DOI: https://doi.org/10.70749/ijbr.v4i2.2925

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://ijbr.com.pk
ISSN: 2960-2793/ 2960-2807

Crossref
OPEN ACCESS

Comparative Agro-Climatic Performance of a New Bitter Gourd Line and Indigenous Cultivars in District Peshawar

Khalid Khan[1], Neelam Ara[1], Lubna Naz[2], Hamza Ali[3], Farzana Fatima[1], Faiza Aman[1], Maria Atta[1], Sidra[1], Abdul Rab[4]

[1]Department of Horticulture, The University of Agriculture, Peshawar, KP, Pakistan.
[2]Agriculture Research Institute, Tarnab, Peshawar, Pakistan.
[3]State Key Laboratory for Crop Stress Resistance and High-Efficiency Production, College of Horticulture, Northwest A&F University, Yangling, Shaanxi, China.
[4]Department of Agronomy, The University of Agriculture, Peshawar, KP, Pakistan.

ARTICLE INFO

Keywords: Bitter Gourd, New Cultivars, Comparative Analysis, NARC-32573, Peshawar Local-1, Quetta Local.

Correspondence to: Neelam Ara/ Hamza Ali,
Department of Horticulture, The University of Agriculture, Peshawar, KP, Pakistan.
State Key Laboratory for Crop Stress Resistance and High-Efficiency Production, College of Horticulture, Northwest A&F University, Yangling, Shaanxi, China
Email: neelam_ara@hotmail.com
hamzaali@nwafu.edu.cn

Declaration

Authors' Contribution
K.K., Research conduction, Data collection, N.A., Supervision, H.A., L.N., M.A., & S., Literature review, A.R. & K.K., Data analysis, H.A., Original manuscript write–up. N.A., F.F., & F.A., Manuscript writing/review

Conflict of Interest: No conflict of interest.

Funding: No funding received by the authors.

Article History
Received: 04-01-2026 Revised: 17-02-2026
Accepted: 23-02-2026 Published: 28-02-2026

ABSTRACT

Bitter gourd is a nutritionally and economically important crop. This study evaluates the performance and adaptability of a newly introduced bitter gourd (*Momordica charantia*) genotype, NARC-32573, collected from NARC Islamabad, and compared with two locally cultivated varieties, Peshawar Local-1 and Quetta Local. The trial was conducted at the Horticulture Research Farm, The University of Agriculture, Peshawar, using a randomized complete block design with three replications. The objective was to identify a suitable germplasm for cultivation under the agro-climatic conditions of Peshawar. Both quantitative and qualitative traits, including germination, vegetative growth, flowering behavior, fruit characteristics, and seed quality, were systematically evaluated. NARC-32573 consistently outperformed the local varieties in emergence, plant vigor, branching, vine growth, stem robustness, and fruit size. It also demonstrated earlier maturity, higher fruit set, and greater overall yield potential, indicating its superior adaptability to local conditions. In contrast, Peshawar Local-1 showed moderate performance, with longer internodes, darker leaves, and delayed maturity, while Quetta Local was the weakest, producing shorter vines, fewer fruits, and a comparatively lower yield. Qualitative attributes supported these findings; NARC-32573 was characterized by thicker stems, more shoots, larger fruit diameter, prominent wart size and density, and dark green skin color, along with uniform spindle-shaped fruits. Peshawar Local-1 exhibited distinctive features such as longer petioles and larger seed edges, whereas Quetta Local generally displayed smaller leaves, thinner stems, and shorter fruits. Overall, the results highlight NARC-32573 as a promising genotype combining superior yield, adaptability, and desirable fruit quality, making it a strong candidate for commercial cultivation in Peshawar.

INTRODUCTION

Bitter gourd (*Momordica charantia* L.) belongs to the cucurbit family and was first cultivated in tropical and subtropical regions of Asia. It is distinguished by climbing vines which tend to be 3 to 4 meters long. It possesses palmate leaves and yellow flowers and contains oblong fruits. The growth and development of bitter gourd are highly affected by environmental conditions (Jat et al., 2024). The fruit matures in 14 to 15 days after pollination at high temperatures, and in 22 to 23 days at cool temperatures. It is vulnerable to environmental factors, creating the necessity of alternative bitter gourd genotypes to enhance production and quality.

It is not only a useful vegetable crop but also a productive medicinal species due to its abundance of essential nutrients and bioactive compounds (Gayathry & John, 2022). It contains a lot of vitamins A, C, and B-complex, as well as Iron, calcium, magnesium, and potassium. It also contains phytochemicals, including saponins, phenolics, flavonoids, cucurbitacins, and hypoglycemic compounds, e.g., charantin, vicine, and polypeptide-P, with diverse therapeutic effects, e.g., anti-diabetic, antioxidant, anti-inflammatory, antimicrobial, and anticancer. Clinical and laboratory research indicates that its active compounds stimulate glucose metabolism by improving insulin secretion, reducing insulin resistance, and lowering blood sugar levels. This has increased its popularity within the nutraceutical and pharmaceutical industries, thereby increasing its economic relevance.

Genetic variability in bitter gourd germplasm is critical for advancing desirable traits, such as yield, disease resistance, fruit quality, and stress tolerance (Digambar, 2024). Morphological differences in fruit size, shape, and color, and in pest and disease resistance (e.g., powdery mildew, downy mildew, and fruit fly infestations) have been noted between genotypes. This diversification is important for establishing new cultivars with high performance under new environmental conditions.

Bitter gourd thrives in warm, humid conditions, with an optimum temperature range of 24 to 30 °C (Dhillon et al, 2017). It needs well-drained, medium-fertility soils and is normally grown on a trellis to maximize production and improve fruit quality. Although the crop is adaptable in other agroecological areas, it is also sensitive to environmental conditions. In Pakistan, it is grown on approximately 4,808 hectares and produces approximately 75,716 tons. It is grown on 1067 hectares in Khyber Pakhtunkhwa with a production of 10,853 tons (Khan *et al.,* 2024). The overall yield of bitter gourd in Pakistan is around 11.24 tons/ha. Low seed germination due to the hard seed coat, resistance to pests and diseases, and susceptibility to abiotic stresses such as drought and temperature extremes are factors that contribute to the yield gap. Pests, e.g., fruit flies, and diseases, e.g., powdery mildew disease and viral diseases, severely affect productivity. Stable yields are also threatened by abiotic stresses such as drought, soil salinity, and varying temperatures. To address these challenges, breeders have been developing hybrids and superior cultivars with a greater yield potential, greater adaptability, and resistance to prevalent pests and diseases.

Peshawar is an important agro-climatic region in Khyber Pakhtunkhwa, Pakistan (Khan *et al.,* 2023). It has favorable climatic conditions, such as warm temperatures and fertile soils, which facilitate bitter gourd production. However, the number of studies evaluating new bitter gourd lines systematically in the region's real agro-climate is limited. Given that the crop is climate-sensitive, it is necessary to identify genotypes adapted to the local weather in Peshawar to maximize objectives and benefit local farmers. Comparing new lines with local cultivars is particularly important. The local cultivars may be highly adapted to local conditions, but they lag behind new lines in yield capacity, disease resistance, and fruit quality. Comparing the new lines with established local varieties will help determine whether there is a major advantage in agronomic performance and adaptation to the local farming system.

The aim of the current study was therefore to determine the performance of the new bitter gourd line (NARC-32573) in the agro-climatic environment of Peshawar relative to two local cultivars (Peshawar Local-1 and Quetta Local) and to determine the suitability of the new bitter gourd line to be used in local breeding systems and its potential use in breeding programs in developing new varieties. The research will have great utility in understanding the agro-climatic flexibility of the new line and, hence, will be beneficial for sustainable bitter gourd production, the enhancement of farmers' livelihoods, and varietal breeding knowledge in Pakistan.

MATERIALS AND METHODS

This comparative study was performed at the Horticulture Research Farm, The University of Agriculture, Peshawar. Two local genotypes, i.e., Peshawar Local-1 and Quetta Local, were obtained from the local seed market, while a new bitter gourd genotype, NARC-32573, was obtained from the National Agricultural Research Center, Islamabad.

Field Preparation

Before sowing seeds, all necessary cultural practices, such as ploughing, weeding, leveling, and ridge preparation, were uniformly carried out to prepare the field. The field layout was a Randomized Complete Block Design (RCBD) with 9 plots, with 3 replications per treatment. Bitter gourd seeds were sown on 14 May, 2024, with row-to-row (R-R) and plant-to-plant (P-P) distances of 60 cm and 45 cm, respectively, on ridges with a length of 274 cm and a width of 30 cm. Stacking was also made in the field on June 29, 2024.

Parameters Studied

Data were recorded on growth, reproductive, and yield attributes. Days to emergence were noted from sowing until 80% seedling emergence. Vine length was measured from the base to the tip of the main vine, while the number of branches per plant was determined by counting the branches from the randomly selected plants. Leaf production was assessed by counting leaves per plant in each replication. Stem diameter was measured at the base of the stem using a vernier caliper. Reproductive traits included days to first flowering, male-to-female flower ratio, and days to first harvest. Yield components included the number of fruits per plant, fruit length, fruit diameter, and single fruit weight, which were measured with a measuring tape, a vernier caliper, and a digital balance, respectively. Additionally, internode length was recorded between successive nodes, and overall yield per hectare was calculated using the standard formula:

$$Yield\ (tons\ h\bar{a}^{1}) = \frac{Yield\ per\ plot\ (kg) \times 10000m^2}{Area\ of\ plot\ (m^2) \times 1000}$$

Qualitative Traits

The qualitative descriptors of bitter gourd were evaluated following the guidelines of the International Union for the Protection of New Varieties of Plants (UPOV). Each parameter was scored according to the UPOV ranking system, which assigns distinct categories specific numerical values (ranging from 1 to 9, depending on the descriptor). Cotyledon intensity of green color was scored as light (3), medium (5), or dark (7). Stem characters included internode length between the 15th and 20th node (short = 3, medium = 5, long = 5), thickness (thin = 3, medium = 5, thick = 7), and number of side shoots (few = 3, medium = 5, many = 7). Leaf descriptors included blade size (small = 3, medium = 5, large = 7), intensity of green color (light = 3, medium = 5, dark = 7), length/width lobe ratio (small = 1, medium = 2, large = 3), number of lobes (five = 1, seven = 2, nine = 3), and depth of lobing (shallow = 3, medium = 5, deep = 7). Petiole length was categorized as short (3), medium (5), or long (7).

Figure 1
Different leaf structures of the different bitter gourd cultivars as per UPOV

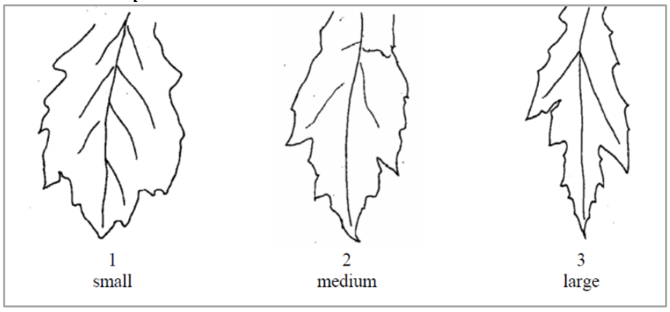
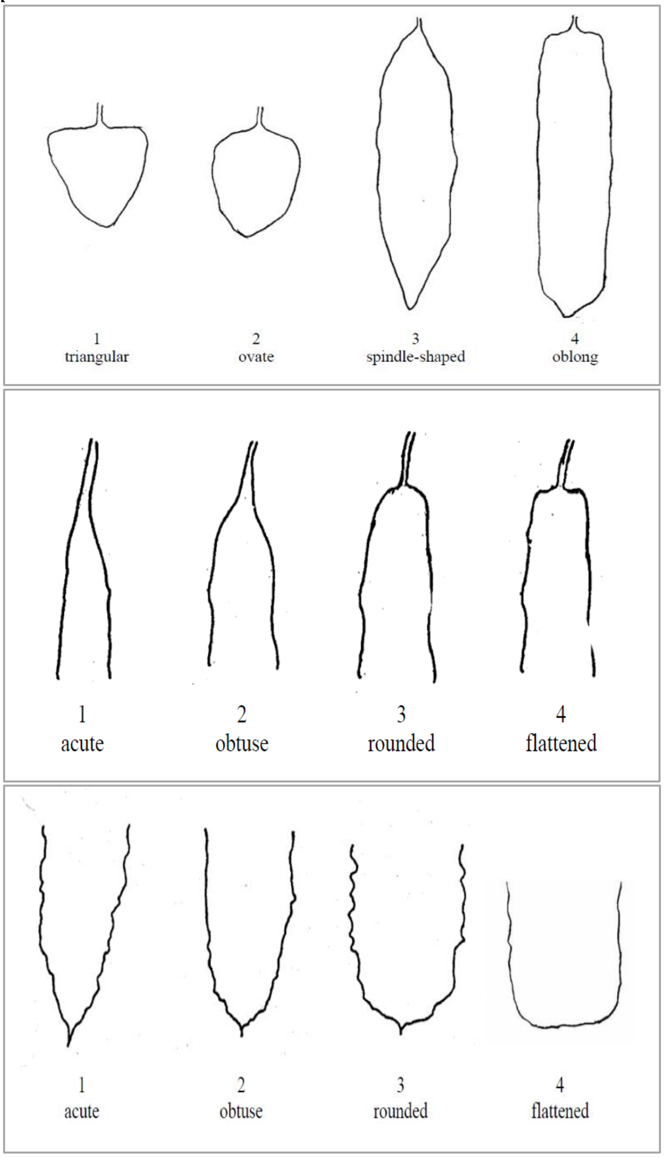


Figure 2
Fruit characteristics of the different bitter gourd cultivars as per UPOV



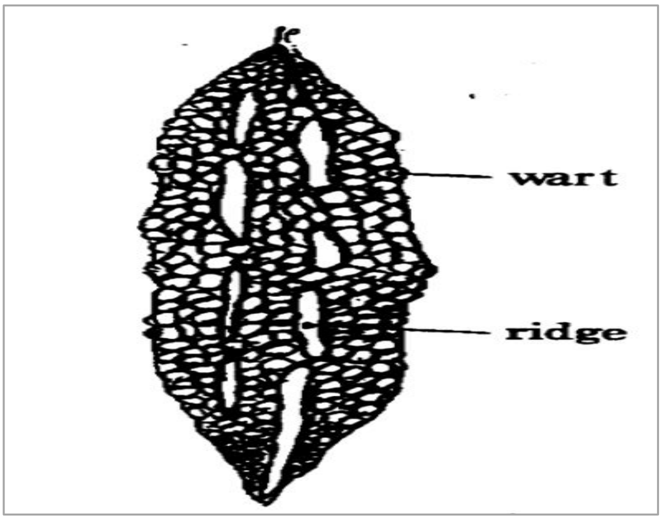
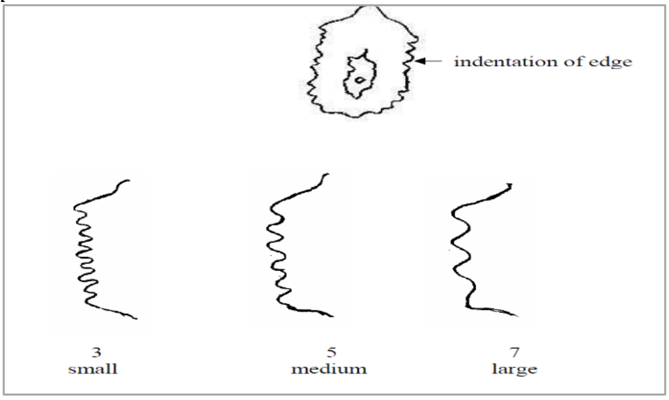


Figure 3
Seed characteristics of the different bitter gourd cultivars as per UPOV



Reproductive traits were also recorded: the number of nodes up to the first female flower (few = 3, medium = 5, many = 7), ovary length (short = 3, medium = 5, long = 7), and stigma intensity of green color (light = 3, medium = 5, dark = 7). Fruit descriptors included length (short = 3, medium = 5, long = 7), diameter (small = 3, medium = 5, large = 7), shape in longitudinal section (triangular = 1, ovate = 2, spindle-shaped = 3, oblong = 4), skin color (white = 1, light green = 2, medium green = 3, dark green = 4), base shape (acute = 1, obtuse = 2, rounded = 3, flattened = 4), and apex shape (acute = 1, obtuse = 2, rounded = 3, flattened = 4).

Wart characters included number (few = 3, medium = 5, many = 7), size (small = 3, medium = 5, large = 7), shape of top (acute = 1, obtuse = 2, rounded = 3), and the presence of spines (absent = 1, present = 9). Ridge length was recorded as short (3), medium (5), or long (7). At the ripe stage, fruit skin color was scored as yellow (1), orange (2), or reddish-orange (3). Bitterness was recorded as absent (1) or present (9), with its intensity ranked as weak (3), medium (5), or strong (7). Seed characteristics included size (small = 3, medium = 5, large = 7), intensity of brown color of testa (light = 3, medium = 5, dark = 7), and edge indentation (small = 3, medium = 5, large = 7). Physiological maturity was classified as early (3), medium (5), or late (7).

Statistical Analysis

The collected data were subjected to analysis of variance to identify significant differences among the different genotypes. The LSD test, on the other hand, was used to find the mean difference at 5% and 1% level of significance (Steel & Torrie, 1997). ANOVA and LSD were found using the statistical software STATISTIX 10.

RESULTS

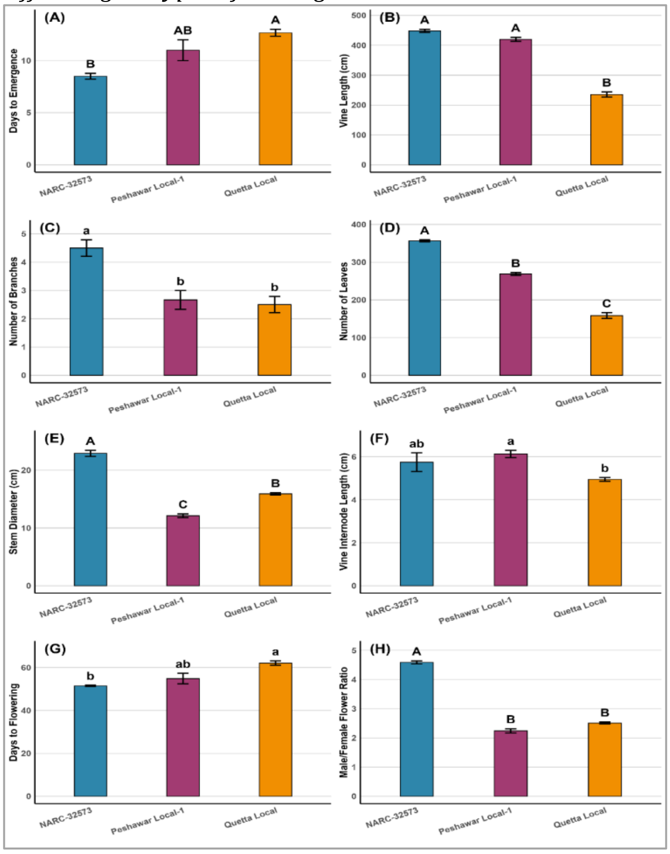
The analysis of variance revealed significant differences among the three bitter gourd genotypes (NARC-32573, Peshawar Local-1, and Quetta Local) across all recorded traits, indicating substantial genetic variability.

Quantitative Traits

Different traits were studied across the three bitter gourd genotypes under the climatic conditions of Peshawar. Days to emergence varied significantly among genotypes (Fig. 4A). NARC-32573 emerged the earliest, requiring an average of 8.5 days, while Peshawar Local-1 and Quetta Local required 11 and 12.67 days, respectively. The coefficient of variance (CV) was 6.67%, reflecting moderate variability among genotypes. Vine length also differed significantly (Fig. 4B). NARC-32573 attained the most extended vine length (448.31 cm), followed closely by Peshawar Local-1 (419.71 cm), whereas Quetta Local remained significantly shorter at 235.37 cm. The trait was stable across replicates, with a coefficient of variation (CV) of 3.55%.

Figure 4

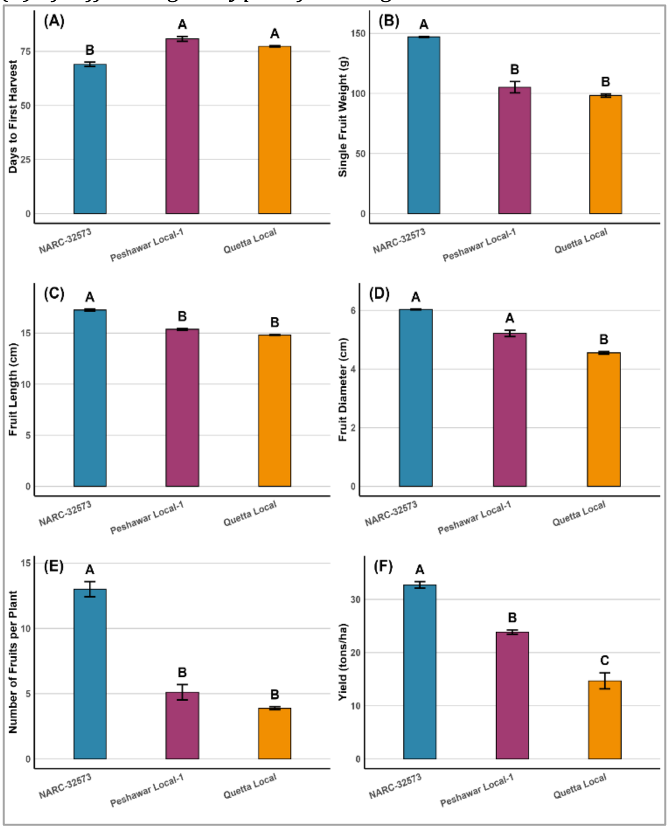
Days to emergence (A), Vine length (B), No. of branches (C), No. of leaves (D), Stem diameter (E), Vine internode length (F), Days to flowering (G), and Male to female flower ratio of different genotypes of bitter gourd



For the number of primary branches per plant, significant genotypic differences were observed (Fig. 4C). NARC-32573 produced the highest number of branches (4.5), while Peshawar Local-1 (2.6) and Quetta Local (2.5) produced significantly fewer. In terms of leaf production, NARC-32573 again outperformed with 354.67 leaves per plant, whereas Peshawar Local-1 and Quetta Local produced 271.33 and 151 leaves, respectively (Fig. 4D). The CV (5.15%) indicated stable expression across replicates. Stem diameter also showed significant variation (Fig. 4E). NARC-32573 developed the thickest stems (22.9 mm), followed by Quetta Local (15.7 mm), whereas Peshawar Local-1 had the thinnest stems (12.3 mm). Genotypes differed for internode length (Fig. 4F). Peshawar Local-1 had the longest internodes (6.25 cm), followed by NARC-32573 (5.75 cm), while Quetta Local recorded the shortest (4.96 cm).

Figure 5

Days to first harvest (A), Single fruit weight (B), Fruit Length (C), Fruit Diameter (D), No. of fruits per plant (E), and Yield (F) of different genotypes of bitter gourd

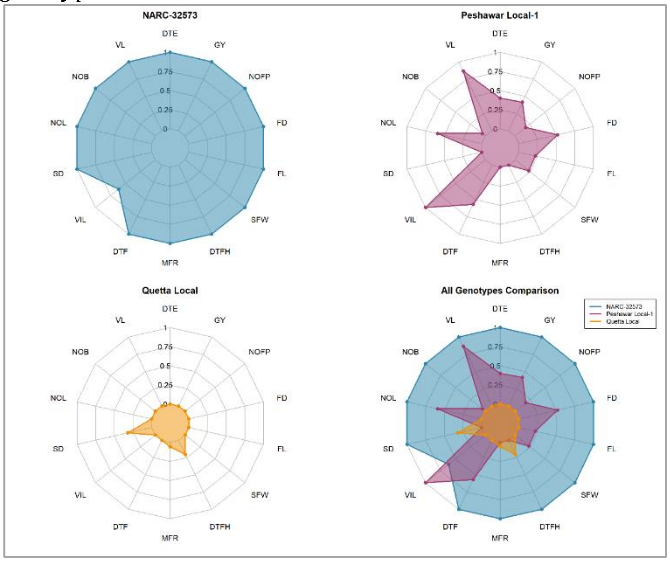


For days to flowering, NARC-32573 showed earlier flowering (51.5 days), followed by Peshawar Local-1 (56.6 days), while Quetta Local was the last to flower (63.3 days) (Fig. 4G). The male-to-female flower ratio varied significantly (Fig. 4H). NARC-32573 exhibited the highest ratio (4.59), whereas Peshawar Local-1 (2.33) and Quetta Local (2.46) were significantly lower. Significant differences were also observed for days to first harvest (Fig. 5A). NARC-32573 reached first harvest at 69 days, compared to Quetta Local at 78 days and Peshawar Local-1 at 80.3 days. For single fruit weight, NARC-32573 recorded the heaviest fruits (147.02 g), followed by Peshawar Local-1 (107.33 g) and Quetta Local (95.63 g) (Fig. 5B). Fruit length also differed significantly (Fig. 5C). NARC-32573 produced the longest fruits (17.26 cm), compared to Peshawar Local-1 (15.35 cm) and Quetta Local (14.81 cm). Similarly, fruit diameter was largest in NARC-32573 (6.03 cm), moderate in Peshawar Local-1 (5.28 cm), and smallest in Quetta Local (4.47 cm) (Fig. 5D).

The number of fruits per plant showed significant variation (Fig. 5E). NARC-32573 produced the maximum (13 fruits per plant), while Peshawar Local-1 produced 5.33, and Quetta Local only 3.66. Significant differences were observed for yield per hectare (Fig. 5F). NARC-32573 recorded the highest yield (33.16 t ha^{-1}), followed by Peshawar Local-1 (24.1 t ha^{-1}) and Quetta Local (17.7 t ha^{-1}). The CV (4.94%) indicated consistent performance across replicates. Overall, NARC-32573 consistently outperformed the local genotypes across all quantitative traits, while Quetta Local performed worst in most traits (Fig. 6).

Figure 6

Radar plot of the studied attributes of the three bitter gourd genotypes



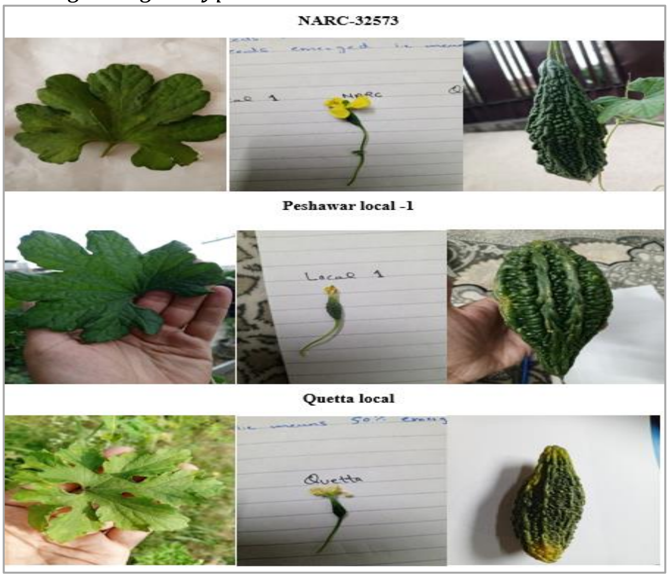
Qualitative Traits

The qualitative evaluation of three bitter gourd genotypes (Quetta Local, NARC-32573, and Peshawar Local-1) revealed distinct morphological differences, as detailed in Table 1. In terms of cotyledon color, Quetta Local displayed a light-green shade (rank 3), whereas both NARC-32573 and Peshawar Local-1 exhibited medium-green cotyledons (rank 5). Variation was also observed in stem traits: the internode length was shortest in Quetta Local (3), longest in NARC-32573 (5), and intermediate in Peshawar Local-1 (7). Stem thickness was thin in both Quetta Local (3) and Peshawar Local-1 (3), while NARC-32573 showed thicker stems (7). The number of shoots was few in Quetta Local (3) and Peshawar Local-1 (3), in contrast to the many recorded in NARC-32573 (7).

Leaf traits showed noticeable variation among genotypes. Leaf blade size was small in Quetta Local (3) but medium in both NARC-32573 (5) and Peshawar Local-1 (5). Leaf blade color was medium green in Quetta Local (5) and NARC-32573 (5), while darker pigmentation was observed in Peshawar Local-1 (5). The length-to-width lobe ratio was small in Quetta Local (1) and Peshawar Local-1 (1), whereas NARC-32573 showed a medium ratio (2). The number of lobes per leaf blade was nine in Quetta Local (3) compared to seven in both NARC-32573 (2) and Peshawar Local-1 (2). Lobing depth was deep in Quetta Local (7) and Peshawar Local-1 (7), while medium in NARC-32573 (5). Petiole length was medium in Quetta Local (5) and NARC-32573 (5), but long in Peshawar Local-1 (7).

Figure 7

Pictorial representation of the characteristics of different bitter gourd genotypes



Reproductive features also differed. Ovary length was short in Quetta Local (3), medium in NARC-32573 (5), and medium in Peshawar Local-1 (5). The green color intensity was medium in Quetta Local (5) and NARC-32573 (5), but light in Peshawar Local-1 (3). Fruit traits demonstrated the highest variability. Fruit length was short in Quetta Local (3) and Peshawar Local-1 (3), but long in NARC-32573 (7). Similarly, fruit diameter was medium in Quetta Local (5), large in NARC-32573 (7), and small in Peshawar Local-1 (3). All three genotypes bore spindle-shaped fruits (3) with an obtuse base (2) and apex (2). Fruit skin color was medium green in Quetta Local (3) and Peshawar Local-1 (3), while dark green in NARC-32573 (4). At maturity, all turned orange-yellow (1).

Table 1

Qualitative attributes of the studied genotypes of bitter gourd

S.No	Parameters	Genotype					
		Quetta Local		NARC 32573		Peshawar Local 1	
		Result	Ranking	Result	Ranking	Result	Ranking
1.	Cotyledon: Intensity of green color	Light	3	Medium	5	Medium	5
2.	Stem: Length of internode of main stem (between 15th and 20th node)	Short	3	Long	5	Long	7

3.	Stem: Thickness of main stem	Thin	3	Thick	7	Thin	3
4.	Stem Number of shoots	Few	3	Many	7	few	3
5.	Leaf blade: Size	Small	3	Medium	5	medium	5
6.	Leaf blade: Intensity of green color	Medium	5	Medium	5	Dark	5
7.	Leaf blade: Ratio length/Width lobe	Small	1	Medium	2	Small	1
8.	Leaf blade: Number of lobes	Nine	3	Seven	2	Seven	2
9.	Leaf blade: Depth of lobing	Deep	7	Medium	5	Deep	7
10.	Petiole: Length	Medium	5	Medium	5	Long	7
11.	Ovary: Length	Short	3	medium	5	medium	5
12.	Stigma: Intensity of green color	Medium	5	Medium	5	Light	3
13.	Fruit: Length	Short	3	Long	7	short	3
14.	Fruit: Diameter	Medium	5	Large	7	short	3
15.	Fruit: Shape in longitudinal section	Spindle	3	Spindle	3	spindle	3
16.	Fruit: Color of skin	Medium green	3	Dark green	4	Medium green	3
17.	Fruit: Shape of base	Obtuse	2	Obtuse	2	obtuse	2
18.	Fruit: Shape of apex	Obtuse	2	obtuse	2	obtuse	2
19.	Fruit: Number of warts	Medium	5	Many	7	Medium	5
20.	Wart: Size	Small	3	Large	7	medium	5
21.	Wart: Shape of top	Rounded	3	Rounded	3	rounded	3
22.	Wart: Presence of spines	Absent	1	Absent	1	Absent	1
23.	Fruit: Length of ridge	Short	3	Long	7	short	3
24.	Fruit: Color of skin at ripe stage	Orange/yellow	1	Orange /yellow	1	Orang/yellow	1
25.	Fruit: Bitterness	Present	9	Present	9	Present	9
26.	Fruit: Intensity of bitterness	Medium	5	Medium	5	Medium	5
27.	Seed: size	Medium	5	Medium	5	medium	5
28.	Seed: Intensity of brown color of testa	Medium	5	Medium	5	Medium	5
29.	Seed: Identification of the edge	Medium	5	Medium	5	Large	7
30.	Time of physiological maturity	Late	7	Early	3	late	7

Wart characteristics showed marked differences. The number of warts was medium in Quetta Local (5) and Peshawar Local-1 (5), whereas a higher number was observed in NARC-32573 (7). Wart size was small in Quetta Local (3), medium in Peshawar Local-1 (5), and large in NARC-32573 (7). Wart tops were rounded in all genotypes (3), while spines were absent (1). Ridge length was short in Quetta Local (3) and Peshawar Local-1 (3), but long in NARC-32573 (7). Bitterness was present in all three genotypes (9), with medium intensity (5). Seed traits were largely uniform across genotypes, with medium seed size (5), medium testa coloration (5), and medium edge identification in Quetta Local (5) and NARC-32573 (5), while Peshawar Local-1 showed a larger edge (7). Physiological maturity varied significantly, i.e., Quetta Local and Peshawar Local-1 were late-maturing (7), whereas NARC-32573 reached maturity earlier (3).

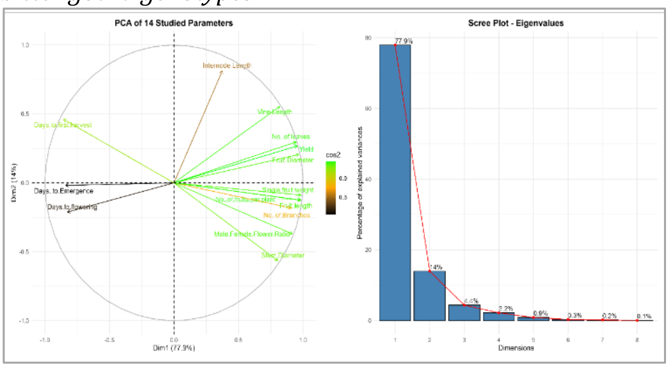
Overall, NARC-32573 ranked highest for most morphological and fruit-related parameters. At the same time, Quetta Local and Peshawar Local-1 displayed either medium or lower values (Fig. 7). Certain traits, such as fruit shape, apex, base, bitterness, wart shape, spine absence, and seed testa color, remained consistent across all genotypes, reflecting their shared bitter gourd identity.

Principal Component Analysis

Principal component analysis was performed on 14 morpho-agronomic traits to examine trait relationships and identify significant sources of variation among the three bitter gourd genotypes (NARC-32573, Peshawar Local-1, and Quetta Local). The PCA revealed distinct patterns of trait associations and genotypic differentiation (Fig.8). The scree plot analysis indicated that the first two principal components captured 92% of the total variation (PC1: 77.9%, PC2: 14.1%), suggesting that these components effectively summarized the significant patterns of variation among the studied genotypes. The steep decline in eigenvalues after PC2 (4.4% for PC3) demonstrated that subsequent components contributed minimally to the overall variation.

Figure 8

Principal Component Analysis of the studied attributes of bitter gourd genotypes



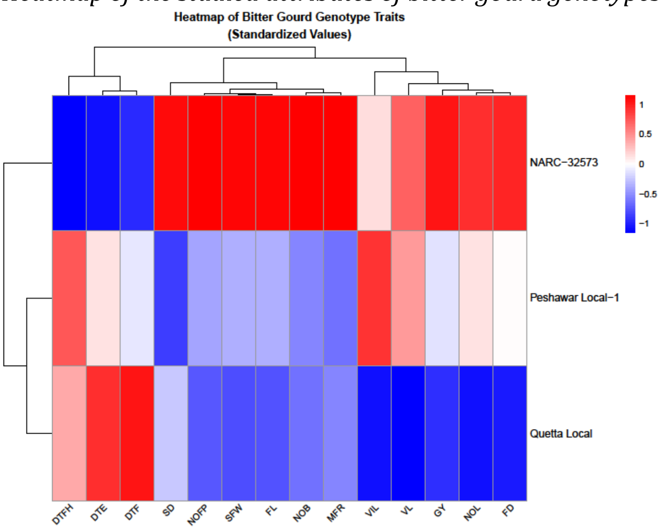
Vine length, number of leaves, yield, fruit diameter, single fruit weight, number of fruits per plant, fruit length, number of branches, and male-female flower ratio were positioned in the positive quadrant of both PC1 and PC2. These traits showed strong positive correlations with each other, indicating that genotypes with longer vines tend to have higher leaf numbers, greater yields, and larger fruits.

In contrast, days to first harvest were positioned in the negative PC1 and positive PC2 quadrant, suggesting an inverse relationship with growth and yield parameters. This indicates that genotypes with delayed maturity may have reduced overall productivity. Days to emergence, days to flowering, and stem diameter were also clustered in the negative quadrants, showing distinct separation from both growth-yield and maturity traits.

The heatmap analysis of standardized trait values revealed clear phenotypic distinctions among the three genotypes (Fig. 9). NARC-32573 demonstrated superior performance across most growth and yield-related parameters, showing positive standardized values for vine length (VL), number of leaves (NOL), yield (GY), fruit diameter (FD), single fruit weight (SFW), number of fruits per plant (NOFP), fruit length (FL), and number of branches (NOB). This genotype also exhibited favorable early-maturity characteristics, with negative standardized values for days to first harvest (DTFH), days to emergence (DTE), and days to flowering (DTF).

Figure 9

Heatmap of the studied attributes of bitter gourd genotypes



Peshawar Local-1 showed a mixed performance pattern, with moderate positive values for some growth parameters but negative values for key yield components, including yield (GY), fruit diameter (FD), and single fruit weight (SFW). This genotype demonstrated intermediate maturity timing. Quetta Local generally exhibited below-average performance across most parameters, particularly for growth and yield-related traits, with negative standardized values predominating across the trait spectrum. However, it showed some positive values for stem diameter (SD) and vine internode length (VIL). Principal component analysis and heatmaps indicate that NARC-32573 performed well as compared to the other local cultivars. It showed better growth, earlier maturity, and greater yield potential. These multivariate analyses provide strong evidence for the agro-climatic suitability of NARC-32573 in District Peshawar, supporting its potential adoption as an improved bitter gourd variety for the region.

DISCUSSION

The contrasting performance of the three bitter gourd genotypes reflects substantial genetic variation in growth, flowering, fruiting, and yield attributes. These differences can be attributed to underlying physiological and morphological mechanisms that collectively influence crop productivity. Seed vigor, as reflected in the early emergence of NARC-32573 compared to local genotypes, is attributed to better carbohydrate reserves, enhanced activity of hydrolytic enzymes such as α-amylase, and the rapid mobilization of stored assimilates during germination (Ali & Elozeiri, 2017). Early germination leads to faster canopy growth, enabling a competitive advantage over weeds and aiding the early acquisition of resources, thereby facilitating further vegetative and reproductive growth. Conversely, later emergence in Peshawar Local-1 and in Quetta Local suggests that they had low seed vigor and poor mobilization of reserves, which probably restricted their initial growth pathways.

Cell division and cell elongation are largely regulated by endogenous phytohormones, including gibberellins, auxins, and cytokinins, to control vine length, stem diameter, and internode length (Li *et al.,* 2022). The optimum growth of NARC-32573 is indicative of increased gibberellin activity, which allows it to induce greater internodal extension and cell growth. Contrastingly, the shorter vine length and thinner stem favor compact growth in Quetta Local, reflecting limited cell expansion and reduced investment in vegetative development, consistent with its weak vigor. No. The number of leaves and branches determines the plant's canopy (Niinemets, 2010). Auxin–cytokinin interactions play a crucial role in branch initiation, with high levels of cytokinin activity triggering axillary bud outgrowth (Tan *et al.,* 2019). A higher number of branches and leaves in NARC-32573 indicates a positive hormonal equilibrium, favoring a larger photosynthetic area and a greater source of assimilates. In comparison, the low branching of Quetta Local and Peshawar Local-1 indicates apical dominance, perhaps due to greater auxin concentration relative to cytokinins, which results in decreased lateral shoot development and alters the source-sink relationship, ultimately affecting crop yield.

Flowering dynamics among genotypes can also be explained by differences in assimilate partitioning and hormonal regulation (Wen *et al.,* 2024). The early flowering of NARC-32573 indicates a lower thermal-time requirement and an efficient transition from vegetative to reproductive growth. This process is strongly influenced by the balance between gibberellins (which promote flowering) and photosynthate accumulation at the shoot apex. In cucurbits, carbohydrate supply at the apex has been reported to advance floral initiation (Pradeepkumar & Lekshmanan, 2024). The late flowering observed in Quetta Local reflects a prolonged vegetative phase, suggesting delayed accumulation of critical carbohydrate and phytohormone thresholds necessary for floral induction.

The male-to-female flower ratio is an essential determinant of fruit set in cucurbits (Nwofia et *al.,* 2015). Genotypic variation in this trait is often regulated by ethylene and auxin signaling, which promote femaleness, while gibberellins tend to enhance maleness (Aparna *et al.,* 2023). The higher male-to-female ratio observed in NARC-32573 may reflect a greater gibberellin influence;

however, the efficient fruit set and yield of this genotype suggest that pollination efficiency and female flower retention were adequate. On the other hand, Peshawar Local-1 and Quetta Local, despite having lower ratios, produced fewer fruits, indicating that factors beyond floral ratio, such as ovary development, pollen viability, or assimilate allocation to developing ovaries, played limiting roles.

Earliness in fruit harvest, as observed in NARC-32573, is closely tied to rapid reproductive transition and efficient sink filling. Once fruits are initiated, rapid cell division and expansion, supported by a strong source such as leaves, accelerate fruit development (Ripoll *et al.,* 2019). Early harvest not only allows multiple pickings but also provides an economic advantage by reducing market supply (Mason *et al.,* 2015). The delayed harvest maturity of Quetta Local and Peshawar Local-1 suggests slower fruit growth rates, possibly due to limited assimilate translocation and weaker sink strength. Fruit traits such as weight, length, diameter, and overall fruit size are primarily governed by the extent of cell division during early fruit growth, followed by cell enlargement during later stages (Mauxion *et al.,* 2021). Larger fruit dimensions in NARC-32573 point to higher sink strength, supported by an abundant assimilate supply from its vigorous foliage. In cucurbits, sink strength is determined by the activity of sucrose transporters and invertase enzymes in developing fruits, which regulate sucrose unloading and hexose accumulation (Lao *et al.,* 2025). It is plausible that NARC-32573 possessed more efficient carbohydrate unloading mechanisms, enabling greater fruit biomass accumulation. In contrast, the smaller fruit size in Quetta Local indicates reduced sink activity and fewer cells undergoing expansion, limiting the final fruit mass.

The number of fruits per plant and, ultimately, yield depend on the balance between fruit initiation, retention, and the ability to support developing fruits with sufficient assimilates (Banjare *et al.,* 2023). The superior fruiting capacity of NARC-32573 suggests both strong reproductive vigor and effective source–sink coordination, allowing simultaneous support of multiple developing fruits. Local genotypes, particularly Quetta Local, likely experienced fruit abortion due to competition for assimilates, exacerbated by their limited leaf area and weaker photosynthetic capacity. This explains their lower fruit numbers and reduced yield.

The qualitative UPOV descriptors support these mechanistic explanations. High genetic vigor and the redirection of assimilates to robust vegetative and reproductive structures are reflected in the vigorous plant habit (Rosati *et al.,* 2024), long ridges, thick stems, and large warted fruits of NARC-32573. The dark green hue of its fruit can also indicate higher levels of chlorophyll and carotenoids, which are commonly associated with better fruit quality and consumer popularity (Gebretsadik *et al.,* 2021). In contrast, Quetta Local shows limited growth, with small leaves, shallow lobes, and small fruit, underscoring its limited genetic potential for growth. Peshawar Local-1 exhibited moderate performance, indicating that it adapts to specific local environmental conditions but does not demonstrate general superiority. Mechanistically, the overall superiority of NARC-32573 based on growth, flowering, fruiting, and yield can be explained by its desirable balance of hormones, more efficient source-sink partitions, stronger sinkage in fruits, and the presence of strong vegetative vigor.

These traits collectively enhance photosynthetic assimilation, reproductive success, and yield accumulation. Local genotypes, though diverse in morphology, lack the physiological efficiency and reproductive vigor required for high productivity (Khadka *et al.,* 2020). However, they still represent essential reservoirs of genetic diversity, especially traits like compactness and specific fruit morphologies, which may hold value for targeted breeding. Overall, the study confirms that genetic variation in bitter gourd is expressed through physiological processes involving hormonal regulation, assimilate allocation, and source–sink interactions. Breeding programs can exploit these mechanisms to develop high-yielding, early-maturing genotypes with desirable fruit traits while preserving unique attributes of local landraces for future crop improvement.

CONCLUSION

The comparative evaluation of bitter gourd genotypes revealed that NARC-32573 demonstrated clear superiority over the local varieties, Peshawar Local-1 and Quetta Local, in both quantitative and qualitative traits. Its advantages in early emergence, vigorous vegetative growth, improved fruit characteristics, and higher yield potential highlight its adaptability to Peshawar's agro-climatic conditions. While Peshawar Local-1 demonstrated moderate performance with certain distinct traits, Quetta Local lagged in most of the studied parameters. In contrast, NARC-32573 consistently excelled across key attributes, establishing itself as the most promising genotype for commercial cultivation.

These findings highlight the potential of NARC-32573 not only to improve bitter gourd production in Peshawar but also to contribute to the development of superior germplasm through future breeding programs. However, as with any newly tested variety, broader adaptability trials across diverse environmental conditions are essential to confirm its stability and consistent performance. Additionally, integrated pest and disease management strategies should be incorporated to ensure sustainable production and minimize biotic stresses. In conclusion, NARC-32573 stands out as a high-yielding, early-maturing, and quality-improving genotype that can significantly enhance bitter gourd cultivation. Its adoption at a commercial scale is strongly supported by the results of this study, provided complementary management practices are employed to address potential pest challenges and to secure long-term productivity.

REFERENCES

Ali, A. S., & Elozeiri, A. A. (2017). Metabolic processes during seed germination. *Advances in Seed Biology*.

https://doi.org/10.5772/intechopen.70653
Aparna, Skarzyńska, A., Pląder, W., & Pawełkowicz, M. (2023). Impact of climate change on regulation of genes involved in sex determination and fruit production in cucumber. *Plants*, *12*(14), 2651. https://doi.org/10.3390/plants12142651
Rimpika, Jain, S., Rathod, M., Banjare, R., Nidhi, N., Sood, A., Shilpa, & Sharma, R. (2023). Physiological aspects of flowering, fruit setting, fruit development and fruit drop, regulation and their manipulation: A review. *International Journal of Environment and Climate Change*, *13*(12), 205-224. https://doi.org/10.9734/ijecc/2023/v13i123677
Dhillon, N. P., Hanson, P., Chen, W., Srinivasan, R., Kenyon, L., Yang, R. Y., ... & Mecozzi, M. (2017). Suggested cultural practices for bitter gourd. *World Vegetable Center.*
Digambar, M. D. M. (2024). *VARIABILITY STUDIES OF F4 GENERATION IN BITTER GOURD (Momordica charantia L.)* (Doctoral dissertation, MAHATMA PHULE KRISHI VIDYAPEETH).
Gayathry, K. S., & John, J. A. (2022). A comprehensive review on bitter gourd (Momordica charantia L.) as a gold mine of functional bioactive components for therapeutic foods. *Food Production, Processing and Nutrition*, *4*(1). https://doi.org/10.1186/s43014-022-00089-x
Gebretsadik, K., Qiu, X., Dong, S., Miao, H., & Bo, K. (2021). Molecular research progress and improvement approach of fruit quality traits in cucumber. *Theoretical and Applied Genetics*, *134*(11), 3535-3552. https://doi.org/10.1007/s00122-021-03895-y
Jat, G. S., Behera, T. K., Singh, A. K., Bana, R. S., Singh, D., Godara, S., Reddy, U. K., Rao, P. G., Ram, H., Vinay, N. D., Kumar, S., & Tomar, B. S. (2024). Antioxidant activities, dietary nutrients, and yield potential of bitter gourd (Momordica charantia L.) lines in diverse growing environments. *Frontiers in Nutrition*, *11*. https://doi.org/10.3389/fnut.2024.1393476
Khadka, K., Earl, H. J., Raizada, M. N., & Navabi, A. (2020). A physio-morphological trait-based approach for breeding drought tolerant wheat. *Frontiers in Plant Science*, *11*. https://doi.org/10.3389/fpls.2020.00715
Khan, P., Imtiaz, M., & Shahzad, H. (2024). Growth and yield of bitter gourd as influenced by inorganic fertilizers in high tunnel with drip irrigation system. *Journal of Agricultural Sciences – Sri Lanka*, *19*(3), 593-599. https://doi.org/10.4038/jas.v19i3.10623
Khan, S., Rehman, S., Ullah, F., Musa, M., Farooq, O., Shah, I., ... & Mehboob10, M. (2023). Comparative Assessment of Advanced and Chinese Hybrid Lines of Wheat Under the Agro-Ecological Context of Peshawar, Pakistan.
Lao, T. D., Nguyen, N. H., Le, T. A., & Nguyen, P. D. (2023). Insights into sucrose metabolism and its ethylene-dependent regulation in Cucumis Melo L. *Molecular Biotechnology*, *67*(1), 27-35. https://doi.org/10.1007/s12033-023-00987-6
Li, J., Li, D., Liu, B., Wang, R., Yan, Y., Li, G., Wang, L., Ma, C., Xu, W., Zhao, L., Li, X., & Wang, S. (2022). Effects of root restriction on phytohormone levels in different growth stages and grapevine organs. *Scientific Reports*, *12*(1). https://doi.org/10.1038/s41598-021-04617-6
Mason, N., Flores, H., Villalobos, J. R., & Ahumada, O. (2015). Planning the planting, harvest, and distribution of fresh horticultural products. *International Series in Operations Research & Management Science*, 19-54. https://doi.org/10.1007/978-1-4939-2483-7_2
Mauxion, J., Chevalier, C., & Gonzalez, N. (2021). Complex cellular and molecular events determining fruit size. *Trends in Plant Science*, *26*(10), 1023-1038. https://doi.org/10.1016/j.tplants.2021.05.008
Niinemets, Ü. (2010). A review of light interception in plant stands from leaf to canopy in different plant functional types and in species with varying shade tolerance. *Ecological Research*, *25*(4), 693-714. https://doi.org/10.1007/s11284-010-0712-4
Nwofia, G. E., Amajuoyi, A. N., & Mbah, E. U. (2015). Response of three cucumber varieties (Cucumis sativus L.) to planting season and NPK fertilizer rates in lowland humid tropics: sex expression, yield and inter-relationships between yield and associated traits. *International Journal of Agriculture and Forestry*, *5*(1), 30-37.
Pradeepkumar, T., & Lekshmanan, D. K. (2024). Mechanism of hybrid seed production in cucurbitaceous vegetables. *Euphytica*, *220*(2). https://doi.org/10.1007/s10681-023-03278-y
Ripoll, J., Zhu, M., Brocke, S., Hon, C. T., Yanofsky, M. F., Boudaoud, A., & Roeder, A. H. (2019). Growth dynamics of the *Arabidopsis* fruit is mediated by cell expansion. *Proceedings of the National Academy of Sciences*, *116*(50), 25333-25342. https://doi.org/10.1073/pnas.1914096116
Rosati, A., Paoletti, A., Lodolini, E. M., & Famiani, F. (2024). Cultivar ideotype for intensive olive orchards: Plant vigor, biomass partitioning, tree architecture and fruiting characteristics. *Frontiers in Plant Science*, *15*. https://doi.org/10.3389/fpls.2024.1345182
Tan, M., Li, G., Chen, X., Xing, L., Ma, J., Zhang, D., Ge, H., Han, M., Sha, G., & An, N. (2019). Role of cytokinin, Strigolactone, and auxin export on outgrowth of axillary buds in Apple. *Frontiers in Plant Science*, *10*. https://doi.org/10.3389/fpls.2019.00616
Wen, L., Liu, Y., Zhou, B., Sun, W., Xiao, X., Wang, Z., Sun, Z., Zhang, Z., & Zhang, Y. (2024). Differences between two wheat genotypes in the development of floret primordia and contents of pigments and hormones. *The Crop Journal*, *12*(4), 1196-1207. https://doi.org/10.1016/j.cj.2024.04.007