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Article

Optimization of tomato cultivars for high tunnel production in Iwollo, Southeast Nigeria: A rank summation index approach

J. O. Adinde[1,*], C. H. Aniodoh[1], U. J. Anieke[2], O. G. Nwankwo[2]

[1] Department of Horticultural Technology, Enugu State Polytechnic, Iwollo 401139, Nigeria
[2] School of General Studies, Enugu State Polytechnic, Iwollo 401139, Nigeria
*** Corresponding author:** J. O. Adinde, adinde.jonathan@espoly.edu.ng

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Abstract: Tomato (*Solanum lycopersicon* L.) is a highly valued crop in the world, particularly in Nigeria with high nutritional and economic benefits. However, its production in Iwollo, Southeast Nigeria, is constrained by unfavorable weather conditions. To address this, a study was conducted at the Teaching and Research Farm, Department of Horticultural Technology, Enugu State Polytechnic, Iwollo, Southeast Nigeria to evaluate and select the best cultivar for high tunnel production using the Rank Summation Index. Completely Randomized Design with three replications was used, and six high-yielding cultivars, namely Roma VF, BHN-1021, Supremo, Pomodro, Money maker, and Iwollo local, were evaluated. Data were collected on key agronomic characters and analyzed with Analysis of Variance (ANOVA) at a 0.05 level of probability. There were significant differences in the number of leaves per plant, plant height, number of branches per plant, days to fruit maturity, fresh fruit weight, number of harvested fresh fruits per plant, and fresh fruit yield per plant among the cultivars. These characters that showed significant differences were ranked and summed up to obtain the Rank Summation Index (RSI) score. The results revealed that the Supremo cultivar had the lowest and best score (18). This suggests Supremo as the best cultivar for high tunnel tomato production in the study area, based on its superior performance across key agronomic traits.

Keywords: adverse climatic conditions; cultivar selection; high tunnel production; *Solanum lycopersicon*; rank summation index (RSI)

1. Introduction

The tomato plant, scientifically known as *Solanum lycopersicon* L., is a member of the Solanaceae family, a large and diverse group of flowering plants that includes other notable species such as potatoes, peppers and eggplants [1–3]. It originated in Mexico and it is widely grown all over the world as a garden crop or field crop [3]. It is a vital horticultural crop in the world and in Nigeria, cultivated not only for its nutritional value but also for its significant economic importance, contributing to food security and income generation for many farmers and other links in the value chain. It is palatable and succulent and used in preparing various types of dishes in Nigeria. Tomatoes are key ingredients in many sauces, including fresh and cooked options like pasta sauces, pizza sauces, ketchups, and salsas, which enhance the flavour and nutritional values of various meals. Tomato fruit contains vitamins, soluble fibers, minerals, sugar, essential amino acids and antioxidants like lycopene, which support overall health and well-being [4].

Despite the nutritional and economic benefits of tomatoes, production in Nigeria is low, especially in Southeast Nigeria, where yield is low due to

unfavorable climatic factors that affect its yield in open-field, rain-fed production, among other factors [5]. Farmers in the area prefer to cultivate crops like maize, cassava, pepper, yam, and some other crops that are easier to manage than tomatoes, which are susceptible to fungal diseases caused by high humidity in the area. The bulk of the tomatoes consumed in the study area are from Northern Nigeria, and they are expensive because of the high cost of transportation and spoilage in the process. These challenges are exacerbated by rising insecurity in northern Nigeria, where there is a comparative advantage, making it necessary to find local solutions.

Climate change is another factor that compounds the challenges faced by farmers in the study area. It is a critical global challenge with profound implications in agriculture, particularly in regions already experiencing environmental stress. Horticultural crops, such as tomatoes (*Solanum lycopersicum*), are highly sensitive to shifts in temperature, rainfall patterns, and extreme weather conditions [6]. In sub-Saharan Africa, including Nigeria, climate change manifests as erratic rainfall, rising temperatures, and altered humidity patterns. These climatic shifts pose significant challenges to tomato farming. In Southeast Nigeria, particularly in Iwollo, high humidity is a dominant feature of the local climate, adding complexity to tomato cultivation. While humidity supports tomato growth, excessive moisture coupled with high temperature increases the risk of diseases in tomatoes and reduces yield [7]. Heat stress impairs tomato growth, reduces nutrient uptake, and disrupts critical biological processes such as photosynthesis, reproduction, and protein functions which can lead to poor fruit setting and reduction in yield and quality [6]. These climate-related stresses threaten local food security and the economy of farmers reliant on tomato cultivation. Globally, tomato farming faces climate change challenges and this jeopardizes yield stability in open field production [8,9]. To address these challenges, innovative and climate-resilient farming practices are necessary.

The reliable way of controlling unfavorable environmental conditions in tomato production is through a close production system. The well-documented close production system in Nigeria is the use of greenhouses. However, greenhouse is very expensive, making it unaffordable for most of the farmers in Southeast Nigeria. A high tunnel is a tunnel-shaped structure that creates a microclimate that impacts biotic and abiotic factors and influences plant growth and development [10]. It offers a cost-effective alternative to traditional greenhouses and can be constructed with improvised material like bamboo, making it an even less expensive, accessible, and affordable option for smallholder farmers who contribute more to the production and availability of horticultural produce in the Nigerian food market. High Tunnel provides a controlled environment against adverse climatic conditions. It enhances tomato fruit quality and yield by providing protection from various stressors, including wind damage, insect attack, disease incidence, bird damage, and rodent attacks [10–12]. According to Gude et al. [13], high tunnels can be employed to prolong the growing season for tomato crops, resulting in extended harvesting periods and enhanced production. Several research studies regarding the use of high tunnels to improve tomato yield and fruit quality have been conducted [13,14].

Tomato cultivars have varied responses to the environment in the expression of the traits they possess. A study by Mesbah et al. [15] revealed significant variations

in the performance of different tomato varieties grown in a high tunnel system, highlighting the importance of selecting suitable varieties for this specific production method. Welde and Diriba [16] noted that the decision on the choice of tomato cultivars to plant is a complex one. Warren et al. [17] highlighted the crucial role of cultivar selection in achieving successful tomato production, noting that multiple key traits collectively impact cultivar performance across various growing conditions, including high tunnel environments. Cultivar selection should be based on multiple factors, as economically promising cultivars typically possess a combination of traits that control productive performance, adaptability, and stability and contribute to their overall performance, rather than relying on a single characteristic [18,19]. Rank Summation Index (RSI) is a multiple-trait selection tool that allows superior and adaptive cultivars to be selected by combining several attributes [20]. The selection tool entails assessing and ranking the cultivars based on their performance in relation to relevant agronomic traits, followed by aggregating and ranking across multiple traits to obtain an overall score for each cultivar, with a lower score suggesting better performance [20,21]. Rank Summation Index has been applied by Okoli [22] and Onwubiko et al. [23] for the selection of superior genotypes in maize and bambara groundnut, respectively.

The lack of information on suitable tomato cultivars for high tunnel production in the study area necessitated an evaluation of cultivars for high horticultural potential, stability, and adaptability under high tunnel conditions. Consequently, this study aimed to optimize tomato production in Iwollo, Southeast Nigeria, by evaluating and selecting high-yielding cultivars for high tunnel conditions using the Rank Summation Index.

2. Materials and methods

2.1. Study site

The study was conducted at the Teaching and Research Farm, Department of Horticultural Technology, Enugu State Polytechnic, Iwollo in Southeast Nigeria, situated at longitude 007016.834′ E and latitude 06016.834′ N.

2.2. Material sources

The tomato cultivars, namely Supremo, Roma VF, Money maker, BHN-1021, Pomodro, and Iwollo local, used in the experiment were obtained from Enugu State Polytechnic, Iwollo, Ezeagu Local Government Area, Enugu State, Nigeria, while the materials for constructing the high tunnel were locally sourced. Supremo, Money maker, BHN-1021, and Pomodro are hybrid varieties originally introduced to Enugu State Polytechnic, Iwollo, from the United States of America in 2015, and they showed great adaptability and high yield in an open-field, rain-fed adaptation trial conducted by the institution in 2015. Roma VF is a commercial hybrid variety that is commonly grown by commercial tomato farmers in Nigeria. Iwollo local is a landrace that is traditionally grown by local farmers in Iwollo, Southeast Nigeria.

2.3. Experimental design and treatments

The experiment was laid out in a Completely Randomized Design (CRD) having three replications. Six high-yielding tomato cultivars, viz., Iwollo local, BHN-1021, Supremo, Roma VF, Money maker and Pomodro, were evaluated in the study, and they served as the treatments. The treatments were assigned to the experimental unit with the aid of a random number table.

2.4. Procedure

A high tunnel of 7 m high by 5 m wide by 9 m long was constructed using bamboo sticks and covered with a blue polyethylene film. Wooden boxes (0.25 m high, 1.5 m long, and 0.5 m wide) filled with topsoil mixed with 1 kg of poultry manure served as growth media. Tomato seedlings in good condition were transferred to the wooden boxes four weeks after sowing, spaced 0.5 m apart, with three plants per box. Watering was done as needed. Manual weeding with small hoes and protection against nematodes using Carbofuran (5G) were carried out. Lambda cyhalothrin (insecticide) was used to control insect pests, while Cabendazem and Mancozeb (fungicides) were used to control fungal diseases.

2.5. Data collection

Observations were made on some important agronomic parameters following the International Plant Genetic Resources Institute descriptors list for tomato, cited in Dasta and Yosef [24]. They included the number of leaves per plant, plant height, number of branches per plant, disease severity, days to 50% flowering, days to fruit maturity, fresh fruit weight, number of harvested fresh fruits per plant, and fresh fruit yield per plant. Data were collected from 2 tagged sample plants.

2.5.1. Plant height (cm)

To determine plant height, a measuring tape was used to measure the sample plants from the base of the plant to the top. This was done at the flowering stage.

2.5.2. Number of leaves

To determine the number of leaves per plant, the leaves on the sample plants were counted and the average was used as the number of leaves per plant. The number of leaves was also counted at the flowering stage of the plant.

2.5.3. Number of branches

The number of branches on the sample plants was counted at the flowering stage of the plants. The average was subsequently calculated as the number of leaves per plant.

2.5.4. Days to 50% flowering

To determine days to 50% flowering, the number of days it took half of the sample plants to flower from the date they were transplanted was counted and recorded as the days to 50% flowering.

2.5.5. Disease severity (DS)

To determine the disease severity, the number of infected leaves of the sample plants was counted and divided by the total number of leaves on the plants, then

multiplied by 100 to get the percentage. The percentage was used to rank the severity, with less than 1% ranked as 0 (no infection), 1%–25% ranked as 1 (low infection), 26%–50% ranked as 2 (moderate infection), 51%–75% ranked as 3 (high infection), and above 75% ranked as 4 (very high infection), as postulated by Omeje et al. [25]

2.5.6. Days to fruit maturity

To determine days to fruit maturity, the date matured fruit was observed on the sample plants, and the difference from the date transplanting was done was recorded as the days to fruit maturity.

2.5.7. Number of harvested fresh fruits per plant

To determine the number of harvested fresh fruits per plant, the number of fresh fruits harvested from the sample plants at the red-ripe stage was counted, and the mean was calculated as the number of harvested fresh fruits per plant.

2.5.8. A fresh fruit weight (g)

To calculate a fresh fruit weight, all the harvested fresh fruits were weighed and the total weight was divided by the number of fresh fruits weighed. An electronic weighing machine was used to weigh the fruits for accuracy. The formula adopted in calculating a fresh fruit weight is given as follows:

A fresh fruit weight (g) = weight of all harvested fresh fruits/Number of fresh fruits weighed.

2.5.9 Fresh fruit yield per plant (kg)

To determine the fresh fruit yield per plant in kilograms, the product of the number of harvested fresh fruits per plant and a fresh fruit weight (g) was calculated and divided by 1000 using the following equation:

Fresh fruit yield per plant (kg) = number of harvested fresh fruits per plant × a fresh fruit weight (g)/1000

2.6. Statistical analysis

Inferential statistical analysis was performed on the collected data to determine the level of differences among the tomato cultivars in the agronomic characters observed. Analysis of Variance (ANOVA) at a 5% level of significance was done using Genstat Release 10.3DE software. The results of the analysis were applied in calculating the Rank Summation Index.

2.7. Rank summation index application

Rank Summation Index was used to rank the cultivars for their overall performance with respect to characters that showed significantly ($p < 0.05$) difference among the cultivars. A Rank Summation Index model: $Ij = \sum nij$ was applied, where Ij is the index for cultivar j and nij is the ranking number of character i for cultivar j. To apply the model, the cultivars were ranked for each of the characters they showed significant differences in using the mean values, and the ranks were summed up to get a score for the individual cultivars.

3. Results and discussion

In the study, some agronomic traits, which included plant height, number of leaves per plant, number of branches per plant, disease severity, days to 50% flowering, days to fruit maturity, fresh fruit weight, number of harvested fresh fruits per plant, and fresh fruit yield per plant, were observed to evaluate the suitability of six tomato cultivars for high tunnel production. These traits were some of the traits included in the International Plant Genetic Resources Institute descriptors list for tomato as cited in Dasta and Yosef [24]. They are essential indicators of plant performance and adaptability under high tunnel conditions [26]. Plant height is crucial as high tunnels have limited vertical space. Cultivars with an appropriate plant height can optimize the use of vertical space for adequate light penetration and air circulation, which are essential for healthy growth and disease prevention [26]. The number of leaves per plant indicates the plant's ability to photosynthesize effectively. Sufficient foliage is necessary for the production of energy required for fruit development. However, excessive foliage can lead to shading and increased humidity, which can promote fungal diseases [7]. The number of branches per plant impacts the plant's structural stability and its ability to support fruit production. More branches can lead to a higher fruit yield, but too many may cause overcrowding and poor air circulation. Days to 50% flowering, days to fruit maturity, number of fruits per plant, and fruit weight have positive effects on tomato yield per plant [27]. Yield per plant is a comprehensive measure of the cultivar's productivity. These traits integrate the effects of other agronomic traits to provide a holistic view of the cultivar's performance under high tunnel conditions.

The results of the analysis of variance done on the data collected in the study revealed significant differences ($p < 0.05$) in the number of leaves per plant, plant height, number of branches per plant, days to fruit maturity, number of harvested fresh fruits per plant, fresh fruit weight, and fresh fruit yield per plant among the cultivars evaluated (**Table 1**). These findings were in conformity with the findings of Gude et al. [13], who reported variations in some growth and yield characters of some tomato cultivars in a high tunnel environment. Welde and Diriba [16] also noted that tomato cultivars have a wide range of characteristics and observed that tomato cultivars are specifically adapted to a particular environment. The result in **Table 1** also showed that the cultivars did not differ significantly in terms of disease severity, and this suggests that high tunnels probably provide protection against disease by warding off insects and protecting the crop against rain splashes that aid the spread of fungal disease in tomato farms. Aurora et al. [26] opined that tomato production under high tunnels could provide more economic return compared to field production.

Table 1. Mean values of some agronomic characters of the tomato cultivars.

Tomato cultivars	Plant height (cm)	Number of leaves per plant	Number of branches per plant	D50% *F*	D.S	DFM	NHFFPP	AFFW (g)	FFYPP (kg)
Roma VF	55.00	58.33	8.83	45.67	1.33	95.20	14.83	50.74	0.75
Supremo	67.00	58.03	7.17	44.67	2.33	68.10	8.33	119.86	1.00
BHN -1021	76.19	58.20	5.33	43.67	2.00	72.00	8.17	102.50	0.84
Iwollo local	64.10	49.50	7.33	41.00	1.33	96.00.	14.67	40.02	0.58
Pomodro	66.19	48.20	7.20	42.67	2.33	78.20	12.42	97.50	0.81
Money maker	65.20	49.80	7.54	43.00	2.00	75.10	14.92	60.20	0.77
	P<0.05	*P*<0.05	*P*<0.05	ns	ns	*P*<0.05	*P*<0.05	*P*<0.05	*P*<0.05

ns = non-significant; $p < 0.05$= probability value is less than 0.05; DS= Disease security; D50%*F* = Days to 50% flowering; NHFFPP = Number of harvested fresh fruits per plant; AFFW= A fresh fruit weight; DFM= Days to fruit maturity; FFYPP = Fresh fruit yield per plant.

Determining the performance of the cultivars through ranking using parameters that varied significantly among the cultivars, the results showed that the lowest Rank Summation Index value was obtained in the Supremo tomato cultivar (18), followed by the Money maker cultivar (22) and Roma VF (25), and the highest was in the Iwollo local cultivar (34) (**Table 2**). The lower the Rank Summation Index scores, the better the performance. Thus, the Supremo cultivar was the best performer under high tunnel conditions, followed by Money maker and the least was Iwollo local. Supremo cultivar probably has superior collective multiple traits for high tunnel environments. Temesgen [28] noted that crop performance is determined by the interaction between its genetic makeup and the environment where it is grown. A cultivar can express its genetic potential under optimal environmental conditions. Supremo cultivar probably had a superior productive genotype and environmental interaction under high-tunnel compared to the other cultivars evaluated. Supremo is a hybrid variety known for its extra-large fruits. The expression of heterosis probably made it possible for it to adapt to the microenvironment and utilize the available resources efficiently, leading to the superior performance observed [29]. The Iwollo local tomato cultivar is used for traditional farming in the locality. It is valued for its nutritional content and pleasant taste, and it is often utilized in various traditional dishes. The cultivar is a landrace that has undergone traditional selection over time, and it is readily available for local farmers for open-field, rain-fed cultivation. Its performance in high tunnel conditions, as shown in the study, was below the other cultivars evaluated, probably due to poor adaptability to the high tunnel microenvironment as a result of its genetic makeup. Tagiakas et al. [30] noted that commercial tomato cultivars outperform landraces in terms of yield due to a lack of genetic improvement in landraces. The other tomato cultivars evaluated in the study are commercial cultivars that were genetically improved, and this probably led to the better performance they showed over Iwollo local. Moreover, solar radiation, nutrient, and water management in high tunnels can differ from that in open fields where the cultivar is often grown [31,32]. The nutrient dynamics, water, and solar radiation requirements of this cultivar may not have been adequately met in the high tunnel microenvironment, resulting in poor performance compared to the other cultivars.

Table 2. Rank the summation index of the tomato cultivars.

Tomato cultivars	Plant height	Number of leaves per plant	Number of branches per plant	DFM	NHFFPP	AFFW (g)	FFYPP (kg)	RSI
Roma VF	6	1	1	5	2	5	5	25
Supremo	2	3	5	1	5	1	1	18
BHN-1021	1	2	6	2	6	2	2	21
Iwollo Local	5	5	3	6	3	6	6	34
Pomodro	3	6	4	4	4	3	3	27
Money Maker	4	4	2	3	1	4	4	22

RSI = Rank Summation Index; NHFFPP = Number of harvested fresh fruits per plant; AFFW= A fresh fruit weight; DFM= Days to fruit maturity; FFYPP = Fresh fruit yield per plant.

For improved and sustainable production of tomatoes in Iwollo, Southeast Nigeria, the use of high tunnels is a climate-resilient, viable option, and the Supremo variety from the study is the most suitable cultivar for the microenvironment. Economically, high tunnel cultivation can be highly beneficial for smallholder farmers [33]. Apart from providing environmental protection and control, high tunnel farming systems can extend the growing season of some horticultural crops, thereby allowing farmers to produce them for a longer period each year [34]. The ability to grow tomatoes for a longer season and produce high-quality yields can lead to increased income and improved food security [35]. This is particularly important in regions like Iwollo, Southeast Nigeria, where traditional open-field, rain-fed tomato farming is challenging due to the unfavorable climatic conditions for the crop in the area. Adopting high tunnel tomato farming using the Supremo variety can offer significant benefits to smallholder farmers in Iwollo, Southeast Nigeria.

In addition to evaluating more cultivars, future studies could focus on understanding the environmental factors that impact cultivar performance under high tunnel conditions, such as temperature variation, humidity, and light availability. Additionally, it would be helpful to explore the economic feasibility and cost-benefit analysis of high tunnel tomato farming in the region.

4. Conclusion

The study showed that there were significant variations in some of the agronomic characters observed among the cultivars evaluated under high tunnel conditions. Rank Summation Index of the cultivars showed that the Supremo cultivar had the best score and could be selected for tomato cultivation in the study area using a high tunnel. Some other cultivars, especially BHN-1021 and Money maker could be considered for selection for improvement for high tunnel tomato production. Further studies should widen the number of tomato cultivars for evaluation and study areas to develop a horticultural protocol for high tunnel tomato production in Southeast Nigeria towards improving tomato production in the agro-climatic region.

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CHA, UJA and OGN ; writing—review and editing, JOA; supervision, JOA; funding, JOA, CHA, UJA and OGN. All authors have read and agreed to the published version of the manuscript.

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References

1. de Souza Ld, Andrade BO, Stehmann JR. An overview on studies of species complexes in Solanaceae. Acta Botanica Brasilica. 2023; 37. doi: 10.1590/1677-941x-abb-2023-0032
2. Poczai P, D'Agostino N, Deanna R, et al. Editorial: Solanaceae VIII: biodiversity, climate change and breeding. Frontiers in Genetics. 2023; 14. doi: 10.3389/fgene.2023.1348372
3. Swamy KRM. Origin, distribution, taxonomy, botanical description, genetic diversity and breeding of tomato (*Solanum lycopersicum* L.). International Journal of Development Research. 2023; 13(4): 62364-62387.
4. Ifagbémi BC, Olouchègoun JO, Sèna ECAD, et al. Tomato Seed (Solanum lycopersicum) Meal Derived From Agrifood Waste as Functional Ingredient: Nutritional Value, Antioxidant and Antimicrobial Activities, and Functional Properties. Journal of Food Processing and Preservation. 2024; 1: 8824581. doi: 10.1155/2024/8824581
5. Enujeke EC. Effects of variety and spacing on growth characters of hybrid maize. Asian Journal of Agriculture and Rural Development. 2013; 3(5): 296-310.
6. Muhammed A, Tariq M, Richard T, et al. An overview of heat stress in tomato (*Solanum lycopersicum* L.). Saudi Journal of Biological Sciences. 2021; 28(3): 1654-1663. doi: 10.1016/j.sjbs.2020.11.088
7. Stefano P, Salvatore D, Andrea GC, et al. A Review of the Most Common and Economically Important Diseases That Undermine the Cultivation of Tomato Crop in the Mediterranean Basin. Agronomy. 2021; 11(11): 2188. doi: 10.3390/agronomy11112188
8. Farooq A, Farooq N, Akbar H, et al. A Critical Review of Climate Change Impact at a Global Scale on Cereal Crop Production. Agronomy. 2023; 13(1): 162. doi: 10.3390/agronomy13010162
9. Habib-ur-Rahman M, Ahmad A, Raza A, et al. Impact of climate change on agricultural production; Issues, challenges, and opportunities in Asia. Frontiers in Plant Science. 2022; 13. doi: 10.3389/fpls.2022.925548
10. Rogers MA, Wszelaki AL. Influence of High Tunnel Production and Planting Date on Yield, Growth, and Early Blight Development on Organically Grown Heirloom and Hybrid Tomato. HortTechnology. 2012; 22(4): 452-462. doi: 10.21273/horttech.22.4.452
11. O'Connell S, Rivard C, Peet MM, et al. High Tunnel and Field Production of Organic Heirloom Tomatoes: Yield, Fruit Quality, Disease, and Microclimate. HortScience. 2012; 47(9): 1283-1290. doi: 10.21273/hortsci.47.9.1283
12. Martínez-Blanco J, Muñoz P, Antón A, et al. Assessment of tomato Mediterranean production in open-field and standard multi-tunnel greenhouse, with compost or mineral fertilizers, from an agricultural and environmental standpoint. Journal of Cleaner Production. 2011; 19(9-10): 985-997. doi: 10.1016/j.jclepro.2010.11.018
13. Gude KM, Pliakoni ED, Cunningham B, et al. High Tunnel Coverings Alter Crop Productivity and Microclimate of Tomato and Lettuce. HortScience. 2022; 57(2): 265-272. doi: 10.21273/hortsci16208-21
14. Díaz-Pérez JC, Bag S, Coolong T, et al. Plant Growth, Fruit Yield, and Tomato Leaf Curl Disease of High Tunnel Organic Tomato Affected by Shade Net and Plastic Mulch Color. HortScience. 2024; 59(3): 323-331. doi: 10.21273/hortsci17516-23
15. Mesbah A, Garcia A, Frost S. Tomato production inside and outside high tunnel. Field Days Bulletin; 2012. pp.143-144.
16. Welde K, Diriba B. Adaptability study and evaluation of improved varieties of tomato (Lycopersicon esculentum L.) under irrigation for their yield and yield components in east Wollega, western Ethiopia. Int. J. Adv. Res. Biol. Sci. 2021; 8(7):118-125. doi: 10.22192/ijarbs.2021.08.07.013
17. Warren ND, Sideman RG, Smith RG. Performance of High Tunnel Tomato Cultivars in Northern New England. HortTechnology. 2015; 25(1): 139-146. doi: 10.21273/horttech.25.1.139
18. Sampaio Filho JS, Olivoto T, Campos M de S, et al. Multi-trait selection in multi-environments for performance and stability in cassava genotypes. Frontiers in Plant Science. 2023; 14. doi: 10.3389/fpls.2023.1282221
19. Bertini CHCM, Almeida WS de, Silva APM da, et al. Multivariate analysis and selection index in the identification of superior cowpea genotypes (Portuguese). Acta Scientiarum Agronomy. 2010; 32(4). doi: 10.4025/actasciagron.v32i4.4631

20. Coutinho G, Pio R, Machado de Souza FB, et al. Multivariate Analysis and Selection Indices to Identify Superior Quince Cultivars for Cultivation in the Tropics. HortScience. 2019; 54(8): 1324-1329. doi: 10.21273/hortsci14004-19
21. Teixeira DHL, Oliveira M do SP de, Gonçalves FMA, et al. Selection indices for the simultaneous improvement of fruit production components in açaizeiro trees (Portuguese). Pesquisa Agropecuária Brasileira. 2012; 47(2): 237-243. doi: 10.1590/s0100-204x2012000200012
22. Okoli EE. Exploitation of rank summation index for the selection of 21 maize hybrids for green maize production in South-eastern Nigeria. Journal of Bioscience and Biotechnology Discovery. 2021; 6(2): 13-18. doi: 10.31248/jbbd2021.150
23. Onwubiko NC, Uguru MI, Chimdi GO. Selection for Yield Improvement in Bambara Groundnut (Vigna subterranea (L. VERDC.). Journal of Plant Breeding and Genetics. 2019; 7(2).
24. Dasta T, Yosef A. Evaluation of Tomato (Solanum lycopersicum MILL.) Genotypes for Quantitative, Qualitative and Quality Traits at Mid-altitude and Central Rift Valley. International Journal of Research in Agricultural Sciences. 2021; 8(1):42-54.
25. Omeje TE, Ugwuoke KI, Adinde JO, et al. Effect of cropping season on the control of Taro Leaf Blight (Phytophthora colocasiae) of cocoyam (Colocasia esculenta L.) in Nsukka, south eastern Nigeria. International Journal of Advanced Biological Research. 2016; 6(1): 30-39.
26. Aurora SC, Florin PA, Adnan A, et al. High Tunnel Cultivation: Evaluating the Growth and Productivity of Different Tomato Varieties. International Journal of Advanced Multidisciplinary Research and Studies. 2024; 4(4): 1276-1284. doi: 10.62225/2583049x.2024.4.4.3177
27. Çelik İ, Aydin S, Kayikçi HC, et al. Evaluation of the Relations between Yield and Yield Components of Tomato (Solanum lycopersicum L.) Hybrids by Correlation and Path Analysis. Horticultural Studies. 2023; 40(2): 49-54. doi: 10.16882/hortis.1283084
28. Temesgen B. Application of Genotype by Environmental Interaction in Crop Plant Enhancement. International Journal of Research Studies in Agricultural Sciences (IJRSAS). 2022; 8(2):1-12. doi: 10.20431/2454-6224.0802001
29. Liu W, Zhang Y, He H, et al. From hybrid genomes to heterotic trait output: Challenges and opportunities. Current Opinion in Plant Biology. 2022; 66: 102193. doi: 10.1016/j.pbi.2022.102193
30. Tagiakas RI, Avdikos ID, Goula A, et al. Characterization and evaluation of Greek tomato landraces for productivity and fruit quality traits related to sustainable low-input farming systems. Frontiers in Plant Science. 2022; 13. doi: 10.3389/fpls.2022.994530
31. Lee M, Rivard C, Wang W, et al. Spectral Blocking of Solar Radiation in High Tunnels by Poly Covers: Its Impact on Nutritional Quality Regarding Essential Nutrients and Health-Promoting Phytochemicals in Lettuce and Tomato. Horticulturae. 2021; 7(12): 524. doi: 10.3390/horticulturae7120524
32. Montri A, Biernbaum JA. Management of the Soil Environment in High Tunnels. HortTechnology. 2009; 19(1): 34-36. doi: 10.21273/horttech.19.1.34
33. Jamarkattel D, Tuladhar F, Jamir C, et al. Tunnel Farming as an Adaptation Tool Against Climate Change Effect Among Smallholder Farmers in Nepal. In: Sustainable Food Value Chain Development. SpringerLink; 2023.
34. Gu S. High Tunnel Farming. North Carolina Agricultural and Technical State University; 2021.
35. KC D, Jamarkattel D, Maraseni T, et al. The Effects of Tunnel Technology on Crop Productivity and Livelihood of Smallholder Farmers in Nepal. Sustainability. 2021; 13(14): 7935. doi: 10.3390/su13147935