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Photosynthetic and Gas-Exchange Traits among Genotypes and F_1 Hybrids in Yardlong Bean [*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt.]

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A B S T R A C T

Photosynthetic rate, stomatal conductance, transpiration rate and chlorophyll content are key physiological determinants for productivity in yardlong bean [*Vigna unguiculata* subsp. *sesquipedalis*]. The present study evaluated 69 yardlong bean genotypes, six selected parents and their 30 F_1 hybrid generated through diallel mating, for these physiological traits along with pod yield, using a portable photosynthesis system and a chlorophyll content meter. Among the 69 genotypes, photosynthetic rate ranged from 18.72 to 28.70 µmol CO_2 m^{-2} s^{-1}, stomatal conductance from 0.25 to 0.66 mol H_2O m^{-2} s^{-1} and transpiration rate from 5.91 to 13.12 mmol H_2O m^{-2} s^{-1}. Arka Mangala, Vyjyanthi, Vellayani Jyothika, Lola, VS 28 and VS 54 recorded the highest photosynthetic rates and were subsequently used as parents. Hybrid evaluation revealed pronounced heterotic vigour, with the cross Arka Mangala × Vellayani Jyothika ($P_1 \times P_3$) recording the highest pod yield (1149.58 g), photosynthetic rate (32.86 µmol CO_2 m^{-2} s^{-1}) and chlorophyll content (56.92), substantially exceeding the mean of parents and the standard check (Iris superlong-77). Most hybrids exceeded the parental mean for all four physiological traits, indicating that hybridization between physiologically superior parents enhances gas-exchange efficiency and pod yield. The results confirm that photosynthetic rate, stomatal conductance and transpiration rate are reliable physiological selection criteria for identifying high-yielding, heterotic combinations in yardlong bean breeding programmes.

Introduction

Yardlong bean [*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdc.], a warm-season legume vegetable of considerable economic and nutritional importance in tropical and sub-tropical regions, is valued for its long, tender pods, short duration and adaptability to diverse agro-climatic conditions. Improvement of yield potential in this crop depends not only on morphological and yield-component traits but also on the underlying physiological efficiency of the plant, particularly its capacity for carbon assimilation and water-use regulation. Photosynthetic rate, stomatal conductance and transpiration rate together govern the gas-exchange behaviour of the leaf and determine the quantity of assimilates available for partitioning into reproductive sinks, while chlorophyll content reflects the photosynthetic pigment status and, indirectly, nitrogen and light-harvesting efficiency of the canopy. Genotypic variation in these physiological attributes provides valuable criteria for parental selection in heterosis breeding, since combining physiologically superior parents can be expected to yield hybrids with enhanced source capacity and, consequently, higher pod yield.

Despite their importance, physiological traits have received comparatively little attention in yardlong bean improvement programmes relative to morphological and yield traits. The present investigation was therefore undertaken to assess the extent of genetic variability for photosynthetic rate, stomatal conductance, transpiration rate and chlorophyll content among a diverse germplasm collection, to identify physiologically superior parents, and to evaluate the resultant F_1 hybrids for these traits with a view to identifying superior heterotic combinations for yield improvement in yardlong bean.

Materials and Methods

Experimental site

The study was conducted at the College Farm, Department of Horticulture, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, between July 2024 and June 2026. The experimental site is situated between 10°49′ and 11°01′ N latitude and 78°43′ and 79°52′ E longitude, at an altitude of 4 m above mean sea level, in a tropical climate with hot summers. The soil was sandy loam of medium fertility, and irrigation was supplied from a rain-water harvesting pond within the farm.

Plant material and breeding programme

69 yardlong bean genotypes, assembled from diverse geographic and genetic sources, were evaluated for *per se* performance. Based on this evaluation, six genotypes Arka Mangala (P_1), Vyjayanthi (P_2), Vellayani Jyothika (P_3), Lola (P_4), VS 28 (P_5) and VS 54 (P_6) were selected as parents and inter-mated in a diallel mating design to generate 30 F_1 hybrids. The hybrids, along with the six parents and a standard check (Iris Super Long-77, BigHaat, Bangalore), were evaluated in a Randomized Block Design with two replications during January–April 2026.

Physiological trait measurement

Photosynthetic rate (μmol CO_2 m^{-2} s^{-1}), stomatal conductance (mol H_2O m^{-2} s^{-1}) and transpiration rate (mmol H_2O m^{-2} s^{-1}) were recorded simultaneously from fully expanded, healthy leaves using a portable photosynthesis system between 09:00 and 11:30 hr to minimise diurnal fluctuation, following Lawson and Blatt (2014). Leaves were enclosed in the chamber without injury or shading, and readings were taken after gas-exchange equilibrium was attained under ambient conditions. Chlorophyll content was measured using a CCM-200 Plus chlorophyll content meter (Opti-Sciences, USA) from three positions on the leaf lamina, avoiding the midrib and major veins, during morning hours under uniform conditions.

Statistical analysis

Data were analysed using standard analysis of variance appropriate to a Randomized Block Design; treatment means were compared using critical difference (CD) values at 5% and 1% probability levels, and coefficient of variation (CV%) was computed for each trait.

Results and Discussion

Variability among 69 germplasm genotypes

Considerable genotypic variation was observed for all physiological traits studied (Table 1). Photosynthetic rate ranged from 18.72 μmol CO_2 m^{-2} s^{-1} (IC 622598) to 28.70 μmol CO_2 m^{-2} s^{-1} (Arka Mangala), with VS 28 (28.40) and Vellayani Jyothika (28.05) also recording high values. Stomatal conductance was highest in Lola (0.66 mol H_2O m^{-2} s^{-1}) and lowest in IC 622601 (0.25), while transpiration rate ranged from 5.91 (VS 53) to 13.12 mmol H_2O m^{-2} s^{-1} (VS 28). Pod yield plant^{-1} showed the widest relative spread, from 306.77 g (IC 622599) to 994.44 g (VS 54). These genotypes with consistently superior photosynthetic performance Arka Mangala, Vyjayanthi, Vellayani Jyothika, Lola, VS 28 and VS 54 were accordingly selected as parents for hybridization.

Physiological performance of parents

Among the six selected parents (Table 2), P_1 (Arka Mangala) recorded the highest pod yield (756.84 g) and photosynthetic rate (28.70 µmol CO_2 m^{-2} s^{-1}), exceeding the parental mean (710.72 g and 28.10, respectively). P_4 (Lola) recorded the highest stomatal conductance (0.66), and P_5 (VS 28) recorded the highest transpiration rate (13.12) and chlorophyll content (50.38). This spread of physiological performance among parents provided a favourable base for exploiting heterosis in the resultant hybrid combinations.

Performance of F_1 hybrids

Pod yield of hybrids ranged from 901.60 g ($P_4 \times P_3$) to 1149.58 g ($P_1 \times P_3$), with a hybrid mean of 979.67 g well above the parental mean (710.72 g), confirming strong heterotic gain (Table 3). The cross $P_1 \times P_3$ (Arka Mangala × Vellayani Jyothika) was consistently the best performer, recording the maximum photosynthetic rate (32.86 µmol CO_2 m^{-2} s^{-1}), the highest chlorophyll content (56.92) and the highest pod yield among all hybrids, exceeding even the standard check (1025.19 g).

The hybrid $P_1 \times P_6$ recorded the maximum stomatal conductance (0.79), and $P_5 \times P_3$ recorded the highest transpiration rate (15.04). Most hybrids exceeded the hybrid mean for photosynthetic rate, stomatal conductance, transpiration rate and chlorophyll content, indicating that combining physiologically elite parents through hybridization generally enhances gas-exchange efficiency in the F_1 generation.

Photosynthetic rate is a key physiological parameter determining the capacity of genotypes to fix atmospheric carbon dioxide and convert it into organic matter, ultimately governing crop productivity. Genotypes with higher photosynthetic rates are able to accumulate more assimilates for partitioning into reproductive organs, contributing directly to pod yield, consistent with the reviews of Suriya and Selvaraj (2026) and Nadeem *et al.,* (2019) on gas-exchange efficiency as a determinant of productivity in Vigna species under normal and stress conditions.

Stomatal conductance reflects the regulatory capacity of the leaf epidermis and is closely linked to CO_2 uptake and water-use efficiency. Higher stomatal conductance facilitates greater CO_2 influx for photosynthesis but simultaneously increases transpirational water loss, indicating a trade-off between carbon gain and water conservation, as also reported by Manasa *et al.,* (2017) in salinity-screened Vigna genotypes.

Transpiration rate reflects the water-use status of the plant and its capacity for evaporative cooling and turgor maintenance. Genotypes combining high photosynthetic rate with moderate transpiration rate possess superior intrinsic water-use efficiency and are best suited to cultivation under limited moisture availability, in agreement with Iseki *et al.,* (2016).

Evaluation of hybrid performance based on per se performance showed that the cross $P_1 \times P_3$ was the outstanding combination across pod yield, photosynthetic rate and chlorophyll content, findings that align with the yield superiority reported in yardlong bean hybrids by Ratnakumari *et al.,* (2023), Sherly *et al.,* (2025) and Abhimanyu *et al.,* (2025), and with the physiological vigour patterns reported by Lakitan *et al.,* (2025) and Choi *et al.,* (2024). The enhanced chlorophyll content of most hybrids over the parental mean further indicates improved photosynthetic potential arising from hybridization, supporting the use of physiological traits as effective indirect selection criteria in yardlong bean heterosis breeding.

In conclusion, Substantial genetic variability exists for photosynthetic rate, stomatal conductance, transpiration rate and chlorophyll content among yardlong bean genotypes, providing effective criteria for parental selection in heterosis breeding. The cross Arka Mangala × Vellayani Jyothika ($P_1 \times P_3$) emerged as the most promising hybrid, combining superior physiological efficiency with the highest pod yield, and merits further evaluation for commercial exploitation and use in recombination breeding programmes aimed at developing high-yielding, physiologically efficient yardlong bean cultivars.

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Table.1 Variability for physiological traits and pod yield among 69 yardlong bean genotypes

Statistics	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})	Stomatal conductance (mol H_2O m^{-2} s^{-1})	Transpiration rate (mmol H_2O m^{-2} s^{-1})	Pod yield $plant^{-1}$ (g)
Mean	21.61	0.381	8.54	471.63
Range	18.72 – 28.70	0.25 – 0.66	5.91 – 13.12	306.77 – 994.44
Highest genotype	Arka Mangala (28.70)	Lola (0.66)	VS 28 (13.12)	VS 54 (994.44)
Lowest genotype	IC 622598 (18.72)	IC 622601 (0.25)	VS 53 (5.91)	IC 622599 (306.77)
CD (0.05)	0.528	0.023	0.449	9.553
CV (%)	10.36	16.12	12.28	1.03

Table.2 Mean performance of parents for pod yield and physiological traits

Parent	Pod yield $plant^{-1}$ (g)	Photosynthetic rate	Stomatal conductance	Transpiration rate	Chlorophyll content
P_1 – Arka Mangala	756.84	28.70	0.65	12.56	49.82
P_2 – Vyjayanthi	683.76	27.96	0.61	11.89	48.67
P_3 – Vellayani Jyothika	700.94	28.05	0.63	13.07	50.14
P_4 – Lola	664.79	27.31	0.66	10.99	47.85
P_5 – VS 28	731.17	28.40	0.63	13.12	50.38
P_6 – VS 54	726.80	27.20	0.64	11.69	48.29
Mean of parents	**710.72**	**28.10**	**0.64**	**12.22**	**49.19**

Table.3 Performance of superior F_1 hybrids for pod yield and physiological traits

Hybrid	Pod yield $plant^{-1}$ (g)	Photosynthetic rate	Stomatal conductance	Transpiration rate	Chlorophyll content
$P_1 \times P_3$	**1149.58****	**32.86****	**0.74****	**14.86****	**56.92****
$P_1 \times P_6$	1092.24**	31.25**	0.79**	14.55**	55.84**
$P_3 \times P_1$	1090.62**	31.42**	0.73**	14.52**	55.71**
$P_6 \times P_1$	1061.66**	31.03**	0.73**	14.37**	55.28**
$P_5 \times P_3$	1041.60**	31.95**	0.76**	15.04**	56.81**
Check hybrid (Iris Super Long-77)	1025.19	27.46	0.61	13.14	52.96
Mean of hybrids	**979.67**	**29.83**	**0.70**	**13.62**	**53.67**
Range of hybrids	901.60 – 1149.58	28.41 – 32.86	0.67 – 0.79	12.54 – 15.04	51.24 – 56.92
CD (0.05)	62.36	0.66	0.023	0.48	0.84
CV (%)	3.52	4.52	3.91	4.34	3.84

Table.4 Mean performance of yardlong bean parents and hybrids for physiological traits

S. No.	Parents and Hybrids	Pod yield plant^{-1} (g)	Photosynthetic rate (μmol CO_2 m^{-2} s^{-1})	Stomatal conductance (mol H_2O m^{-2} s^{-1})	Transpiration (mmol H_2O m^{-2} s^{-1})	Chlorophyll
1	P_1	756.84	28.70*	0.65*	12.56*	49.82
2	P_2	683.76	27.96	0.61	11.89	48.67
3	P_3	700.94	28.05*	0.63*	13.07*	50.14*
4	P_4	664.79	27.31	0.66*	10.99	47.85
5	P_5	731.17	28.40*	0.63*	13.12*	50.38*
6	P_6	726.80	27.20	0.64*	11.69	48.29
7	$P_1 \times P_2$	945.25	29.12*	0.68*	13.28*	52.34*
8	$P_1 \times P_3$	**1149.58** **	**32.86** **	0.74 **	14.86 **	**56.92** **
9	$P_1 \times P_4$	912.11	29.03*	0.69*	12.88*	51.24
10	$P_1 \times P_5$	961.45	30.08**	0.71**	14.22**	54.13**
11	$P_1 \times P_6$	1092.24 **	31.25 **	**0.79** **	14.55 **	55.84 **
12	$P_2 \times P_1$	930.23	28.95*	0.67*	13.11*	52.06*
13	$P_2 \times P_3$	940.68	29.41*	0.69*	13.58*	53.24*
14	$P_2 \times P_4$	997.50*	28.76	0.68*	12.65	51.42
15	$P_2 \times P_5$	971.85	29.88**	0.70*	13.96**	54.08**
16	$P_2 \times P_6$	972.90*	28.92*	0.68*	12.91*	52.11*
17	$P_3 \times P_1$	1090.62**	31.42**	0.73**	14.52**	55.71**
18	$P_3 \times P_2$	938.00	29.66*	0.69*	13.66*	53.46*
19	$P_3 \times P_4$	913.36	28.85	0.68*	12.91	51.96
20	$P_3 \times P_5$	946.00	31.44**	0.75**	14.92**	56.04**
21	$P_3 \times P_6$	962.88*	29.84*	0.70*	13.42*	53.81*
22	$P_4 \times P_1$	918.72	29.18*	0.70*	12.95*	52.52*
23	$P_4 \times P_2$	986.48*	28.52	0.67*	12.54	51.94*
24	$P_4 \times P_3$	901.60	29.11*	0.69*	13.04*	52.63*
25	$P_4 \times P_5$	972.90*	29.85**	0.71**	13.85**	54.01**
26	$P_4 \times P_6$	919.38	28.41	0.68*	12.61	51.38
27	$P_5 \times P_1$	961.45	30.11**	0.71**	14.19**	54.36**
28	$P_5 \times P_2$	978.12	29.75*	0.69*	13.82*	53.89*
29	$P_5 \times P_3$	1041.60 **	31.95 **	0.76 **	**15.04** **	56.81 **
30	$P_5 \times P_4$	974.97*	29.38*	0.70*	13.29*	53.16*
31	$P_5 \times P_6$	960.48	30.22**	0.72**	14.01**	54.48**
32	$P_6 \times P_1$	1061.66**	31.03**	0.73**	14.37**	55.28**
33	$P_6 \times P_2$	961.45*	28.91*	0.68*	12.85*	52.07*
34	$P_6 \times P_3$	953.44*	30.14**	0.71**	13.74**	54.16**
35	$P_6 \times P_4$	912.78	28.88	0.69*	12.68	51.74
36	$P_6 \times P_5$	957.90	30.17**	0.72**	13.96**	54.27**
37	Check hybrid	1025.19	27.46	0.61	13.14	52.96
	SED	31.18	0.32	0.011	0.24	0.41
	CD(0.05)	62.36	0.66	0.023	0.48	0.84
	CD(0.01)	82.94	0.87	0.031	0.63	1.11
	CV(%)	3.52	4.52	3.91	4.34	3.84
	Mean of parents	710.72	28.10	0.64	12.22	49.19
	Range of parents	664.79 – 756.84	27.20–28.70	0.61–0.66	10.99–13.12	47.85–50.38
	Mean of hybrids	979.67	29.83	0.70	13.62	53.67
	Range of hybrids	901.60 – 1149.58	28.41–32.86	0.67–0.79	12.54–15.04	51.24–56.92

Author Contributions

B. Bavithra: Investigation, formal analysis, writing—original draft. V. Kanthaswamy: Validation, methodology, writing—reviewing. M. S. Marichamy:—Formal analysis, writing—review and editing. V. Krishnan: Investigation, writing—reviewing. S. Nadaradjan: Resources, investigation writing—reviewing. U. Bagavathi Ammal: Validation, formal analysis, writing—reviewing. N. Bavya: Conceptualization, methodology, data curation, supervision, writing—reviewing the final version of the manuscript. S. Priyanga: Investigation, formal analysis, writing—original draft.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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