the fruit sink. Pollination was aided by vibrating the top crop support manually during the flowering stage. Chemical control of mite and leaf miner attacks was done as incidences appeared (PAEA, 2010).

Experimental Design

There were three treatments each in the two Trials conducted in polytunnels (greenhouses) representing the diversity of greenhouse climate control (CC); (T1) an intensive CC with a double-cladded polythene roof and an Internet of Things (IoT)-based automatically controlled exhaust fan and misting system according to the preset temperature values, (T2) a semi-intensive CC with a single hard plastic roof and a timer-controlled misting, and (T3) a less-intensive CC with a single polythene roof, with natural ventilation.

The experiments (Trials) were laid out as a completely randomized design (CRD) with each Trial comprising of three replicates. Each replicate consisted of 70 plants. Trial 1 (variety 'Bolseno') and Trial 2 (variety 'Sylviana') received the same crop management and agronomic practices. The monitoring and controlling system described in Jaliyagoda et al. (2023) was installed in three polytunnels to compare different internal CC conditions maintained or prevailed during the cropping season (Figs. 1 and 2).

Table 1: Rate of Albert's fertilizer application.

Plant growth stage (WAP)	Albert's fertilizer (g plant^{-1} day^{-1})	Water (mL plant^{-1} day^{-1})	Approximate EC (dS m^{-1})
0 - 2	0.1 - 0.2	150 – 300	0.4 - 0.8
2 - 4	0.3 - 0.4	300 – 400	0.8 - 1.2
4 - 6	0.6 - 0.8	600 – 800	1.2 - 1.4
6 - 12	1.0 - 1.2	1000 – 1500	1.4 - 1.6

(Source: PAEA, 2010)

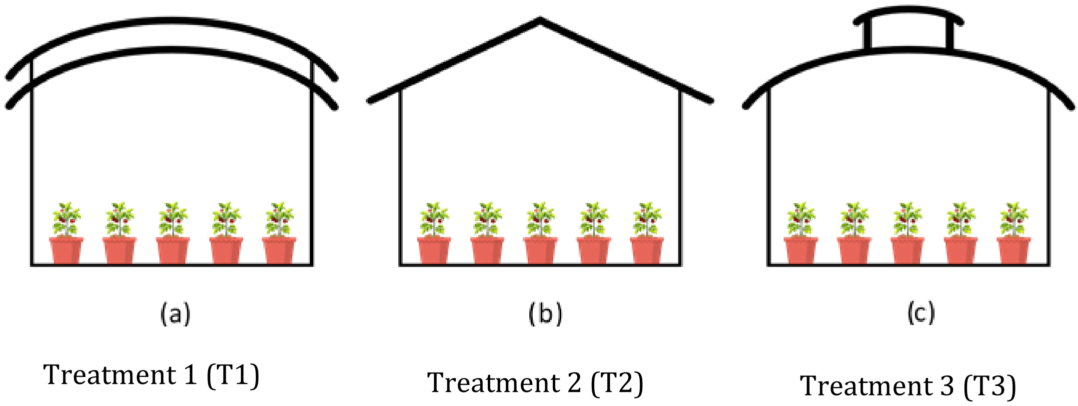

Figure 1. Cross sections of greenhouses that were used to create different internal environmental conditions during the experiment; (a) T1 - Intensive control greenhouse with a double cladded polythene roof, insect -proof net covered side walls, and an IoT-based automatically controlled exhaust fan and misting system according to the preset temperature values, (b) T2 - Semi-intensive greenhouse with a single hard plastic roof, insect-proof net covered side walls, and a timer-controlled misting, (c) T3 - Less-intensive greenhouse with a single polythene roof consisting of a top vent, insect-proof net covered side walls with natural ventilation.

Figure 2. Plant arrangement and greenhouse setup in three treatments; (a) T1 - Intensive control greenhouse, (b) T2 - Semi-intensive greenhouse, (c) T3 - Less-intensive greenhouse.

Evaluation of Greenhouse Environment, Plant Growth and Development

Greenhouse environment:

During the Trial 1, a climatic data acquisition system was used in T1 where air temperature and relative humidity data were acquired using sensors. Temperature was measured using dry-bulb thermometers whereas relative humidity was measured using wet-bulb, dry-bulb thermometers in other treatments. In the Trial 2, in all three treatments and outside weather data were acquired using an automatic data acquisition system with sensor systems as described by

Jaliyagoda et al. (2023). The average values of greenhouse environmental data (January 2019 – July 2020) were taken by averaging the daily values during the growing period separately for both Trials.

Plant growth and flower formation:

Plant height (from the surface of the medium to the apical meristem), stem thickness (measured using a Vernier caliper at the base collar of the plant) and the number of fully expanded leaves of the plants were determined at two-week intervals. The leaf area index was taken using the grid method at two-week intervals during the vegetative growth. The average number of days taken for each crop for 50% flowering (50% of flowering of the first flower cluster of each crop) was also recorded.

Yield and fruit quality:

Fruit samples were collected from randomly selected plants from each treatment for determining yield parameters. Harvesting was started at the breaker stage of tomato (Approximately 70% ripened), and the number of fruits per plant was determined in each experimental unit. A sample of fruits was weighed using a top-loading balance for determining the average fruit weight at early harvesting. Readings were taken up to three decimals. The average fruit diameter was taken using a Vernier caliper.

pH and Electrical conductivity (EC):

The same number of replicated samples of growth media from the grow-bags were collected, and the pH and EC (dS/m) of the plant growth medium were measured using a digital pH and EC meter. The measurements were taken in both trials, during the vegetative and reproductive growth stages of plants.

Sample preparation and extraction to determine the total phenolic content (TPC) and Antioxidant activity of tomato fruits:

Tomato fruit samples were extracted using the methods described by Luthria et al. (2006) with minor modifications. Three sets of tomato fruits of the variety 'Sylviana' were collected at maturity from each treatment. The selected fruits were comparable in size and development. All tomato fruits were stored under -80 °C temperature until analysis. Prior to freeze-drying, each tomato sample (whole fruit) was cut into small pieces and freeze-dried using a freeze drier (Telstar, LyoQuest Laboratory Freeze-dryer, Spain). The freeze-dried samples were ground and screened through a size 20 standard sieve to obtain uniform particle size.

For each extraction, approximately 200 mg of ground freeze-dried tomato sample was placed in a 15 mL centrifuge tube with 5 mL of the solvent mixture MeOH: H_2O (80:20, %v/v). After centrifuging the mixture for 15 minutes at 4,000 rpm, the supernatant was poured into a 10 ml volumetric flask. The residue was resuspended in 5 mL of MeOH: H_2O (80:20, %v/v), gently mixed manually by shaking and centrifuged at 4,000 rpm for 15 min. The initial extract and the extract of supernatant were combined, and the volume was increased to 10 mL with solvent mixture, using a volumetric flask.

Determination of the total phenolic content (TPC)

For the determination of TPC, tomato extracts were assayed by Folin Ciocalteu (FC) procedure as described by Luthria et al. (2006). Extractions and analyses were carried out in triplicates for each sample. Approximately 100 µL of tomato fruit extract was pipetted out into a 15 mL tube followed by the addition of 7.9 mL of water. This mixture was vortexed for 10 s and 500 µL of FC reagent was added. The mixture was vortexed for an additional 20 s and 1.5 mL of 20% sodium carbonate solution was added. The mixture was then vortexed for 20 s and after 2 h at ambient temperature, the absorbance was measured at 765 nm using a spectrophotometer (BIO Spectrometer, Kinetic-Eppendorf, Germany). A calibration curve was created using different concentrations of standard gallic acid solutions. The level of TPC (Total content of phenolic compounds) in the extract was calculated from the standard calibration curve. Results were expressed on the basis of mg of

Gallic Acid Equivalent per gram (mg GAE/g) of dried tomato powder.

1, 1- diphenyl-2-picrylhydrazyl (DPPH) radical scavenging assay

The scavenging ability of stable 1,1- diphenyl-2-picrylhydrazyl (DPPH) radicals by methanol extraction of fruits of variety 'Sylviana' was measured using the method described by Elbadrawy and Sello (2016) with minor modifications. One milliliter (1 mL) of the tomato extract was mixed with 4 mL of 0.004 % methanolic solution of DPPH. The mixture was shaken vigorously and left to stand for 30 min in the dark at 30 °C, and the absorbance was then measured at 517 nm using a spectrophotometer (BIO Spectrometer, Kinetic-Eppendorf, Germany) against the corresponding control. The percentage of DPPH decolorization of the samples was calculated according to Equation 1 (Elbadrawy et al., 2016).

$$Antioxidant\ activity\ (\%) = \frac{(absorbance\ \ of\ control\ - absorbance\ \ of\ sample\ )}{absorbance\ \ of\ control} \times 100$$

………… (Equation 1)

Data Analysis

All data were tested for normality and homogeneity followed by one-way analysis of variance. ANOVA was performed to analyze significant differences among different treatments on each parameter separately and individually for each of the two varieties once they met ANOVA assumptions and if not, the Kruskal-Wallis test was performed. Data are presented as mean ± standard deviation. Tukey post hoc test at 95 % significance level (P=0.05) was used for the identification of significant differences. All the statistical analyses were conducted using the Minitab statistical software (version 19).

RESULTS AND DISCUSSION

Greenhouse Environmental Conditions

Temperature variation

Data collection throughout the growing season in both Trials indicated that external as well as internal temperatures start to rise around 9.00 a.m. and peak at 12.00 noon to 2.00 p.m. Then it declines gradually, reaching the lowest at 5.00 p.m. (Figs.3 and 4). This pattern of variation matches with earlier reports on daily temperature variation in the mid-country wet-zone in the open-field and greenhouses (Weerakkody et al., 2009). The external temperature during daytime in both Trials varied between 24 °C to 33 °C. Independent of the outside temperature, the internal greenhouse temperature of T3 reached up to 35 °C in both Trial periods, which may be due to the absence of a temperature control system in T3. The T2 showed a marginally lower temperature values in Trial 1 than in Trial 2, which was higher than T1 in both Trials. It may due to maintaining an even-mist in the greenhouse even though the outside environmental temperature was at lower limits (T2 had a timer-based non-automated misting system). The T1 was able to maintain the inside temperature below 33 °C during both Trials. As such, environmental conditions were similar during both Trials for T1 and T3.

The higher blowing capacity (forced-air exhaust system) together with the automated mist cooling system and temperature set-point-based automatic switching contributed to maintaining a lower mean temperature in T1, compared to T2 and T3 in both Trials. It clearly shows that an IoT-based automated system could maintain the inside temperature of greenhouses at a level favourable for crop growth when the cooling mechanism operates on given set points (*i.e.* presetting to start the misting system automatically when the inside air temperature reaches 32 °C). Jaliyagoda et al. (2023) also reported the same controlling pattern in an automated greenhouse. It can be assumed that the temperature control methods used in T2 (timer-based misting system) and T3 (natural ventilation) were not sufficient to maintain a favourable temperature for plants inside greenhouses on sunny days (Figs. 3 and 4).

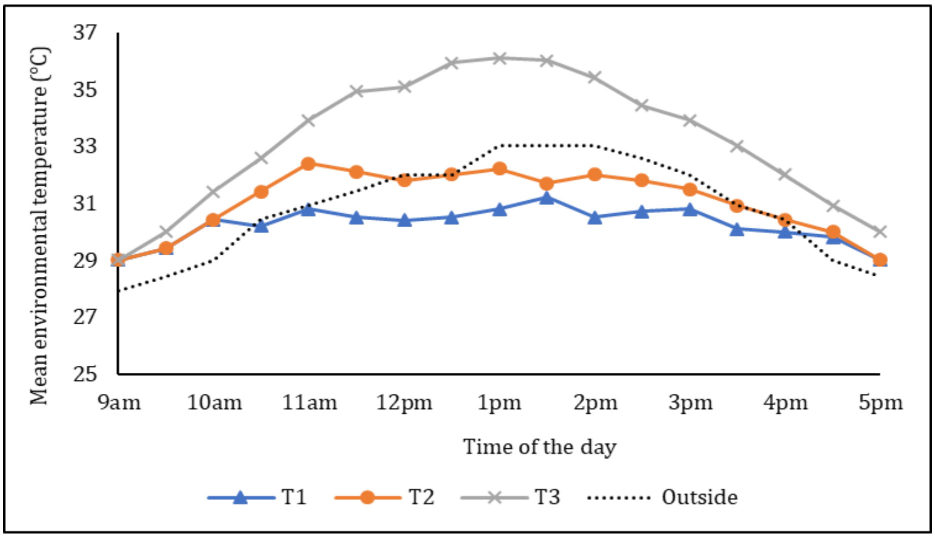

Figure 3: Variation of mean air temperature inside and outside greenhouses in Trial 1
T1 - Intensive control greenhouse, T2 - Semi-intensive greenhouse, T3 - Less-intensive greenhouse

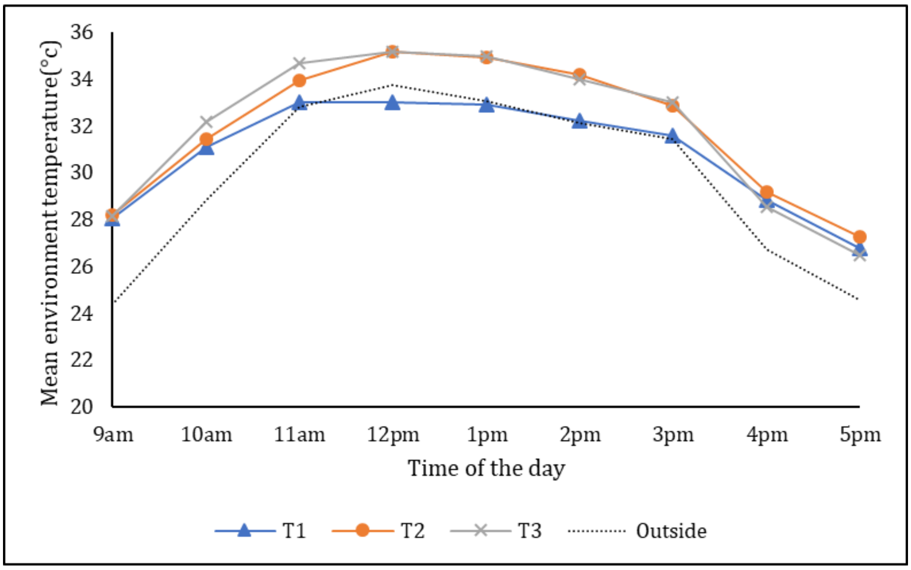

Figure 4: Variation of mean air temperature inside and outside greenhouses in Trial 2
T1 - Intensive control greenhouse, T2 - Semi-intensive greenhouse, T3 - Less-intensive greenhouse

Relative Humidity variation

During the daytime, outside and internal relative humidity (RH) varied from 45% to 90% in both Trials with little fluctuations. Among the three treatments, T3 showed the lowest RH values in most part of the days in both Trials. It may be due to the high temperature maintained in T3, without forced-air ventilation and misting. Further, T1 and T2 showed a higher RH variation compared to T3 and outside due to the presence of a misting system.

Plant Growth Parameters

All four growth parameters measured (Fig. 5) during the vegetative growth phase resulted in similar results at 1 week after planting (WAP) for both the varieties (Trial 1 and Trial 2). Deviations among the treatments were observed from 3 WAP. All four parameters showed an increasing trend (Fig. 5) with time as a result of photosynthesis and the growth of vegetative parts (Ho, 2017).

For the var. 'Bolseno', T2 showed the highest stem thickness, number of leaves per plant, and LAI during the first 7 WAP probably due to the favourable internal temperature and relative humidity achieved. The temperature in T2 was lower in Trial 1 (with var. 'Bolseno') than in Trial 2 (with var. 'Sylviana'). Plant height of var. 'Bolseno' was the highest in T1 only at the 9 WAP; whereas, T3 gave the lowest at all sampling stages. Ambient temperature of 18-32 °C is considered the optimal temperature for tomato plant growth (Cherie, 2010; Hochmuth and Hochmuth, 2012). In the present study, var. 'Bolseno' showed the best results with T2 (Fig. 5).

In the var. 'Sylviana', all treatments resulted in similar plant growth at early stages. At 5 WAP and later, the T2 showed a lower plant height than T1. Although T1 and T3 maintained similar plant heights up to 7 WAP, T1 showed prominence after 7 WAP, followed by T3 and T2. The highest plant height in T1 could be a result of maintaining a favourable mean temperature in the greenhouse by an effective temperature control mechanism during Trial 2. When the plant reached a height of 150 cm, those in T3 were taller than T2 (Fig. 5b). It may due to variation of temperature in different heights of plant canopies. At 3 WAP, T2 showed a comparatively higher stem thickness, reaching the highest at 7 WAP (Fig. 5d) without showing significant difference. The highest leaf numbers were reported in T2 and T3 at 5 WAP but at 7 WAP, the leaf number of T3 increased (Fig. 5f) without showing any significant differences. It could be an influence of the lower air temperature maintained at the upper canopy level of T3. As illustrated in Fig. 5h, LAI showed significant differences, despite the fact that the other plant growth parameters were not significantly different ($P>0.05$) among treatments. Subsequently, the LAI of T3 increased gradually at a rate higher than the others up to 7 WAP and was followed by T1.

Both the varieties showed similar trends in the vegetative parameters during the initial growth stages. Although there was an increasing trend with respect to all the four vegetative growth parameters with time, there was no significant differences ($P>0.05$) between the treatments in var. 'Sylviana'. Further, the var. 'Bolseno' showed significant differences ($P<0.05$) among the treatments at 5 WAP and 7 WAP. The two trials provided evidence that the two tomato varieties performed differently under similar growing conditions, where the var. "Sylvinia" showing a better overall growth pattern than the var. "Bolseno".

As stated above, the var. 'Sylviana' is a hybrid developed for greenhouses whereas 'Bolseno' is a dual-purpose variety, with higher vegetative growth performance in the former in the greenhouse environments. Further, similar performance among treatments in var. 'Sylviana' could be a positive varietal trait possibility of adapting to different environments. This variety may have an adaptive mechanism to environmental stress conditions. According to Chen et al. (1982), the ability of crop plants to adapt to heat stress is potentially an important component of tolerance to heat stress. Therefore, the results of the present study would help identifying the suitability of tomato varieties to be grown under changing greenhouse environments.

Reproductive Development

In the var. 'Bolseno', although the vegetative growth performances were better in T2, the reproductive performances were better in T1. Plants at reproductive growth phase are more sensitive to surrounding air temperature than the plants at vegetative growth phase. The favourable environmental condition maintained inside T1 (e.g. air temperature < 31 °C) may be the reason for better reproductive performance in T1 compared to T2. The disturbances to the fruit development process resulting from temperatures above 35 °C must have reduced the fruit weight and fruit diameter values in T3. The mean individual fruit weight and the mean fruit width were significantly higher ($P<0.05$) in T1 in var. 'Bolseno' compared to T2 and T3, resulting in better yield parameters in the former that was maintained at a favourable internal environment (Table 2).

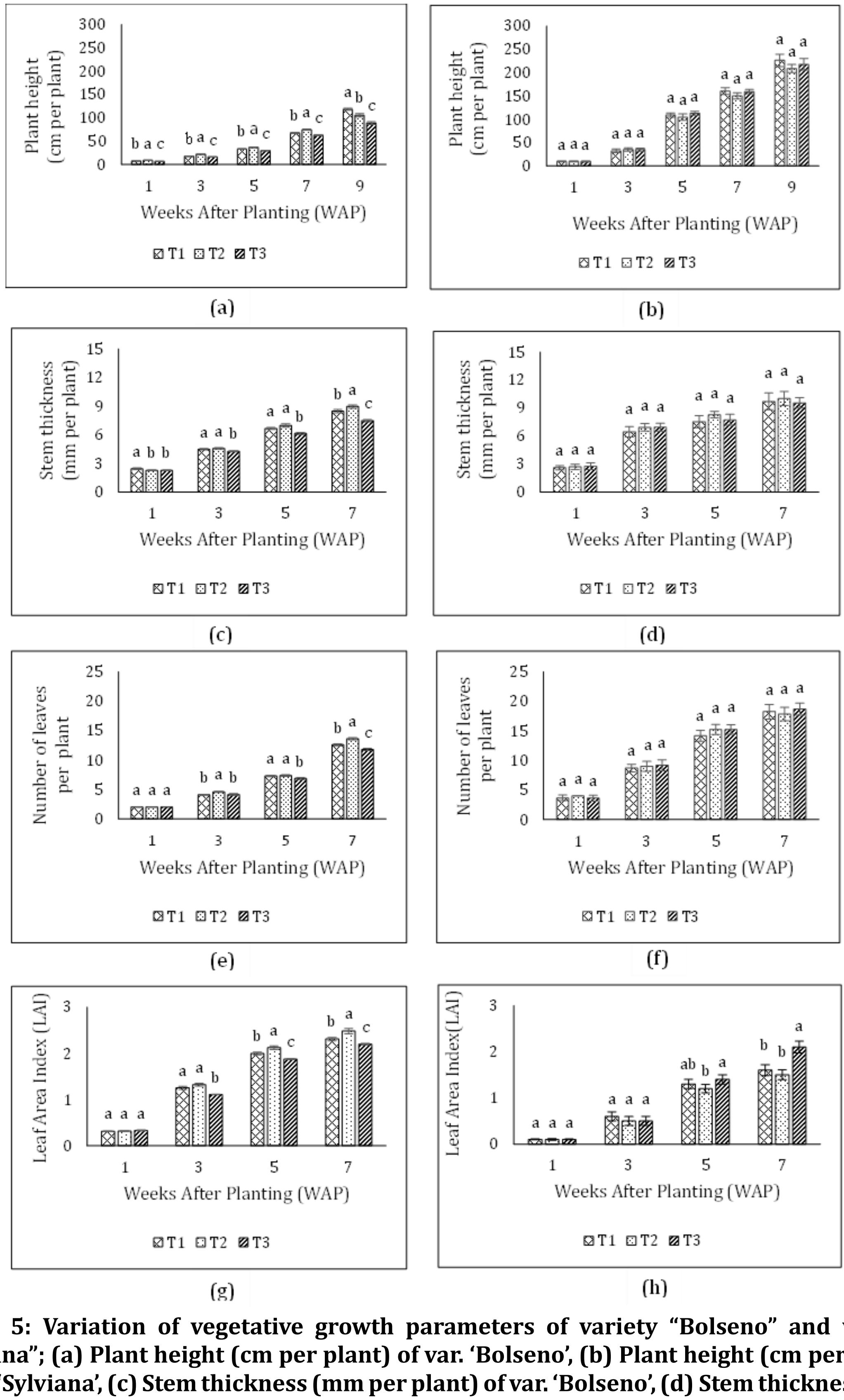

Figure 5: Variation of vegetative growth parameters of variety "Bolseno" and variety "Sylviana"; (a) Plant height (cm per plant) of var. 'Bolseno', (b) Plant height (cm per plant) of var. 'Sylviana', (c) Stem thickness (mm per plant) of var. 'Bolseno', (d) Stem thickness (mm per plant) of var. 'Sylviana', (e) Number of leaves per plant of var. 'Bolseno', (f) Number of leaves per plant of var. 'Sylviana', (g) Leaf Area Index of var. 'Bolseno', (h) Leaf Area Index of var. 'Sylviana'. T1: Intensive control greenhouse, T2: Semi-intensive greenhouse, T3: Less-intensive greenhouse. Note: Error bars indicate standard error of the means. At a given time point (week), the verticial bars followed by the same letter are not significantly different at P=0.05.

Table 2. Number of days taken for 50% flowering, mean number of fruits per plant at early harvesting, mean individual fruit weight(g), mean fruit width(cm) of var. 'Sylviana' and var. 'Bolseno'

Variety	Treatment	Number of days taken to 50% flowering	Mean number of fruits per plant at early harvesting	Mean individual fruit weight at early harvesting (g)	Mean fruit width(cm)
Sylviana	T1	27± 2 a	10±3 a	158±15.7 a	6.06±0.28 a
	T2	22± 2 b	10±2 a	116±31.0 b	5.23±0.24 b
	T3	26± 2 ab	11±2 a	136.6±21.8 ab	5.83±0.61 a
Bolseno	T1	52± 3 a	8±3 a	54.6±5.2 a	5.17±0.49 a
	T2	48± 2 b	7±1 a	46.5± 6.7b	4.29±0.48 b
	T3	53± 3 a	3±1 b	32.9± 4.7 c	3.89±0.89 b

T1: Intensive control greenhouse, T2: Semi-intensive greenhouse, T3: Less-intensive greenhouse; Values are with mean ±SD; Within a column of a given variety, the means of three treatments followed by the same letter for a given variety are not significantly different at p=0.05

In the case of var. 'Sylviana', though all treatments resulted in similar plant growth at early stages, T1 demonstrated a better performance in fruit quality and quantity. The lowest number of days taken (from the day of transplanting) to 50% flowering was achieved by T2; whereas, the highest was reported in T1. According to Kang and Van (2001), plants flowered earlier in high temperatures as a heat escape mechanism. Plants in T2 and T3 were exposed to a higher temperature just before flowering, which could have resulted in early flowering compared to T1. The mean number of fruits per plant was not significantly different among treatments ($P>0.05$). However, the mean individual fruit weight and the fruit width of T1 were higher than the other two treatments. T1 has shown better yield performance than the rest probably due to the favourable environmental conditions maintained inside the greenhouse (Table 2).

These results support previous observations on retardation of flowering, pollination, fruit setting and fruit development processes when ambient temperature exceeds 32 °C (Adams et al., 2001). The two varieties tested showed similar patterns for performances under three different treatments. Environmental conditions of T1 and T3 were similar in both trials, but marginally higher temperature was observed in T2 in the Trial 2 than in Trial 1. The best performance in terms of fruit quality and quantity was in T1 with better-maintained conditions for both varieties. However, under the same environmental conditions, var. 'Sylviana' showed better performances in terms of the mean number of fruits per plant, mean individual fruit weight, and mean fruit width(cm) at early harvesting than var. 'Bolseno', similar to the vegetative growth pattern. Therefore, the 'Sylviana' hybrid may have the genetic capacity or expressed genes in responding to enviornmental changes.

EC and pH of the medium:

The EC and pH measured 12 hours after stopping fertigation (overnight) indirectly indicate the adequacy of plant nutrient supply and its availability for uptake (assuming water uptake was adequate). Compared to EC in the supply solution (Fig. 6), EC in the medium of all treatments showed nearly 50-75 % reduction in Trial 2 (in var. 'Sylviana') in both growth stages. This result assures adequate nutrient uptake rate in all three treatments. The pH in the used nutrient solution (medium) was between 5.3 and 5.6, indicating an approximate availability of plant nutrients as it is within the favourble range of 5.5–6.5. However, in Trial 1 (var. 'Bolseno'), a significant difference of EC in the growth medium ($P<0.05$) was observed among treatments, i.e. a relatively higher EC in T2 and T3 during the vegetative growth and a very low EC in T1 during reproductive stage (Figure 6a), compared to the supply solution (Table 1). Even though the mean pH values of the medium were relatively higher in Trial 1 than in Trial 2, there were no significant difference (P>0.05) in EC was observed among treatments. Therefore, the effect of pH-based availability of plant nutrients or its influence for the uptake rate of nutrients on concentration of dissolved ions in the solution cannot be used to justify the differences in EC of the growth medium across treatments.

Since Sylviana showed better growth and yield characteristics under different microclimate conditions, it was selected for assessing selected fruit quality parameters. Given the nutritional richness exhibited by tomatoes, it is imperative to systematically examine potential variations in the fruit's biochemical constituents in response to varying environmental conditions. The study focused on analyzing the antioxidant activity (AOX) and total phenolic content (TPC) of tomato fruits as an initial step.

Total phenolic content (TPC)

The TPC of variety Sylviana fruits were significantly higher in T2 and T3 compared to T1 (Fig. 7a). The pattern of the results of the present study is similar to those reported by Marsic et al. (2011) and Dasgan et al. (2021). According to Dasgan et al. (2021), generally the total phenol content in tomato genotypes increased under high-temperature stress mainly in fruits of heat-tolerant tomato genotypes. Phenolic compounds are important antioxidants produced by plants under stress as a defense mechanism. According to the present study, the rise in TPC in tomato fruits that were grown in T2 and T3 may be a plant's defense against heat stress since T2 and T3 showed higher internal temperature than T1. The fruits of the heat-tolerant tomato genotypes are also a significant source of antioxidants for humans.

1, 1- diphenyl-2-picrylhydrazyl (DPPH) radical scavenging assay

The Fig. 7b illustrates that the antioxidant activity of T1 was significantly high (P<0.05) followed by T3. In plants, antioxidants and phytochemicals accumulate in organ-specific ways, and the distribution and accumulation of these substances is influenced by a range of environmental factors such as temperature, light, water availability, and other factors like minerals, growing conditions before and after harvest, and cultivars or genotypes (Brovelli, 2006). The antioxidant content of tomato dependend on environmental elements and their effects are greatly influenced by the interactions with genotypes and agronomic methods (Dumas et al., 2003). According to the current study, the environmental condition existed inside T1 was favorable for increase in the antioxidant activity. Giovanelli et al. (1999) reported that carotenoids, ascorbic acid, and phenolic compounds are the primary antioxidants found in tomatoes. The overall antioxidant activity of tomato varies considerably according to the genotype, ripening stage, and growing conditions (Leonardi et al., 2000). In the present study, even with the lowest total phenolic content reported in T1 compared to T2 and T3, the antioxidant activity was still highest in T1. The variations in the effect of different compounds other than TPC, such as carotenoids and ascorbic acid, which were not analyzed in the current study, would also decide the antioxidant activity of tomato fruits (Giovanelli et al., 1999)

The seasonal variations could affect on crop growth up to some level even though they are grown under greenhouse environments, depending on the intensities of greenhouse-environmental control. The most precise way to do a varietal comparison is growing them in the same Trial side by side. In the present study, as two varieties were grown in two Trials, there could be an effect of seasonal environmental variations on plant growth and fruit characteristics. Nevertheless, according to the environmental data collected, both outside and internal environmental variations did not differ much between two Trials. Therefore, the comparison carried out between two varieties is acceptable to have an overall idea on how they performed under different microclimatic conditions. However, if the two varieties were grown during the same period, the growth, yield and fruit quality parameters (which could be affected by the environmental changes but not by the varietal characters) are expected to demonstrate marginal differences, not deviating much from the current results. Information such as how the varietal characteristics play a role in responding to environmental variation is important for future breeding efforts in developing tomato varieties that can perform better in different environments. Until new varieties are developed, it is recommended to assess the suitability of existing varieties and make recommendations accordingly..

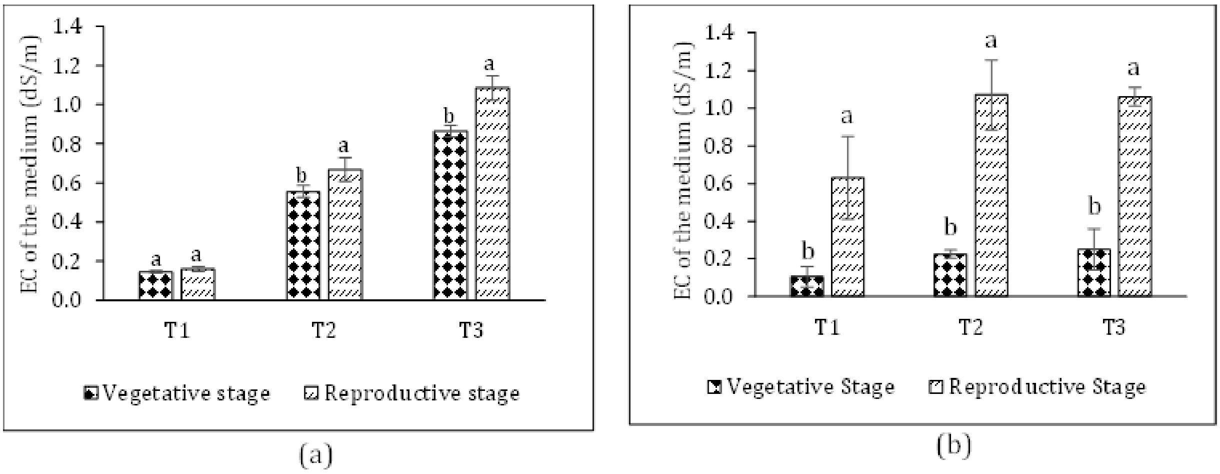

Figure 6. Variations in the Electrical Conductivity (EC) in the media during the vegetative and reproductive stages of two varieties. (a) var. 'Bolseno', (b) Var. 'Sylviana". T1: Intensive control greenhouse, T2: Semi-intensive greenhouse, T3: Less-intensive greenhouse
Note: Error bars indicate standard error of the means. The verticial bars followed by the same letter for a given treatment (T1 to T3) are not significantly different at P=0.05.

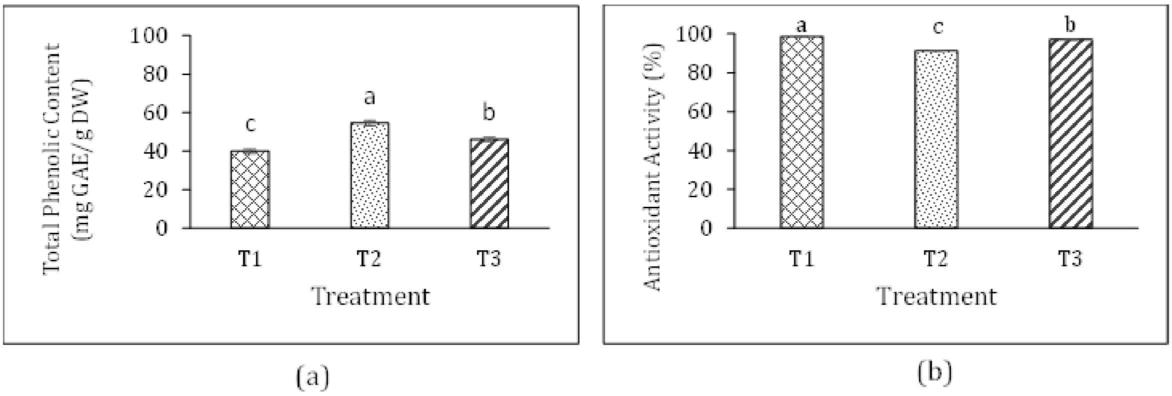

Figure 7: Total phenolic content and Antioxidant activity of fruits of var. 'Sylviana'. (a) Total phenolic content (mg GAE/g dried tomato powder) and (b) Variation of Antioxidant activity of fruits of variety 'Sylviana' of T1, T2, and T3 during the reproductive stage of plants. T1: Intensive control greenhouse, T2: Semi-intensive greenhouse, T3: Less-intensive greenhouse.
Note: Error bars indicate standard error of the means. The verticial bars followed by the same letter are not significantly different at P=0.05.

CONCLUSION

Differences in the intensity of greenhouse-environment control resulted in mild daytime temperatures (<33 °C) under intensive environment control (T1) where the temperature increased up to 36 °C under semi-intensive (T2) and less-intensive (T3) controls. During the daytime, outside and internal relative humidity (RH) varied between 45% and 90% in both Trials with little fluctuations. The hybrid 'Sylviana' performed better than var. 'Bolseno' in terms of most of the plant growth and fruit characteristics in all three greenhouse environments (T1, T2, T3). There was no significant difference in vegetative growth between the treatments in var. 'Sylviana' but was different in var. 'Bolseno'. Influenced by the favourable environmental conditions under intensive environment control (T1), var. 'Sylviana' resulted in greater fruit number and weight, compared to var. 'Bolseno' during early reproductive stage. Considering the total phenolic content and antioxidant activity in fruits of 'Sylviana' grown under different greenhouse conditions, it can be ascertained that fruit quality is affected by the greenhouse environmental conditions. According to the present study, the hybrid greenhouse tomato performed well under different greenhouse environments than the dual-purpose variety. The hybrid also showed a moderate level of heat-tolerance. This study highlights the importance of considering differences among genotypes in responding to the environmental conditions for optimizing productivity in greenhouse-cultivation of tomato. The findings are important in breeding new varieties and recommending existing varieties for different microclimatic conditions.

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