Research Article

ISAH Indian Journal of Arid Horticulture
Year 2024, Volume-6, Issue-1&2 (January -June)

Performance of the bottle gourd variety Thar Avani for morphological traits under rainfed semi-arid conditions

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ARTICLE INFO

Received: 15 January 2025
Accepted: 17 January 2025

Keywords: Thar Avani, principal components, correlation, ascorbic acid, semi-arid region

doi:10.48165/ijah.2024.6.1.7

ABSTRACT

Among 29 physiological traits in bottle gourd varieties, highly significant correlation in FL and FW with FG and NFMF, respectively (r=+1.00; P≤0.05) were observed. Likewise, FW with FL (r=+1.00; P≤0.001). High magnitude and significant correlation were found between IL and LPL (r=+1.00; P≤0.01). Similarly, high magnitude and significant correlation links were noticed in NFFF (r=+1.00; P≤0.01), DFFA (r=+1.00; P≤0.05) and NMFP (r=+1.00; P≤0.01) with LW; DFFA with NFFF(r=+1.00; P≤0.05); NMFP with NFFF (r=+1.00; P≤0.05); NFP with NFFP with NFFF (r=+1.00; P≤0.01); SYH with SYP with NFFF (r=+1.00; P≤0.001); FYP with SYP (r=+0.99; P≤0.01), SYH (r=+0.99; P≤0.01) and PL (r=+1.00; P≤0.01); FYH with SYP (r=+0.99; P≤0.01), SYH (r=+0.99; P≤0.01), PL (r=+1.00; P≤0.01) and FYP (r=+1.00; P≤0.001); RT with NSF (r=+1.00; P≤0.05); AAS with NSF (r=+1.00; P≤0.05) and RT (r=+1.00; P≤0.001); SYF with NSF (r=+1.00; P≤0.05). The findings indicate that Thar Avani demonstrates strong performance under semi-arid conditions, showcasing substantial variability that can be leveraged in breeding programs focused on yield improvement.

Introduction

Bottle gourd [*Lagenaria siceraria* (Mol.) Standl.], also known as Calabash, white flower gourd, or locally as *ghia* or *lauki*, is one of the most significant cucurbitaceous vegetables cultivated in tropical and subtropical regions worldwide (Yadav *et al.*, 2023). The chromosome number of bottle gourd is 2n = 22 (Reddy *et al.*, 2017). The fruit shape of bottle gourd can vary from flat to round, oval, oblong, and long. The name "bottle gourd" is believed to have originated from the mature, harvested fruits, which were traditionally used as bottles, utensils, or pipes (Yadav *et al.*, 2023). The term "Calabaza" is thought to have come from the Arabic *qar'a yabisa* (meaning "dry gourd"), Persian *kharabuz* (used for various large melons), or from pre-Roman Iberian *calapaccia* (Basu *et al.*, 2017). In India, bottle gourd is known by several names, including Lauki, Ghia, Doodhi, Jatilao, Sorakaya, and Bhopla, among others. Historical Sanskrit texts also reference bottle gourd as *alabu*, and it was used to make musical instruments such as the *tambura*, *veena*, and *kamandalu* (Yadav *et al.*, 2023).

Bottle gourd is primarily grown for its tender leaves and young fruit, which are consumed as vegetables, usually cooked. The mature fruit's hard shell is used to create a variety of domestic items, including musical instruments, jugs, utensils for storing liquids and food, and floats for fishing nets (Chadha,

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2001). The fruit colour can range from green to cream or yellow, with the flesh typically being white. Uniquely, bottle gourd undergoes anthesis in the evening, and the flowers are white, earning it the moniker "white flowered gourd". Its fruit possesses medicinal properties and is traditionally used as a cardiotonic, aphrodisiac, hepatoprotective, analgesic, anti-inflammatory, expectorant, diuretic, and antioxidant.

Considered one of the oldest crops in the tropics, bottle gourd is believed to be indigenous to Africa and has a wide adaptability to arid and semi-arid regions. In India, significant cultivation areas include Uttar Pradesh, Rajasthan, Haryana, Punjab, Delhi, Andhra Pradesh, Bihar, and Karnataka (Yadav *et al.*, 2023). Local varieties are often grown in backyard gardens or kitchen gardens, particularly in semi-arid tribal regions, where they exhibit significant morphological diversity.

Considering its broad potential and importance, efforts to improve bottle gourd were initiated at the ICAR - Central Horticultural Experiment Station, Godhra, Gujarat, through hybridization, followed by selection from the segregating population of promising lines LS-4 x LS3-2. This work led to the development of the variety Thar Avani, which was advanced to the F_8 generation between 2016 and 2020 and identified at the institute level in 2021. Thar Avani is a highly vigorous variety with dense foliage. Male and female flowers appear from the 7^{th} and 11^{th} nodes, respectively. Each plant produces 24-32 female flowers and sets harvestable-sized fruits between 57 and 62 days after sowing. The fruit is round in shape, with an average length of 22.8 cm, a girth of 39.4 cm, and weighs between 750-860 g. Additionally, the variety shows a TSS of 8.1-8.7° Brix, a content of 21.6 mg/100g AAF, and an average fruit weight of 12.91 kg per plant.

Material and Methods

The comparative evaluation of bottle gourd variety Thar Avani along with Pusa Sandesh and Arka Bahar was carried out for different traits. The experiment was laid out during rainy season of 2021 and 2022 in randomized block design with eight replications under rainfed semi-arid condition at Vegetable Experiment Block, ICAR- Central Horticultural Experiment Station, Godhra, Gujarat situated at latitude 22°41"38" N, longitude 73°33′ 38" E and elevation of 113-115 m above mean sea level.

The cultural practices and production technology were followed according to (Yadav *et al.*, 2023). The mean maximum and minimum temperature varied between 28.5 to 47.1°C and 12.6 to 26.8°C, respectively, and total annual minimum and maximum rainfall of ranged from 462.46 mm to 764.82 mm with relative humidity 27.55-92.50 per cent during the period under study. The crop was raised during rainy season of 1^{st} week of July, 2021 and 2022.

The physiological traits of bottle gourd varieties were recorded by following standard methods (Yadav *et al.*, 2022; Yadav *et al.*, 2019) and morphological traits according to (Biodiversity International for Cucurbitaceae, 2007). Ascorbic acid content was determined in accordance with the dinitrophenylhydrazine (DNPH) method. The value was expressed as mg/100 g FW (Yadav *et al.*, 2019).

The best linear unbiased predictor (BLUP) was calculated to eliminate the different environmental effect, using the Meta-R program V.6.0 (Alvarado *et al.*, 2020). Variability package in the R program (Team R.C.R., 2017) was used for the analysis of variance (ANOVA), where varieties and environments were treated as fixed and random effects, respectively. Statistical significance was determined at $P < 0.001$. Descriptive statistics including mean, range, and standard error, were estimated using the same package of the R program (Alvarado *et al.*, 2020). Additionally, the biplot PCA graphs were generated by aggregating mean data of all traits with the assistance of *FactoMineR* and *factoextra* packages in R program (Team R.C.R., 2017).

Results and Discussion

Among 29 physiological traits in bottle gourd genotypes, highly significant correlation in FL and FW with FG and NFMF, respectively (r=+1.00; P≤0.05) were observed. Likewise, FW with FL (r=+1.00; P≤0.001). High magnitude and significant correlation was found between IL and LPL (r=+1.00; P≤0.01). Similarly, High magnitude and significant correlation links were noticed in NFFF (r=+1.00; P≤0.01), DFFA (r=+1.00; P≤0.05) and NMFP (r=+1.00; P≤0.01) with LW; DFFA with NFFF(r=+1.00; P≤0.05); NMFP with NFFF (r=+1.00; P≤0.05); NFP with NFFP with NFFF(r=+1.00; P≤0.01); SYH with SYP with NFFF(r=+1.00; P≤0.001); FYP with SYP (r=+0.99; P≤0.01), SYH (r=+0.99; P≤0.01) and PL (r=+1.00; P≤0.01); FYH with SYP (r=+0.99; P≤0.01), SYH (r=+0.99; P≤0.01), PL (r=+1.00; P≤0.01) and FYP (r=+1.00; P≤0.001); RT with NSF (r=+1.00; P≤0.05); AAS with NSF (r=+1.00; P≤0.05) and RT (r=+1.00; P≤0.001); SYF with NSF (r=+1.00; P≤0.05).

High magnitude and non-significant correlation were found between NFMF with FG (r=+0.97) and NFMF (r=+0.99); FL and FW with LL (r=+0.96); LW, NFFF, DFFA, NMFP with LL (r=+0.95; r=+0.95; r=+0.93 and r=+0.92, respectively); SYP and SYH with NFFP and NFP (r=+0.95); PL with SYP and SYH (r=+0.96); FYP and FYH with NFFP, NFP (r=+0.94) and SYP and SYH (r=+0.99), respectively; DMFA with FYP and FYH (r=+0.90); PtL and SKW with DMFA (r=+0.90); NSF with SKW (r=+0.92) and FT (r=+0.97); RT with SKW (r=+0.86), FT (r=+0.90) and NSF (r=+0.96); AAF with SKW (r=+0.90) and FT (r=+0.96); SYF with DMFA (r=+0.84), PL (r=+0.91), SKW (r=+0.94) and FT (r=+0.95); SW with DMFA (r=+0.87), PL (r=+0.93), SKW (r=+0.96), FT (r=+0.93), NSF (r=+0.99), RT (r=+0.99) and AAF (r=+0.99); AATL with DMFA (r=+0.84), PL (r=+0.94), SKW (r=+0.96), FT (r=+0.93), NSF (r=+0.99), RT (r=+0.98) and AAF (r=+0.98).

Subsequently, NFFP and NFP conveyed strong negative connections with LL (r=-1.0; P≤0.05). Likewise, SYP and SYH with LW (r=-1.0; P≤0.01), NFFF (r=-1.0; P≤0.001), DFFA (r=-1.0; P≤0.05) and NMFP (r=-1.0; NS), respectively; PL with PdL (r=-1.0; P≤0.05); FYP and FYH with DFFA (r=-1.0; P≤0.05) and NMFP (r=-1.0; P≤0.01), respectively; DMFA with LPL (r=-1.0; P≤0.01).

Besides this, LPL, IL, PdL, LW, NFFF, DFFA and NMFP are found negatively correlated with SKW, PtL, DMFA, FYH, FYP, PL, SYH, SYP, NFP and NFFP, which are not useful (LPL, IL, PdL, LW, NFFF, DFFA and NMFP) as they governed by non-additive gene action. Among all 29 traits of bottle gourd varieties in combined form, FYP and S were highly and significantly correlated with FYH (r=+1.00; P≤0.001). Similarly, S with FYP and S (r=+1.00; P≤0.001); SYH and SYP with S (r=+1.00; P≤0.001); SYP with SYH (r=+1.00; P≤0.05); NFFP with NFP (r=+1.00; P≤0.05); TP with NFP and NFFP (r=+1.00; P≤0.001); SW with AATL (r=+1.00; P≤0.01); SYF with AATL and SW (r=+1.00; P≤0.05); NSF with SYF (r=+1.00; P≤0.05); AAF and RT with NSF and ViC (r=+1.00; P≤0.05); RT with AAF (r=+1.00; P≤0.001); Fe, Ca and FRAP with PL (r=+1.00; P≤0.05); SKW, Ca with Fe (r=+1.00; P≤0.05); FRAP with Ca (r=+1.00; P≤0.05); K with FRAP and DMFA (r=+1.00; P≤0.05); LW, Mn and DFFA with NFFF (r=+1.00; P≤0.01 and P≤0.05); Mn and DFFA with LW (r=+1.00; P≤0.05); DFFA with NMFP (r=+1.00; P≤0.05); FL with FW (r=+1.00; P≤0.01); NFMF and FG with FW and FL (r=+1.00; P≤0.05); Mg with LL (r=+1.00; P≤0.01). In this context, same link was observed non-significant correlation among the different traits in combination form viz. SYH and SYP with FYH and FYP (r=+0.99).

Similarly in PL, NFP, NFFP and TP with FYH, FYP, S, SYH, SYP and PL; P, TF and AATL with DPPH, CUPRAC and P. the same link was also noticed in NSF, AAF, Rt, FT, PtL, Fe, SKW, Cu, Ca, FRAP, DMFA and K with AATL, SW, SYF, NSF, AAF, RT, Ft, PtL, and SKW, FW and FG also indicated positive non-significant correlation with NFFF, LW, Mn and DFFA. The symmetrical links were also noticed in LL and Mg with FW, FL, NFMF and FG. The remaining traits showed negatively non-significant results. Simultaneously, NFFF and LW mapped strong negative connections with SYH and SYP (r=-1.0; P≤0.01); S (r=-1.0; P≤0.05). The traits indicated similar finding like Mn with SYH and SYP (r=-1.0; P≤0.05). The NMFP with FYH and FYP (r=-1.0; P≤0.01); DFFA with FYH, FYP, SYH and SYP (r=-1.0; P≤0.05); PdL with PL (r=-1.0; P≤0.05); LL with NFP (r=-1.0; P≤0.05) and TP (r=-1.0; P≤0.01); Mg with TP (r=-1.0; P≤0.05). Rest of the traits showed negatively non-significant results. These results are in support with the findings of Bharathi et al. (2014) in M. dioca and (Yadav et al. (2023), Sirohi et al. (1988) and Samadia (2002) in bottle gourd.

High correlation between core collection (CC) entire population of the bottle gourd germplasm (r= 0.974 for normalized Mantel Statistic Z) demonstrated that CC represents the most of total genetic variation with minimum redundancy in of Turkey (Tas et al., 2019). Surprising findings of correlations were noticed for seed weight with seed length ($R^2 = 0.259$) by (Sari et al., 2020). A strong positive correlation among morphological traits was observed by Samadia (2002) in bottle gourd genotypes. The results pertaining to this study are in support with the findings of (Gürcan et al., 2015).

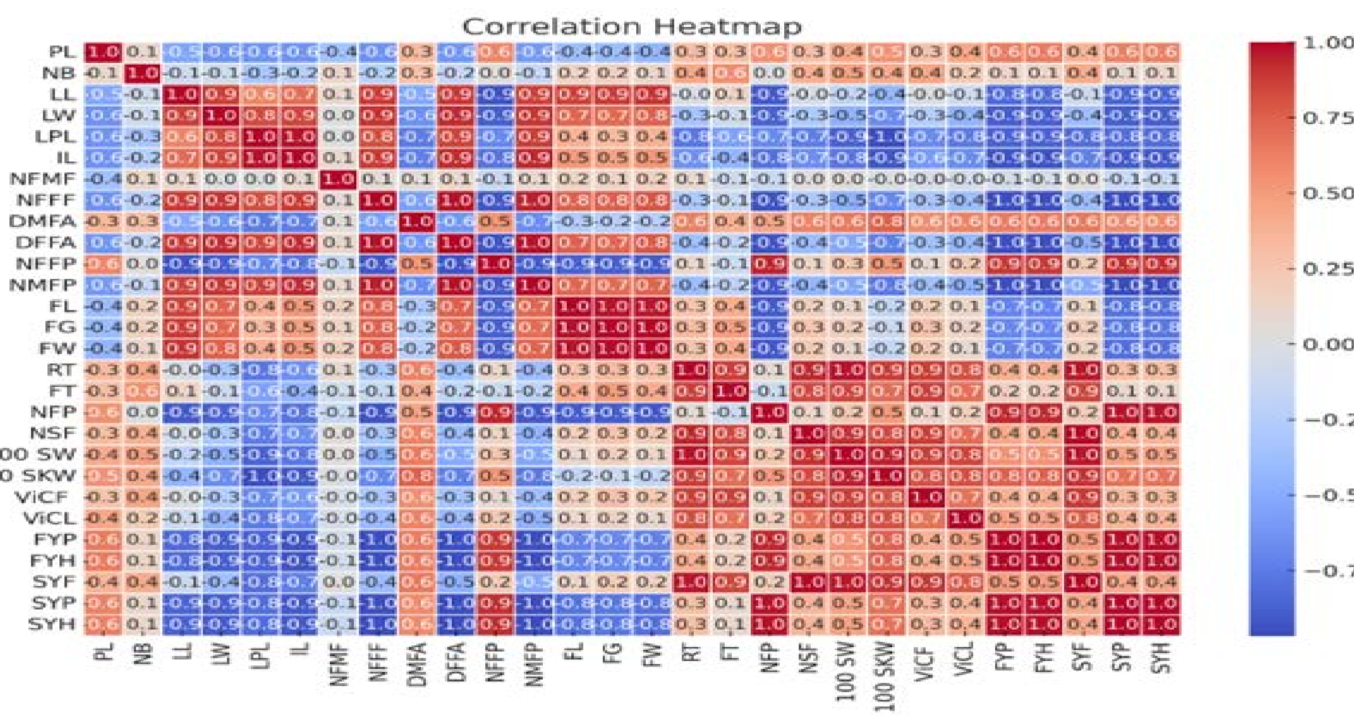

Fig. 1. Pearson correlation coefficients among all 28 traits calculated by using the BLUPs. (Significant at * P≤0.05, ** P≤0.01, and *** P≤0.001)

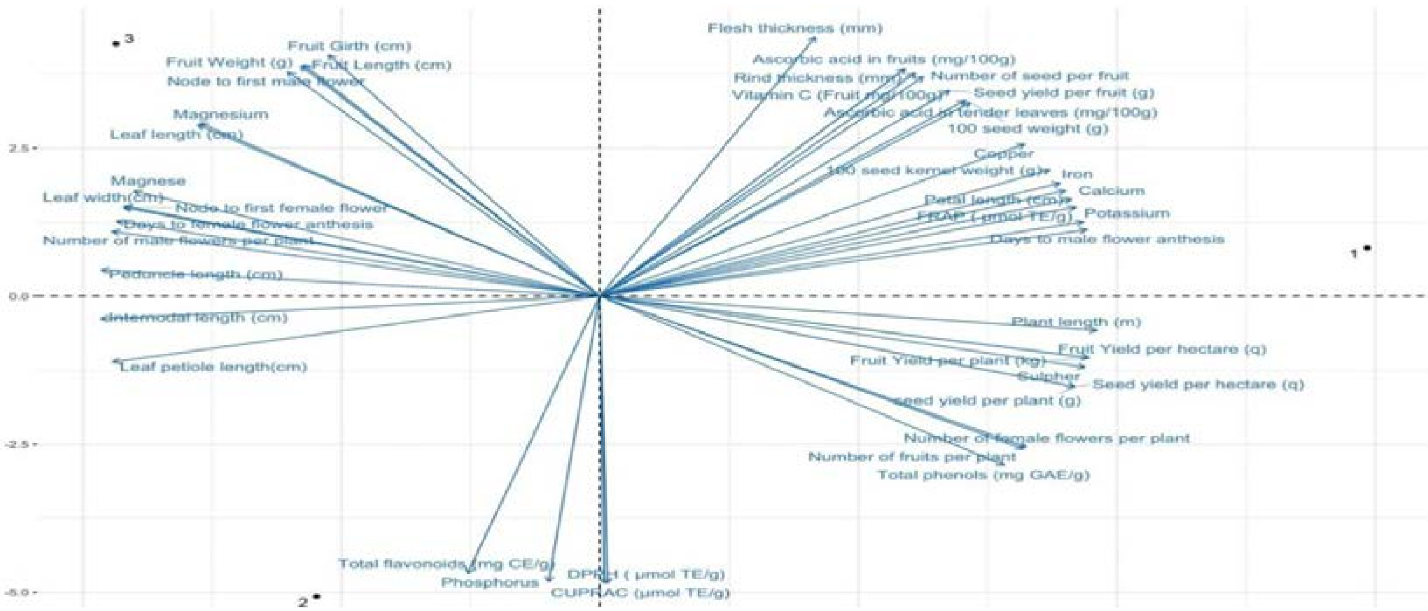

Fig. 2. Genotype by trait biplot graphical display of the measured traits in bottle gourd genotypes

The analysis of variance (ANOVA) revealed significant variation among the three varieties of bottle gourd for 29 different physiological traits were depicted in Table 1. This indicated the presence of high degree of variation within the genotypes. One of the ways by which variability is assessed through a simple approach of examining the range of variations. Range of variation observed for all the traits is presented in Table 2.

Various genetic traits like phenotypic and genotypic coefficient of variability (PCV, GCV), heritability, genetic advance (GA) and genetic advance as per cent of mean (GAM) for the 29 traits like PL-Plant length (m), LL-Leaf length (cm), LW-Leaf width (cm), LP-Leaf petiole length (cm), IL-Internodal length (cm), NFMF-Node to first male flower, NFFF-Node to first female flower, DMFA-Days to male flower anthesis, DFFA-Days to female flower anthesis, NFFP-Number of female flowers per plant, NMFP-Number of male flowers per plant, PtL-Petal length (cm), FL-Fruit length (cm), FG-Fruit girth (cm), PdL-Peduncle length (cm), FW-Fruit weight (g), RT-Rind thickness (mm), FT-Flesh thickness (mm), NFP-Number of fruits per plant, NSF-Number of seed per fruit, SW-100 seed weight (g), SKW-100 seed kernel weight (g) AAF-Ascorbic acid in fruits (mg/100g), AATL-Ascorbic acid in tender leaves (mg/100g), FYP-Fruit yield per plant (kg), FYH-Fruit yield per hectare (q), SYF-Seed yield per fruit (g), SYP-Seed yield per plant (g), SYH-Seed yield per hectare (q), High PCV and GCV were recorded for the TF (24.5398 and 25.1457), LPL (32.812 and 33.0797), IL (26.4953 and 26.6832), NFFF (44.5599 and 45.3748), DFFA (23.9766 and 24.1199), NFFP (60.336 and 61.3191), NMFP (26.8572 and 27.2372), FL (30.2802 and 31.4789), FG (50.0635 and 50.2592), FW (66.1507 and 66.3744), NFP (66.752 and 68.1876), FYP (37.6462 and 38.6746), FYH (37.6464 and 38.6749), SYP (74.9487 and 76.552) and SYH (74.9489 and 76.5522).

The findings revealed that the estimates of the phenotypic PCV were greater than the GCV for all the evaluated traits which signifying that the apparent variation is not only due to the genetic effects but also due to environmental effects. While, the variation between PCV and GCV for most of the traits were small, indicating high possibility of genetic progress through selection, apparently, the environmental impact on any trait is indicated by magnitude of the differences between the GCV and PCV. Whereas large differences reflect a large environmental influence, while small differences show a high genetic influence, and these findings conformed with the findings of (20). Moderate PCV and GCV were recorded for antioxidants including TP (16.1697 and 16.3706), CUPRAC (17.4532 and 18.1472), FRAP (18.232 and 18.9743), AAF (10.8654 and 10.9649); mineral content including Ca (10.9894 and 13.2227); and physiological traits including PL (11.5225 and 15.8628), LL (10.3656 and 10.8454), LW (11.6807 and 12.3559), PdL (10.8469 and 11.4547), RT (19.414 and 19.6855), FT (10.2848 and 10.748), AAF (10.5699 and 11.5069), and SYF (14.5073 and 14.7749). Besides this, remaining traits exhibited lower PCV and GCV.

These results explained the existence of limited variability or low genetic variability in the bottle gourd varieties for the trait. High heritability (>60%) was noticed for all the characters during study except DPPH P, Mg, S, Mn, PL and DMFA). Which indicates that these traits are less influenced by environmental factors and are under the control of additive gene effect and selection for improvement of such characters would be rewarding. GCV along with heritability estimates would provide a better picture of the amount of advance expected by phenotypic selection. High heritability coupled with high genetic gains is more effective and dependable in predicting the improvement through selection. High genetic advance as per cent mean was observed for TP (22.07%), AAF (21.38%), K (67.44%), DFFA (29.85%), NFFP (23.64%), FL (25.74%), FG (49.31%), FW (99.61%), FT (22.68%), NFP (25.29%), NSF (22.62%), FYP (26.93%), FYH (23.88%) and SYP (45.51%) indicating that these traits are controlled by additive gene action.

Further selection for these characters will improve the different traits. Moderate genetic advance as per cent mean was observed for P (14.72%), Ca (14.42%), LPL (10.07%), NFFF (12.13%), SYP (17.69%) and SYH (15.22%). Whereas, low genetic advance as per cent mean was observed for CUPRAC, FRAP, DPPH, Mg, S, Fe, Mn, PL, LL, LW, IL, DMFA, NMFP, PtL, PdL, RT, SW, SKW, AAF and AATL governed by non additive gene action and selection for these traits is not useful. Similar results were reported by (Gürcan et al., 2015; Sirohi et al. 1988; Samadia, 2002; Yadav et al. 2022; Yadav et al. 2023; Yadav et al., 2023).

Table 1. Analysis of Variance (ANOVA) for 28 different physiological traits in bottle gourd genotypes

Sources of Variation	Mean Square		
	Replication (DF=7)	Genotypes (DF=2)	Residuals (DF=14)
Plant length (m)	2.04	3.175**	2.237
Leaf length (cm)	0.074	14.520***	0.169
Leaf width (cm)	0.454	35.808***	0.525
Leaf petiole length(cm)	0.456	194.514***	0.398
Internodal length (cm)	0.03	45.191***	0.08
Node to first female flower	2.47	289.042***	1.327
Days to male flower anthesis	4.571	70.542***	5.589
Days to female flower anthesis	8.85	1702.17***	2.55
Number of female flowers per plant	2.95	1093.04***	4.47
Number of male flowers per plant	34.6	8368***	29.7
Petal length (cm)	0.003	0.395***	0.027
Fruit length (cm)	1.5	509.81***	5.09
Fruit girth (cm)	1.3	4624.8***	4.5
Peduncle length (cm)	0.093	6.361***	0.090
Fruit weight (g)	8490	438652***	3711
Rind thickness (mm)	0.0233	5.073***	0.018
Flesh thickness (mm)	29.08	1071.63***	12.2
Number of fruits per plant	2.74	462.18***	2.5
Number of seed per fruit	14.64	1087.88***	15.02
100 seed weight (g)	0.007	10.257***	0.008
100 seed kernel weight (g)	0.001	0.849***	0.002
Ascorbic acid in fruits (mg/100g)	0.915	35.896***	0.812
Ascorbic acid in tender leaves (mg/100g)	2.64	62.711***	2.25
Fruit yield per plant (kg)	0.681	96.11***	0.661
Fruit yield per hectare (q)	756	106790***	734
Seed yield per fruit (g)	0.586	116.32***	0.539
Seed yield per plant (g)	2369	412087***	2215
Seed yield per hectare (q)	2.63	457.87***	2.46

Significant at *P≤0.05, ** P≤0.01, and *** P≤0.001

Table 2. Maximum, minimum, mean, GCV, PCV, heritability (h^2) and genetic advance of 28 traits

Character	Max	Min	Grand Mean	GCV	PCV	h^2 (%)	Genetic Advance %
PL	5.1	2.9	3.666	11.523	15.863	52.76	0.63

LL	14.8	11	12.920	10.366	10.845	91.35	2.64
LW	20.7	14.8	17.979	11.681	12.356	89.37	4.09
LPL	19.8	9.1	15.012	32.812	33.080	98.39	10.07
IL	10.8	6	8.962	26.495	26.683	98.6	4.86
NFFF	22	6	13.458	44.560	45.375	96.44	12.13
DMFA	53	42	47.833	5.957	7.740	59.23	4.52
DFFA	79	44	60.791	23.977	24.120	98.82	29.85
NFFP	32	5	19.333	60.336	61.319	96.82	23.64
NMFP	163	80	120.208	26.857	27.237	97.23	5.58
PtL	14.4	13.5	13.937	1.539	1.944	62.67	0.35
FL	37.3	19.2	26.231	30.280	31.479	92.53	25.74
FG	77.6	29.79	48.002	50.064	50.259	99.22	49.31
PdL	9.2	6.8	8.162	10.847	11.455	89.67	1.73
FW	2118	583	1118.915	66.151	66.374	99.33	99.61
RT	4.87	3.04	4.094	19.414	19.686	97.26	1.62
FT	126	93.8	111.890	10.285	10.748	91.57	22.68
NFP	21	2.84	11.355	66.752	68.188	95.83	25.29
NSF	146	112	130.25	8.891	9.376	89.93	22.62
SW	21.19	18.71	20.046	5.646	5.664	99.36	2.32
SKW	8.84	8.09	8.431	3.860	3.900	97.96	0.66
AAF	23.1	17.1	19.812	10.570	11.507	84.38	3.96
AATL	35.6	24.7	31.3	8.783	10.005	77.06	4.97
FYP	14.03	5.10	9.175	37.646	38.675	94.75	26.93
FYH	467.66	170.02	305.843	37.646	38.675	94.75	23.88
SYF	30.92	21.35	26.223	14.507	14.775	96.41	17.69
SYP	649.3	74.23	302.005	74.948	76.552	95.86	45.51
SYH	21.65	2.47	10.066	74.948	76.552	95.86	15.22

Conclusions

The physiological traits in bottle gourd showed significant variation among genotypes, with strong positive correlations observed for traits like fruit length and weight, and yield-related traits. Genetic analysis revealed high heritability and genetic advance for traits such as fruit yield and fruit girth, indicating their potential for selection. Overall, traits with high genetic advance, such as fruit yield, are most suitable for selection, while those influenced by non-additive gene action are less responsive to selection. Keeping in view of the above significant findings and wider adaptability of the variety Thar Avani under rainfed semi-arid conditions recommended for commercial cultivation with its important characters viz. earliness in female flowering and round fruit shape.

Acknowledgements

The authors extend their sincere gratitude to the Indian Council of Agricultural Research (ICAR), New Delhi and Director, ICAR-CIAH, Bikaner for generously providing the necessary facilities.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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