Performance Evaluation of Tomato Production in a Covered Structure Environment of Belize

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Abstract

Tomato cultivation in Belize faces significant environmental challenges, including extreme weather conditions, soil nutrient availability, and pests and diseases. This study evaluated the performance of eight indeterminate tomato varieties in a polyethylene-enclosed cover structure to mitigate these challenges and improve yield stability. A randomized complete block design with four replicates was used to assess germination, flowering, survival rates, growth habits, yield, and organoleptic features. Results showed that the covered structure significantly enhanced overall plant performance. PVF1 and IA1915 were the top-performing varieties, achieving yields of 1.27 and 1.19 tons per hectare, respectively, with efficient resource allocation between vegetative growth and fruit production. Additionally, organoleptic analysis indicated strong consumer preferences for specific varieties. IA1915 was the most preferred variety for size, scoring an average of 4.36 out of 5, while 8498F1 was the top variety for color, with an average score of 4.33. The study concluded that controlled environments can improve tomato production in Belize by enhancing yield, fruit quality, and post-harvest shelf life, offering valuable insights for sustainable commercial production

Keywords: Tomato cultivation, smallholder farmers, Belizean agriculture, covered structures

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Introduction

Tomato (*Solanum lycopersicum*) is a vital crop in Belize, contributing to both the national diet and agricultural economy. Smallholder farmers and commercial producers rely on tomato cultivation for income generation, yet production is highly vulnerable to environmental stressors, including extreme weather events, fluctuating soil nutrient availability, and pests and diseases. These challenges often lead to increased dependency on agrochemicals, which can reduce profitability and contribute to environmental degradation and potential threat to human health. Consequently, there is an urgent need for sustainable cultivation methods that improve tomato yield and quality while minimizing synthetic chemical inputs.

The 2019 World Bank Report identified Belize's agricultural sector as highly susceptible to climate variability, with drought alone causing an estimated 2.9% loss to the country's GDP (Statistical Institute of Belize, 2019). Therefore, farmers need to practice effective methods to adapt to a changing climate. Research by Khapte et al. (2018) demonstrated that greenhouse tomato cultivation significantly enhanced plant survival and yield in arid and tropical environments by reducing exposure to extreme weather and pests. Given these findings, implementing controlled environments such as covered structures present a promising solution for stabilizing tomato yields in Belize.

This study evaluated the impact of a polyethylene-enclosed covered structure on tomato production in Belize by assessing the performance of eight indeterminate tomato varieties. The research focused on key agronomic factors, including germination, flowering, survival rates, growth habits, yield, and organoleptic analysis. The methodology followed standardized agronomic protocols adapted from World Vegetable Centre (WVC) research guidelines (World Vegetable Centre, 2017). By identifying high-performing tomato varieties suited to controlled environments, this study aimed to provide practical recommendations for optimizing tomato production, improving sustainability, and supporting the long-term resilience of Belizean agriculture.

Methodology

Geographic Location and Soil Type

The experiment was carried out at the University of Belize — Central Farm Campus (17°12′04.4" N, 89°00′16.6" W). The slope position was toe slope, and the relief was characterized as a broad floodplain valley with flat land stretching from both sides of the river. The soil used for this evaluation was classified as loam soil. The initial characteristics of the soil type are shown in Table 1. Soil type information helped with the fertilizer and pesticide program for the duration of the research.

Table 1. Baseline soil characteristics used for the performance evaluation of several tomato varieties were analyzed at the Sugar Industry Research and Development Institute, Corozal, Belize. N.B.: Baseline analysis was conducted at Belize Sugar Industry Research and Development Institute (2023).

Analysis	Characteristics
Grid reference	17°12'04.4"N 89°00'16.6"W
pH	7.2
Available N (ppm)	5 (low)
Available P (lbs./acre)	10
Magnesium	Very low
Organic matter	Medium
Aluminum (ppm)	5
Manganese (ppm)	5 (low)
Calcium (ppm)	2800
Iron (lbs./acre)	5
Chloride (ppm)	500
Electrical conductivity (ds/m)	1.4
Texture	Clay

Cover Structure and Agronomic Practices

A polyethylene-enclosed sawtooth rooftop greenhouse structure was used for this experiment. The cover structure was 61 m x 12 m and was located at an altitude of 56 m above sea level. Conditions monitored for the greenhouse environment included temperature, irrigation and pests and diseases. The experimental plot within the structure was 23.7 m by 11.2 m.

The experimental site was thoroughly tilled to a depth of 0.2 m to 0.3 m and was prepared by tilling the soil with a rototiller. The beds were measured, demarcated, and formed. Seeds and stubbles were removed one month before transplanting, and the soil was brought to a fine till. Each plot was mixed with 45.3 kg of decomposed chicken manure. Seeds were sown in 72 cell plastic trays. A potting mix planting medium was used for sowing the seeds. Water was mixed to the medium until well incorporated to an 80% water content. Seeds were then sown to a depth of 1 cm. Seedlings were transplanted at a distance of 30 cm spacing from each plant in double rows. A total of 30 seedlings were transplanted per variety and replicated. The trellising system was installed by running the upper wires over each bed with tensioners at the end of the cables. A trellising hook was hung on the upper wire for each tomato plant. A tomato clip was used to secure the trellising twine at the base of the tomato plant. Weekly Pruning was done. Lateral buds and bottom leaves were pruned. The plants were fertigated one hour daily with a drip irrigation system. Plants were watered before noon or late evening.

Experimental Design

A randomized complete block design (RCBD) with four replicates was used for a total of 32 experimental units. Each experimental unit had a dimension of 0.6 m x 4.8 m. The height of the beds was 0.3 m. There was a 0.6 m distance between each unit. Thirty tomato seedlings were transplanted per unit at 0.23 m between rows and 0.3 m within rows. A total of 960 tomato plants were transplanted in the experimental plot. The overall size of the plot used for this experiment was 11.2 m x 23.7 m (265 m^2), which translates to a planting density of 3.6 plants per m^2 or 14,664 plants per acre. The evaluation consisted of eight indeterminate tomato varieties, all beef-type: IA1914, IA1912, IA1915, 03F1, 8498 F1, Pura Vida (PV -F1), 8503 F1, Rambo F1 (R-F1) – commercial variety.

Variables Measured

Two types of data were collected: production data and organoleptic tests for market preference. The production data encompassed several key parameters. First, the germination percentage was documented. The percentage of flowering was tracked by noting the number of days after transplanting when 50% of the plants in a plot had open flowers; this was monitored three times per week. The survival rate measured the percentage of total plants that remained in the experimental unit at the time of the final harvest. Growth habit data, such as the height and length of stems, aerial biomass, and root biomass, were recorded. Yield and weight data were collected by recording the number and weight (kg/plot) of marketable and nonmarketable fruits. This process continued until harvesting was completed, six months after the first harvest. The total marketable yield was calculated by summing the yields of individual harvests, and the yield per plot (kg/plot) was converted into tons per hectare. Additionally, the average fruit weight (in grams) was determined by selecting 20 randomly chosen marketable fruits per plot. Finally, the shelf life was assessed by counting the number of days the tomatoes could be stored at ambient temperature before beginning to deteriorate.

Statistical Analysis

The data were analyzed using IBM SPSS Statistics 26, with a one-way ANOVA performed to assess the significance of differences among the tomato varieties across key parameters such as germination, flowering, survival rates, plant height, biomass, and yield. A significance level of $p < 0.05$ was used, and Tukey's HSD test was applied for post-hoc comparisons to identify pairwise differences between varieties. Descriptive statistics, including means and standard deviations, were calculated, and the yield data were converted to tons per hectare. Additionally, organoleptic analysis data were evaluated using ANOVA to determine significant differences in consumer preferences for fruit color, size, juiciness, and texture. Graphs and visualizations were used to illustrate these differences, providing a comprehensive analysis of varietal performance.

Results

Germination and Flowering

The germination percentage was highest for the IA1912 variety, which achieved a germination rate of 96%, followed closely by 8498F1 at 94% and 03F1 at 92%. The differences in germination rates across varieties may be due to the genetic vigor of the seeds and the controlled environmental conditions in the covered structure, which provided optimal moisture and temperature for seed emergence. These results highlight the adaptability of these varieties to nursery-like conditions, making them suitable candidates for commercial production under controlled environments (Figure 1).

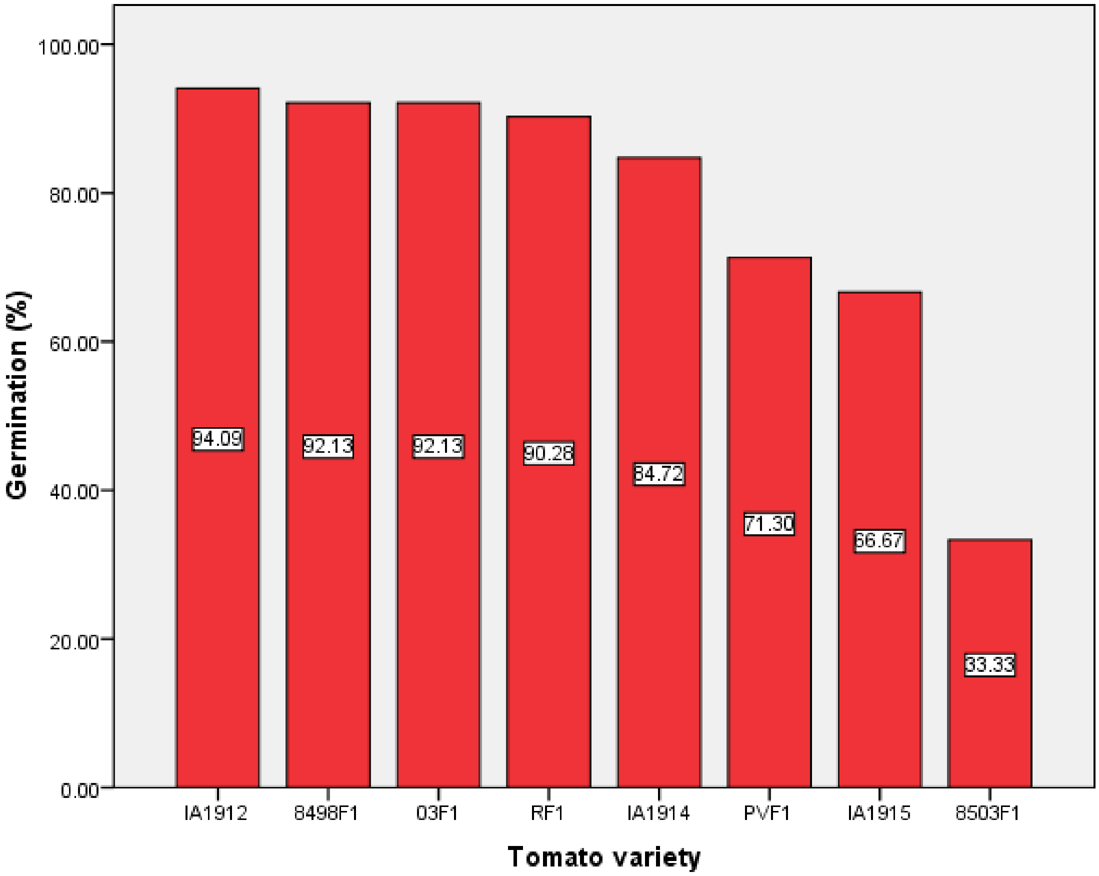

Figure 1. Germination percentage of indeterminate tomatoes 14 days after sowing.

Flowering was initiated as early as 12 days after transplanting, with the varieties PVF1, IA1915, and RF1 reaching a flowering rate of over 90% by day 30. In contrast, other varieties like IA1912 and 8503F1 lagged slightly, showing a flowering rate of 80% by the same period. These differences suggest that PVF1, IA1915, and RF1 are faster to transition into reproductive growth, likely benefiting from precise nutrient management and consistent light levels in the greenhouse environment. This early flowering indicates a potential for earlier and possibly extended fruit production (Figure 2).

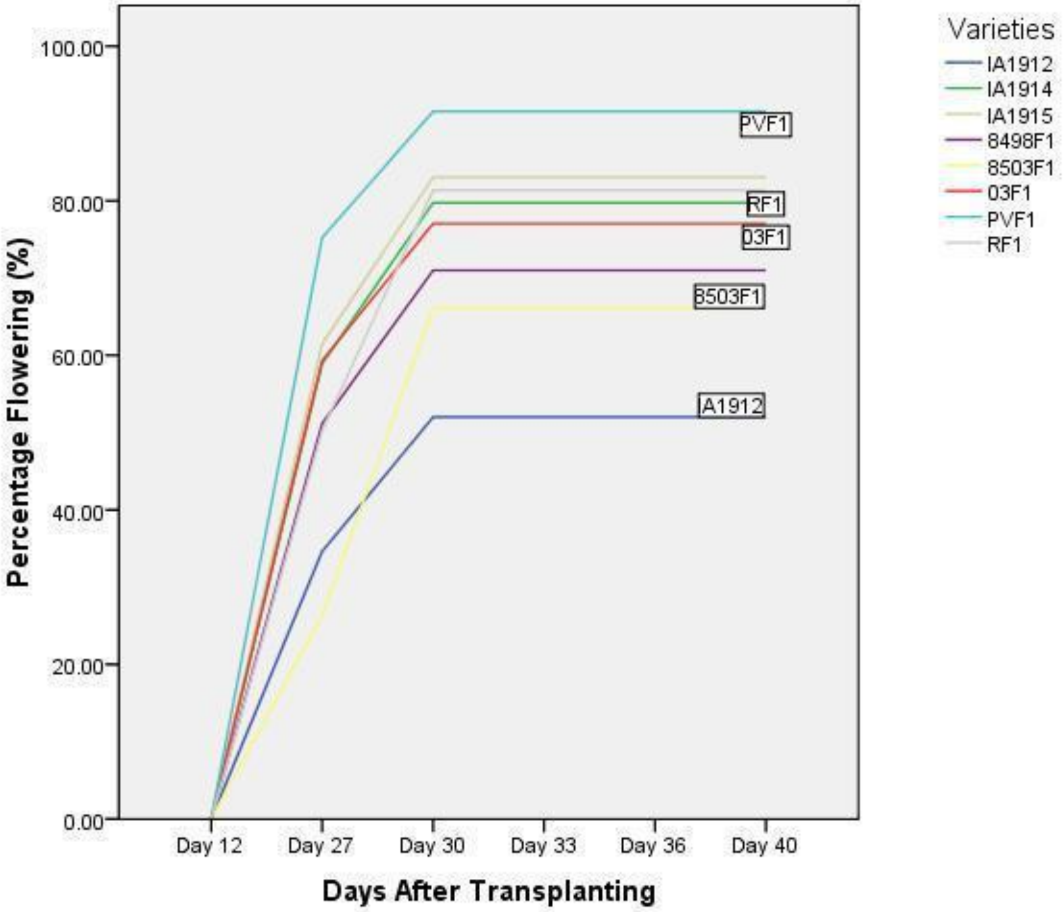

Figure 2. Percentage of flowering plants days after transplanting

Survival and Growth Habit

The survival rates of the tomato varieties were recorded at the final harvest, six months after the first harvest. The varieties IA1915, IA1914, and 8498F1 showed the highest survival rates, with over 95% of the plants surviving to the final harvest. These high survival rates reflect the resilience of these varieties to the environmental conditions in the greenhouse, including pest pressure and potential disease stress. The high survival rate directly influences overall yield, as more plants remain productive throughout the growing season (Figure 3).

The growth habit data showed variability among the varieties, with the tallest plants recorded in PVF1, 8503F1, and RF1, reaching heights between 2.3 m and 2.4 m. Varieties such as IA1914 and 8498F1 had more compact growth, ranging between 2 m and 2.1 m in height, respectively. The measurements for aerial biomass also revealed that PVF1 and RF1, while having relatively low aerial biomass, produced some of the highest yields. This suggests efficient resource use in terms of energy allocation between vegetative growth and fruit production (Figure 4).

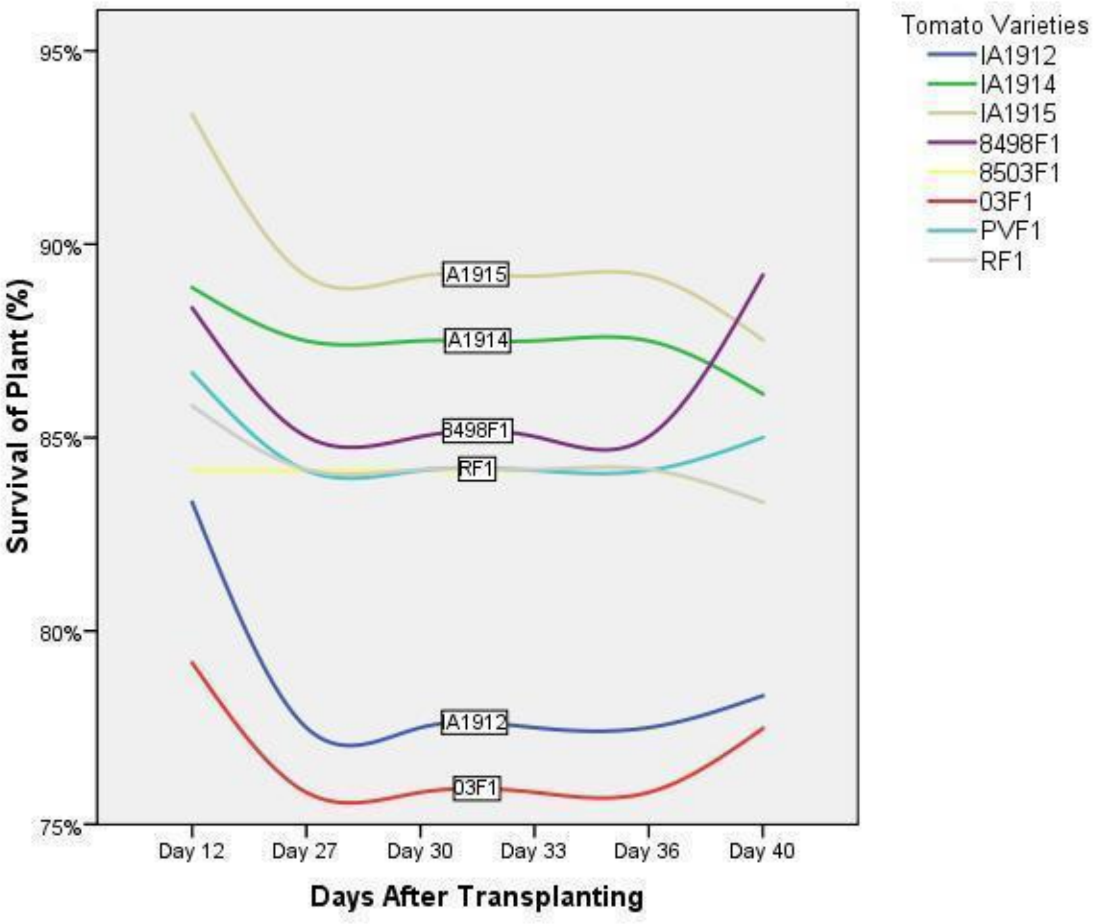

Figure 3. Survival of plants vs days after transplanting.

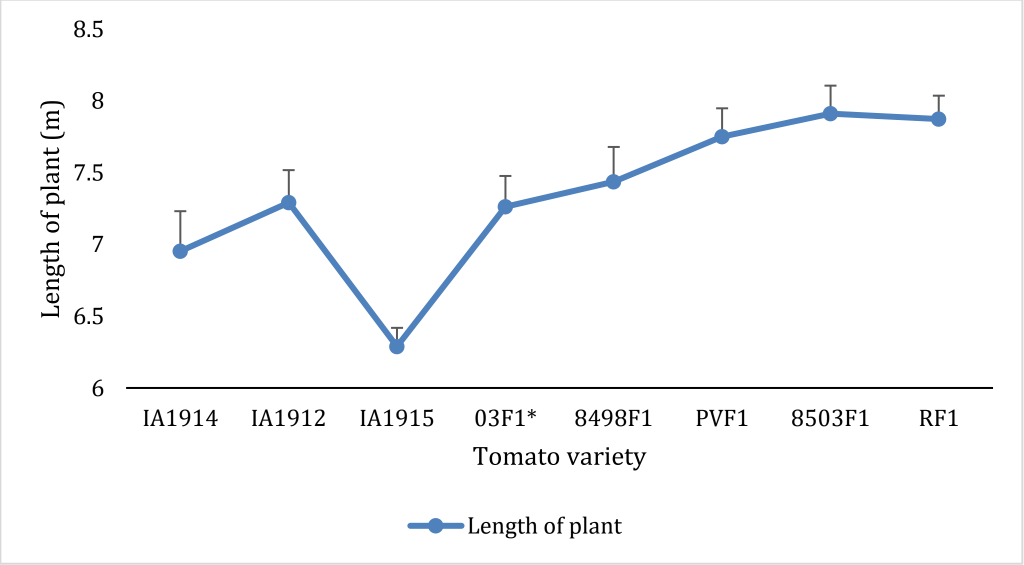

Figure 4. Lengths of several varieties of indeterminate tomatoes

Biotic Stressors

Several biotic stressors were observed in the tomato plants during the study, including broad mites, whiteflies, army worms, and thrips (Table 2). Broad mites were found on the shoots and treated with Abamectin, while armyworms, present on the fruits and leaves, were controlled with Engeo. Whiteflies were identified on the abaxial surface of leaves, though no treatment was applied. Thrips were observed in the flowers, but their population threshold did not trigger the need for treatment. Timely interventions helped manage these pests, reducing their impact on plant health and fruit yield (Figure 5).

Table 2. Type of pests typically present in tomato plants.

Common name	**Scientific name**	**Where in plant**	**Present**	**Treatment**
Broad mite	*Polyphagotarsonemus latus*	Shoots	√	Abamectin
White fly	*Bemisia tabaci*	Abaxial side of the leaves		
Army worm	*Spodoptera frugiperda*	Fruits / leaves	√	Engeo
Thrips	*Frankliniella schultzei*	Flowers		

Figure 5. Army worm damage to tomato plants and fruit.

Shelf Life

Shelf life analysis showed that the varieties RF1, IA1915, and 8498F1 had the longest shelf lives, maintaining quality for 35 to 38 days under ambient temperature. This extended shelf life is particularly beneficial for reducing post-harvest losses, which is crucial in regions like Belize where cold storage facilities may be limited. On the other hand, varieties like 03F1 and 8503F1 had shorter shelf lives, lasting only 3 to 5 days. The extended shelf life of RF1 and IA1915 adds to their appeal as viable varieties for both fresh market consumption and potential export (Figure 6).

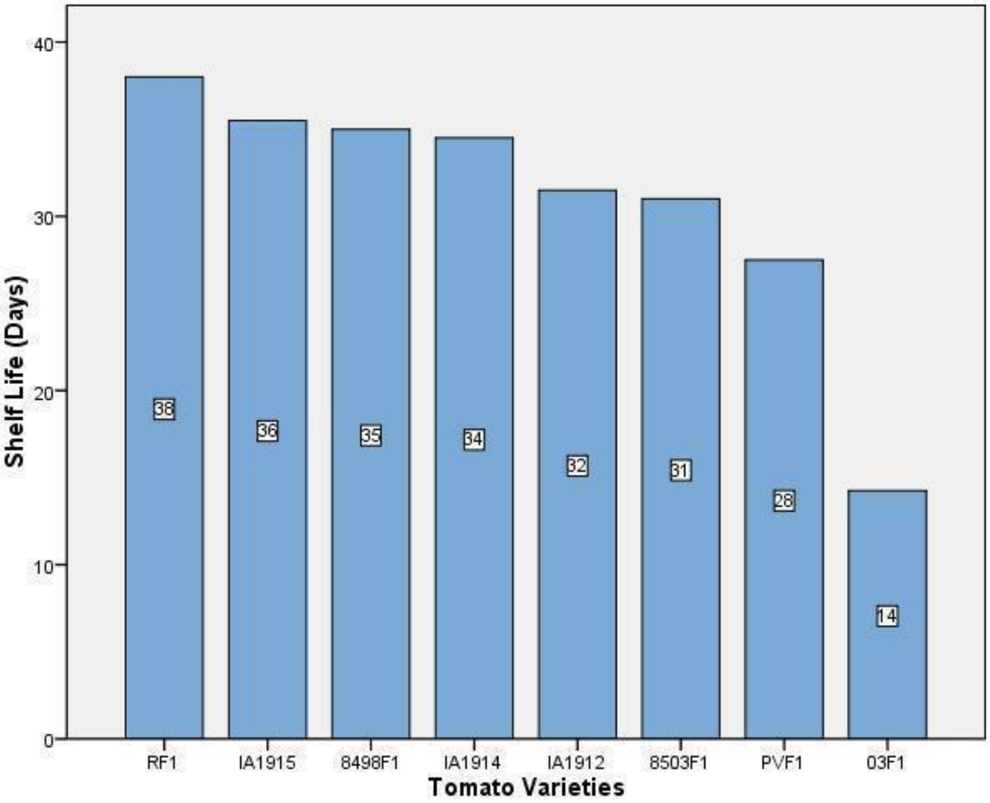

Figure 6. Comparison of mean shelf life amongst the tomato varieties.

Yield and Weight

PVF1 stands out with the highest mean yield of 1.2728 kg per plant, followed closely by IA1915 with 1.1997 kg per plant respectively. These two varieties clearly performed better than the others in terms of fruit production, highlighting their potential suitability for commercial tomato cultivation in controlled environments. The high yield of PVF1 is especially noteworthy given its relatively moderate aerial and root biomass, suggesting that this variety efficiently allocates resources to fruit production. In contrast, IA1912 and 8503F1 exhibited the lowest yields, with 0.7088 kg and 0.6927 kg per plant respectively, making them less competitive in terms of overall productivity.

The aerial biomass was highest in IA1915, which also had one of the top yields. This indicates that IA1915 invests significantly in vegetative growth, which may contribute to its high yield. However, other varieties like PVF1, with a lower aerial biomass but comparable yield, demonstrate that greater vegetative growth does not always directly correlate with higher fruit production. This suggests that PVF1 may be more efficient in converting vegetative growth into fruit production, making it a potentially more desirable variety for farmers looking to maximize yield with minimal vegetative growth.

Root biomass across the varieties was generally low, with the highest being in RF1, which had a root biomass of around 0.02 kg per plant. Despite having the highest root biomass, RF1 did not achieve the highest yield, though it still performed well at 1.0383 kg. This indicates that while strong root systems can support healthy plant growth, other factors, such as aerial biomass and resource allocation to fruit production, also play a crucial role in determining overall yield (Figure 7).

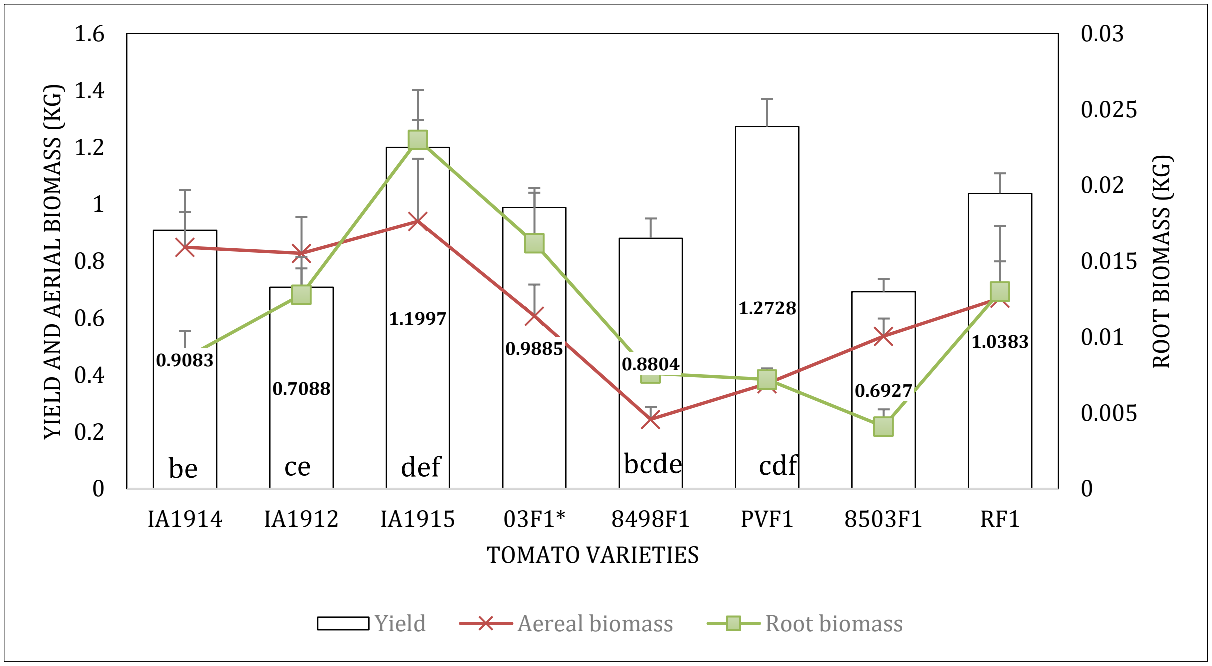

Figure 7. Comparison of yield, areal and root biomass of different varieties of tomatoes used in this study. N.B., * denotes a variety that is not statistically significantly different to the other tomato varieties; varieties with similar letters indicate that the varieties are statistically significantly different from each other based on aerial yield.

Organoleptic Analysis and Consumer Preference

The organoleptic analysis revealed notable preferences among consumers for specific attributes across the tomato varieties. IA1915 was the most preferred variety for size, scoring an average of 4.36 out of 5. 8498F1 was the top variety for color with an average score of 4.33, while IA1912 was rated highest for juiciness with a score of 4.21. These results indicate that different varieties excel in various organoleptic characteristics, making them suitable for targeted market segments based on consumer preferences. The significant differences in color and size also suggest that these attributes are important factors in consumer decisions when selecting tomatoes for purchase (Table 3).

Table 3. Comparison of organoleptic attributes per variety of tomato.

Tomato variety	**Organoleptic attributes**															
	Colour*		Firmness		Size		Flavour		Juiciness		Skin texture		Flesh texture		Aroma	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
IA1914	3.06**	1.14	4.03	0.98	3.76	1.03	3.30	1.31	3.42	1.25	3.88	1.05	3.85	1.00	3.55	1.23
IA1912	3.94	1.06	3.91	0.98	3.91	0.95	**3.97**	1.13	**4.21**	0.89	3.88	0.93	**3.91**	0.91	3.70	1.07
IA1915	3.94	1.03	3.79	1.05	**4.36**	0.93	3.79	1.02	3.64	1.08	3.82	1.18	3.79	1.17	3.82	0.98
03F1	4.06	1.00	4.06	0.97	4.18	0.98	3.48	1.18	3.85	1.15	3.79	0.96	3.79	1.17	**3.88**	1.11
8498F1	**4.33**	0.96	**4.12**	0.78	4.18	0.85	3.48	1.15	3.82	1.10	3.91	0.80	3.79	1.05	3.82	0.98
PVF1	4.24	0.94	4.06	0.86	3.94	0.90	3.79	1.19	3.61	1.30	3.64	1.11	3.58	1.03	3.67	1.16
8503F1	3.70	1.05	4.03	0.98	4.09	0.84	3.61	1.03	3.91	1.01	**3.94**	0.97	3.88	0.93	3.70	1.02
RF1	4.12	0.89	3.97	0.85	4.18	0.73	3.76	1.12	3.82	1.16	3.82	1.18	3.88	1.02	3.82	1.16

N.B; M = mean; SD = standard deviation; one asterisk represents statistically different results amongst organoleptic attributes; two asterisks in the same column represent statistically different results amongst tomato varieties in accordance with Tukey's test ($p < 0.05$); bold numbers within a column represents the highest mean for the corresponding attribute.

Discussion

The results of this study highlight the significant impact of covered structures on tomato production in Belize. By offering protection from harsh environmental conditions and allowing for more controlled inputs, the covered structure environment was shown to improve several critical production parameters, including germination, flowering, survival rate, growth habit, yield, and fruit quality. These findings support the broader notion that controlled environments can enhance agricultural productivity, particularly in regions facing challenging climatic conditions such as Belize.

Germination and Flowering

The high germination rates observed, particularly for varieties such as IA1912 (96%), 8498F1 (94%), and 03F1 (92%), can be attributed to the controlled environmental conditions inside the covered structure. The consistent temperature, moisture, and light availability within the greenhouse likely played a key role in ensuring optimal seed germination (Adekiya et al., 2001). These results align with findings from similar studies where controlled environments led to improved germination rates for tomato seeds (Sousaraei et al., 2021). Notably, the ability to maintain soil moisture without waterlogging—a common issue in Belize's open-field systems during the wet season—was a significant advantage of the greenhouse system.

Flowering data revealed that certain varieties, such as PVF1, IA1915, and RF1, exhibited rapid flower onset and had a higher percentage of flowering plants (over 90%) by day 30. This indicates that these varieties are well-suited to transition from vegetative to reproductive growth in a controlled environment, likely due to the availability of consistent light, proper nutrient management, and optimal temperature. Previous research has emphasized the importance of temperature and nutrient balance in triggering flowering in tomato plants (Ayarna et al., 2020), and the results of this study confirm that these conditions are essential for maximizing the reproductive potential of the crop. The early flowering observed in this study suggests that the use of covered structures may also allow for earlier and potentially extended harvests, offering a strategic advantage to farmers looking to optimize both yield and market timing.

Survival and Growth Habit

The high survival rates observed across most varieties, with IA1915, IA1914, and 8498F1 all achieving over 95% survival by the final harvest, demonstrate the resilience of these varieties under greenhouse conditions. The covered structure likely provided a buffer against extreme weather events, pest pressure, and potential disease outbreaks—factors that frequently impact survival rates in open-field tomato production (Khapte et al., 2018). The increased survival rates translate directly to greater productive capacity, as more plants are able to reach maturity and contribute to the overall yield.

The growth habit data, which showed that varieties such as PVF1, RF1, and IA1915 reached heights of 2.2 to 2.4 m, also point to the advantages of controlled environments for optimizing plant development. These varieties were able to achieve substantial vegetative growth while simultaneously maintaining high yields. The relatively low aerial biomass for high-yielding varieties such as PVF1 and RF1 indicates that these plants efficiently allocate resources between vegetative growth and fruit production, a characteristic that is advantageous for maximizing both the size and quality of marketable fruit (Amoako et al., 2022).

Biotic Stressors

The management of biotic stressors was another important outcome of this study. Although pests such as broad mites, whiteflies, army worms, and thrips were observed in the tomato plants, timely interventions and the use of targeted pest control measures helped to minimize their impact on plant health and fruit yield. For example, broad mites, which were found on the shoots of the plants, were successfully controlled with Abamectin, while army worms, which targeted both the fruits and leaves, were managed using Engeo. The ability to monitor and control pest populations within the enclosed environment of the greenhouse likely contributed to the higher survival and yield rates observed in this study, as uncontrolled pest infestations are a major cause of crop loss in open-field systems (Scarlato et al., 2023).

Shelf Life

One of the key findings of this study is the extended shelf life observed for varieties grown in the covered structure. Varieties such as RF1, IA1915, and 8498F1 maintained quality for 7 to 9 days under ambient temperature conditions, which is a significant advantage for farmers and retailers in Belize. In regions where cold storage facilities are limited or non-existent, the ability to extend the shelf life of tomatoes can reduce post-harvest losses and improve profitability. The extended shelf life of these varieties may also open up new opportunities for export, as longer-lasting tomatoes are more suitable for transportation to distant markets (Rana et al., 2014). Previous research has shown that covered structures can help reduce the incidence of post-harvest diseases and extend the shelf life of perishable crops (Tagele et al., 2022; Vicente et al., 2015), and the results of this study provide further evidence of the benefits of controlled environments for improving post-harvest quality.

Yield and Weight

Yield data indicated that PVF1 was the top-performing variety, with an average yield of 1.27 tons per hectare, followed closely by IA1915 (1.19 tons per hectare) and RF1 (1.03 tons per hectare). These results are particularly notable when compared to open-field production systems in Belize, where tomato yields are often compromised due to environmental stressors such as excessive rainfall, drought, and fluctuating temperatures. The consistent environmental conditions within the covered structure allowed these varieties to produce larger and more uniform fruits, as indicated by the average fruit weights, which ranged from 0.7 kg for 03F1 to 0.9 kg for PVF1. The ability to produce larger fruits under controlled conditions is a key finding, as fruit size is often a primary determinant of market value and consumer preference (Sharma et al., 2015).

The results also suggest that the use of covered structures can significantly reduce the variability in fruit size and yield that is often seen in open-field systems. In open fields, variability in environmental conditions, pest pressure, and disease outbreaks can lead to uneven fruit development, reducing both the marketability and the profitability of the crop. By contrast, the consistency provided by the covered structure in this study resulted in more uniform fruit production, which is critical for meeting both local and export market standards.

Organoleptic Analysis and Consumer Preference

The results of the organoleptic analysis revealed significant consumer preferences for certain tomato varieties based on attributes such as size, color, and juiciness. IA1915 was the most preferred variety for size, scoring an average of 4.36 out of 5, while 8498F1 was the top variety for color, with an average score of 4.33. IA1912 was rated highest for juiciness, with a score of 4.21. These findings suggest that different varieties excel in various organoleptic characteristics, which can be leveraged to target different market segments. For instance, larger tomatoes like IA1915 may be more suitable for consumers who prioritize size, while juicier varieties like IA1912 may appeal to consumers who prefer tomatoes for salads or fresh consumption. The significant differences in color and size also suggest that these attributes are important factors in consumer decisions when selecting tomatoes for purchase, aligning with previous studies that highlight the role of visual and organoleptic attributes in consumer choice (Figàs et al., 2018).

Overall, this study demonstrates the potential of covered structures to improve tomato production in Belize. By providing a controlled environment that mitigates the effects of extreme weather, pests, and diseases, covered structures can help farmers achieve higher yields, better fruit quality, and reduced post-harvest losses. Additionally, the ability to extend the growing season and produce uniform, high-quality fruits has important implications for both local and export markets. As Belize continues to face challenges related to climate change and environmental stressors, the adoption of covered structures could play a crucial role in ensuring food security and improving the profitability of the agricultural sector.

Conclusion

This study evaluated the performance of several tomato varieties under a covered structure in Belize, focusing on key factors such as yield, aerial biomass, and root biomass. PVF1 and IA1915 emerged as the top-performing varieties, with PVF1 demonstrating high yield efficiency by allocating fewer resources to vegetative growth while maintaining strong fruit production. In contrast, varieties like IA1912 and 8503F1 produced lower yields, indicating the need for optimization. Although differences in biomass allocation were observed, the study shows that controlled environments can effectively enhance tomato production, particularly for varieties like PVF1 that exhibit efficient resource use. These findings highlight the potential of controlled environments to improve both yield and resource efficiency, offering valuable insights for tomato producers in Belize.

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