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RESEARCH ARTICLE

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Assessment of Transgressive Segregants for Yield and its Component Traits in French Bean (*Phaseolus vulgaris* L.)

K. Pramanik[1,3], M. Kumari[2], G.S. Sahu[3], G.C. Acharya[4], P. Tripathy[3], M. Dash[5], C. Jena[1]

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ABSTRACT

Background: Extreme phenotypes carried on by transgressive segregation are, moreover, heritably stable in contrast to heterosis. It has been hypothesized that the development of extreme or "transgressive" traits in segregating hybrid populations assists in the adaptive divergence of hybrid taxa. The investigation on French bean was experimented to evaluate transgressive segregants generated in the F_2 generation for yield and related traits.

Methods: The present study on French bean was conducted during *rabi* 2019 to 2022 to elicit data on transgressive segregants produced for yield and related traits in F_2 generation. Fertile F_1 hybrids were developed from three crosses: IC 632961 × Arka Sukomal, IC 632961 × Arka Arjun and Arka Arjun × IC 63296. Heterosis was estimated for yield and related traits in these hybrids. The F_2 progeny were evaluated in open field condition. Mean, standard deviation and percentage of transgressive segregants were estimated for quantitative traits under investigation.

Result: Transgressive segregants were observed in all three crosses, with the highest number of transgressive segregants for yield traits found in the progeny of the cross IC 632961 × Arka Sukomal. The identification and isolation of such transgressive segregants indicate that the parents possess favourable alleles and genes governing the traits of interest, which can be consolidated into a single or a few genotypes through stringent selection. Superior and desirable transgressive segregants were observed for all sixteen yield and its component traits, except for leaf length, in the two cross combinations Arka Arjun × IC 632961 and IC 632961 × Arka Arjun. The highest percentage of transgressive segregation was observed for the number of inflorescences per plant (79.49%), followed by the number of pods per plant (78.46%) and pod yield per plant (75.61%) in the F_2 generation.

Key words: Complementary gene action, Extreme phenotypes, F_2, Heterosis.

Abbreviation: BPH: Better parent heterosis; CHES, ICAR-IIHR: Central Horticultural Experiment Station, Indian Council of Agriculture and Research-Indian Institute of Horticultural Research; F_2: Second filial generation; N: North; PCA: Principal component analysis; S: South; SH: Standard heterosis; TGS: Transgressive segregants.

INTRODUCTION

French bean (*Phaseolus vulgaris* L.) is a nutrient-dense legume vegetable containing 4.5% fat, 1.8% fibre, 1.7% protein, 0.1% carbohydrates and 0.5% mineral content (Thamburaj and Narendra Singh, 2016).

Since French bean is self-pollinated, its genetic diversity is limited. Therefore, hybridization and subsequent recombination are necessary to obtain segregating materials for population selection. This process leads to the development of new varieties with higher yields and better environmental adaptation. Genetic variability plays a crucial role in the selection process (Tiwari and Lavanya, 2012) and hybridization in domesticated plants enables the utilization of intermittent hybrid vigor, the exchange of desirable variations among lineages and the production of novel phenotypes (Goulet *et al*., 2017). High heritable variation in polygenic traits facilitates the effective selection (Mallu *et al*., 2014). However, lack of genetic variability can constraint effective crop improvement programme and transgressive segregation is a useful approach for improving yield and its contributing traits. Progeny phenotypes that deviate from parental expectations are referred to as transgressive segregates (Koide *et al*., 2019); these phenotypes can result from new genetic combinations that

[1]M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi-761 211, Odisha, India.
[2]ICAR-Research Complex for Eastern Region, RS, Patna-800 014, Bihar, India.
[3]Department of Vegetable Science, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar-751 003, Odisha, India.
[4]Central Horticulture Experiment Station, ICAR-Indian Institutes of Horticultural Research, Bhubaneswar-751 019, Odisha, India.
[5]Department of Genetics and Plant Breeding, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar-751 003, Odisha, India.

Corresponding Author: K. Pramanik, M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi-761 211, Odisha, India.
Email: kartik.pramanik@cutm.ac.in

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outperform parental types and are extremely helpful. Transgressive segregants are observed within the progenies of early segregating generations (Jayalakshmi, 2000). Due to the accumulation of favourable genes from both parents through genetic recombination, the performances of transgressive segregants fall outside the range of their parents. Complementary gene action is considered the primary cause for transgression in quantitative characters, although overdominance and epistasis also contribute to transgression (Rieseberg *et al*., 1999). It may involve either positive or negative complementation (Reyes *et al*., 2019). Heterosis can be established through the accumulation of dominant alleles (Shreya *et al*., 2017). Transgressive segregants can result from crossbreeding between parents with similar values but different genes regulating a trait. This allows for the creation of new gene combinations in the F_2 generation, which is beneficial for improving self-pollinating crops like French beans. Consequently, this presents an opportunity for selecting superior plants that can become new cultivars. Transgressive segregants hold promise in achieving genetic gains in cultivated plants and may enhance resistance against major biotic and abiotic stresses. Earlier studies have shown evidence of transgressive segregation reported in crosses such as California Dark Red Kidney × Yolano crosses (Johnson *et al*., 1996), groundnut (Jayalakshmi, 2000; Sirisha 2005), cowpea (Adeyanju *et al*., 2007; Kurer *et al*., 2007), urdbean (Rana, 2013; Gandi *et al*., 2018), blackgram (Chauhan *et al*., 2018). This occurs because genetic recombination takes place between linked and unlinked alleles (Briggs and Allard, 1953).

MATERIALS AND METHODS

The experiment was conducted at CHES, ICAR-IIHR, Bhubaneswar, Odisha (20.015°N latitude, 85.053°E longitude and 25.5 m AMSL) during the *rabi* seasons of 2019 to 2022. Three parents were selected based on their diverse characteristics: Arka Arjun, a bush-type French bean; Arka Sukomal, a pole-type French bean; and IC 632961, a pole-type local collection from Raikia, Phulbani. The crosses were made and evaluated with randomized block design with three replications. The F_1 seeds were collected and advanced to the F_2 generation, which was screened to isolate transgressive segregants. A total of 39 F_2 progenies (IC 632961 × Arka Sukomal), 41 F_2 progenies (Arka Arjun × IC 63296) and 65 F_2 progenies (IC 632961 × Arka Arjun) were spaced planted for evaluation. Randomly five plants were selected for each parent, while individual plants were considered in the F_1 and F_2 generations for recording quantitative traits. Statistical analysis was performed according to (Panse and Sukhatme, 1967). Following the methodology recommended by Falconer and Mackay (1996), heterosis measures such as better parent heterosis (BPH) and economic heterosis (SH) in percentage, were calculated for the characters that exhibited significant differences among genotypes (including crosses and parents). These heterosis measures have important implications for commercial breeding, particularly in self-pollinated crops. The PCA, eiganvalues and correlation values were estimated using Grapes software, version1.0.0 (Gopinath *et al*., 2020).

Estimation of segregating parameters

Transgressive segregants (TGS) were identified in the F_2 population based on plants that scored higher than the better parent and lower than the lower parent, respectively. The parent with a higher trait mean was considered the better parent except traits like plant height and days to 50% flowering, the parent with a lower trait mean was regarded as the better parent.

RESULTS AND DISCUSSION

Statistically significant difference among the parents and crosses were observed for yield and its component traits. Mean performance of the parents showed that IC 632961 performed better in term of pod length, average pod weight, pod dry weight, 100 seed weight and seed yield but it was late in days to 50% flowering and days to harvest. In contrary, variety; Arka Arjun found as busy, earliest in 50% flowering having long pod and overall performed well. Analysis of heterosis revealed significant heterosis in all three crosses for better parent and standard parent (Table 1). Transgressive segregation illustrates the emergence of individuals in the offspring of a hybrid that outperform either of the parents in terms of one or more characteristics. The segregants emerged with different frequency and may perform positively or negatively depends on traits of interest due to the complementation of additive alleles, epistatic interactions of unique parental attributes, unmasking of recessive alleles from a heterozygous parent, or any combination of these mechanisms. Therefore, the frequency of transgressive segregants was estimated for all the three crosses and is presented in Table 2.

Plant height

The data indicated that the maximum heterobeltiosis (16.62%) and standard heterosis (23.48%) for plant height were observed in cross IC 632961 × Arka Sukomal, while the minimum per cent (8.94% and 15.35% respectively) were observed in cross Arka Arjun × IC 632961 (Table 1). TGS were determined based on values exceeding those of the lower parent, which was considered as the better parent (Arka Arjun). A high frequency of transgressive segregants (21.95%) was observed in the F_2 plants derived from the cross IC 632961 × Arka Arjun (Table 2). It is observed that transgressive segregations are frequently noticed in crossing of diverse crosses *i.e*., IC 632961 and Arka Arjun French bean leads to increase in plant height. Genesists explained it as accumulation of genes from both parents and subsequent recombination in segregating generations.

Leaf length and leaf width

The maximum better parent heterosis (32.9%, 28.06%) and economic heterosis (51.7%, 88.54%) were observed

Table 1: Estimated heterobeltiosis (%) and standard heterosis (%) in F_1 crosses.

Traits	Mean	SEm (±)	CD (P=0.5)	MSS	C1		C2		C3	
					H (%)	SH (%)	H (%)	SH (%)	H (%)	SH (%)
PH	278.08	7.09	24.57	23183.96**	16.62**	23.48**	8.94*	15.35**	10.06*	16.54**
LL	12.09	0.42	1.46	7.56**	14.88 *	31.12 **	23.05 **	40.45 **	32.90 **	51.70 **
LW	10.13	0.18	0.61	9.94**	11.06 **	63.50 **	24.49 **	83.28 **	28.06 **	88.54 **
LA	177.73	5.43	18.83	4161.71**	13.50*	43.63**	25.97**	59.41**	38.22**	74.92**
DF	46	1.95	6.77	133.50**	-13.51*	12.94ns	29.41*	3.53ns	20.59*	-3.53ns
NIP	18.5	0.9	3.14	17.50**	32.35 **	28.57 **	14.71 ns	11.43 ns	29.41 **	25.71 *
PL	18.44	0.92	3.20	8.08**	7.41ns	29.93*	-2.82ns	17.56ns	10.39ns	33.53**
PW	8.36	0.33	1.16	3.71**	9.35 ns	1.35 ns	-6.45 ns	-13.29 *	15.91 *	7.43 ns
NPP	22.42	1.07	3.72	42.40**	33.33**	26.32*	25.00*	44.74**	31.82**	52.63**
APW	12.29	0.51	1.79	12.25**	5.29ns	17.91*	17.41*	31.48**	29.44**	44.96**
PYP	276.64	17.10	59.24	14951.95**	37.71*	32.59*	55.27**	56.62**	78.09**	79.61**
APDW	2.9	0.08	0.28	0.67**	-3.51 ns	16.83 **	5.75 ns	28.05 **	20.93 **	46.42 **
PDWP	54.99	1.88	6.52	1113.91**	-45.31 **	-7.90 ns	-44.44 **	-6.44 ns	20.80 **	103.42 **
NSP	9.03	0.3	1.04	5.41**	-20.96 **	-3.60 ns	-33.29 **	-18.64 **	8.26 ns	32.04 **
HSW	28.38	1.08	3.75	41.51**	-37.52 **	-22.26 *	-1.56 ns	22.48 **	4.07 ns	29.49 **
SYP	63.35	0.33	1.15	0.76**	-24.01 **	189.97 **	-39.27 **	131.75 **	33.82 **	410.64 **

C1: IC 632961 × Arka Sukomal, C2: Arka Arjun × IC 632961, C3: IC 632961 × Arka Arjun, H: Heterobeltiosis, SH: Standard heterosis, PH: Plant height (cm), LL: Leaf length (cm), LW: Leaf width (cm), LA: Leaf area (cm^2), DF: Days to 50% flowering, NIP: Number of inflorescences $plant^{-1}$, PL: Pod length (cm), PW: Pod width (mm), NPP: Number of pods $plant^{-1}$, APW: Average Pod weight (g), PYP: Pod yield per plant, APDW: Average Pod dry weight (g), PDYP: Pod dry yield per plant (g), NSP: Number of seeds pod^{-1}, HSW: Hundred seeds weight (g), SYP: Seed yield $plant^{-1}$.

Table 2: Percentage of TGS estimated over better parents from three crosses in F_2.

Traits	F_2 plants of C1			Parents		TGS			F_2 plants of C2			Parents		TGS			F_2 plants of C1			Parents		TGS		
	Mean	V_{max}	V_{min}	P1	P2	>P1	>P2	% TGS	Mean	V_{max}	V_{min}	P1	P2	>P1	>P2	% TGS	207.67	425.31	35.00	330	52	5	9	21.95
PH	307.90	420.11	165.02	330.13	242.23	19	4	10.26	243.37	455.14	45.50	330.11	52	16	3	4.62	12.09	14.78	5.86	10.46	14.85	0	6	0.00
LL	10.23	13.36	6.34	10.46	10.37	19	20	48.72	11.08	14.40	7.82	10.46	14.85	0	22	0.00	9.99	13.12	4.40	9.59	11.07	11	16	26.83
LW	8.60	12.54	5.68	9.59	8.94	16	19	41.03	9.27	13.54	7.00	9.59	11.07	9	36	13.85	177.98	280.36	71.10	323.24	149.14	9	10	21.95
LA	182.59	287.67	68.29	223.24	166.38	17	13	43.59	175.46	309.69	66.05	213.24	149.14	14	22	21.54	49.63	62.00	36.00	51.00	39.00	14	5	12.20
DF	53.19	65	41	51	49	25	6	15.38	50.52	70.00	40.00	51.00	39.00	22	2	3.08	22.00	47.00	5.00	18.80	16.70	24	17	58.54
NIP	28.81	47.00	10.00	18.80	16.70	31	7	79.49	28.00	55.00	7.00	18.80	16.70	45	12	69.23	76.74	96.00	61.00	77.00	55.00	16	0	0.00
PL	20.59	24.00	15.10	18.78	19.28	28	9	71.79	18.12	20.98	15.50	18.78	17.83	22	35	33.85	20.05	23.92	15.48	19.78	15.83	21	2	51.22
PW	7.64	10.54	3.71	9.77	9.75	6	34	15.38	7.14	9.68	4.53	8.77	7.44	8	38	12.31	8.47	13.15	3.20	9.77	7.44	12	17	29.27
NPP	33.14	61.00	6.00	22.60	20.80	30	8	76.92	45.65	86.00	11.00	22.60	23.20	51	13	78.46	35.09	87.00	6.00	22.60	23.20	28	13	68.29
APW	10.50	17.26	4.12	11.21	10.20	12	25	30.77	7.22	12.59	3.63	11.21	8.02	3	10	4.62	10.14	17.99	3.26	11.21	8.02	15	9	36.59
PYP	353.36	802.46	38.07	240.83	171.57	28	5	71.79	336.16	868.37	83.49	240.83	202.48	43	12	66.15	374.61	917.49	19.53	240.83	202.48	24	12	58.54
APDW	3.32	5.15	0.71	3.63	2.05	17	0	43.59	2.62	4.65	0.35	3.63	2.13	6	9	9.23	3.42	5.66	1.92	3.63	2.13	15	4	36.59
PDWP	116.64	314.21	16.41	81.97	42.54	23	7	58.97	123.52	339.27	26.96	81.97	49.42	45	13	69.23	120.30	307.22	13.91	81.97	49.42	16	3	39.02
NSP	9.47	13.00	5.00	10.20	9.80	8	25	20.51	8.19	10.80	4.80	10.20	7.30	4	11	6.15	9.34	12.80	6.80	10.10	7.60	17	9	41.46
HSW	31.85	43.64	16.24	33.83	29.12	17	9	43.59	30.56	40.86	21.82	32.83	30.85	19	28	29.23	35.64	54.60	23.44	33.83	35.85	16	23	39.02
SYP	105.64	330.36	14.85	84.87	48.46	22	4	56.41	119.91	320.09	24.49	84.87	63.12	42	12	64.62								

C1: IC 632961 × Arka Sukomal, C2: Arka Arjun × IC 632961, C3: IC 632961 × Arka Arjun, V_{max}: Maximum plant value, V_{min}: Minimum plant value, P1 (parent 1): IC 632961, P2 (parent 2): Arka Sukomal, TGS: Transgressive segregants.

in cross IC 632961 × Arka Arjun while the minimum percentages were estimated in cross IC 632961 × Arka Sukomal (Table 1). Regarding the TGS, the maximum frequency (48.72% and 41.03%) for leaf length and width respectively was reported in the F_2 plants of cross IC 632961 × Arka Sukomal as presented in Table 2. The IC 632961 is a primitive cultivar grown in Kandhamal district of Odisha projected higher transgressive segregants when crossed with Arka Sukomal which insisted earlier findings that crosses involve domestic lines commonly witnessed transgressive segregation (Rieseberg *et al*., 1999).

Leaf area

Significantly, the maximum heterobeltiosis (38.22%) and the standard heterosis (74.92%) were estimated for the leaf area in cross IC 632961 × Arka Arjun whereas, the minimum value was observed in IC 632961 × Arka Sukomal. In contrast, the highest TGS (43.59%) were observed in IC 632961 × Arka Sukomal (Table 2) as both the parents having bigger leaf size where the overdominance or non-additivity of allelic interaction within a locus may be contributed.

Days to 50% flowering

For earliness negative heterosis is desirable to obtain segregants that flower earlier compared to parent. The cross IC 632961 × Arka Sukomal showed a significantly minimum heterosisbeltiosis (-13.51%) than other cross combination. For TGS estimation, the value of the lower parent value was considered and the maximum frequency TGS (15.38%) was observed in cross IC 632961 × Arka Sukomal followed by 12.2% and 3.08% in cross IC 632961 × Arka Arjun and Arka Arjun × IC 632961 respectively in F_2 generation which may be due to non-additivity allelic interaction between loci or epistasis. Reports confirmed that transgressive segregation shown elevating potential premating barriers like flowering time in pigeon pea (Srivastava and Saxena, 2019). The results were in conformity with Aditya *et al*. (2013) in soybean crosses and Kshirsagar *et al.* (2013) in tomato who reported transgressive segregation for days to first flowering in F_3 generation.

Number of inflorescences

Significantly higher percentages of heterosis for inflorescences (32.35% and 28.57%) were found in the better parent and standard parent, respectively, in cross IC 632961 × Arka Sukomal, whereas in the cross Arka Arjun × IC 632961, the difference was non-significant. Regarding transgressive segregants, the F_2 plants exhibited a higher percentage of transgressive segregants in reciprocal cross combination *i.e*., IC 632961 × Arka Arjun (79.49%) and Arka Arjun × IC 632961 (69.23%) explained cross between two diverse parents *i.e*., IC 632961 (pole type) and Arka Arjun (bush type) with additive and additive × additive epistatic allelic interactions along with dominance effects lead to increase in inflorescence counts in segregating generations.

Pod length and pod width

Due to the low heritability observed for pod length and pod width in French bean, the heterosis was found to be non-significant for all crosses. However, significant standard heterosis (29.32% and 33.53%) was observed (Table 1). The cross IC 632962 × Arka Arjun showed moderate heterosis in comparison to the better parent. The data on TGS on pod length depicted that the cross combination; IC 632961 × Arka Sukomal observed with maximum number of TGS (71.79%) may be due to involvement of overdominance effects as both the parents expressed longer pods phenotypically which was not observed in cross; Arka Arjun X IC 632961 (TGS = 0) (Table 2). As far pod width is concerned less percentage of TGS were observed in all crosses due to low heritability.

Number of pods

Significantly, higher positive heterobeltiosis (33.33%) was estimated in cross IC 632961 × Arka Sukomal and standard heterosis (52.63%) was observed in cross IC 632962 × Arka Arjun resulting in the maximum emergence of TGS (78.46%) for number of pods plant^{-1} followed by IC 632961 × Arka Sukomal (76.92%). The results explained the evaluation of TGS is due to accumulation of favourable genes and complementary action of additive alleles that are dispersed between the parental lines (Reddy and Singh, 1989). Shirkole (2006) and Kshirsagar *et al.* (2013) worked on tomato interparietal crossing reported higher transgressive segregation for pod number in F_3 generation.

Pod weight and pod yield

The cross IC 632962 × Arka Arjun exhibited maximum heterobeltiosis (29.44% and 78.09%) and standard heterosis (44.96% and 79.61%) for average pod weight and yield per plant, respectively. Additionally, the same cross combination showed the highest percentage of TGS (68.29% and 75.61% respectively) due to the presence of high heterosis, involvement of complementary genes action and additive gene action and fixing of those genes in homozygous state as *prima facie* evidence of emergence of transgressive segregants in such polygenic quantitative traits. The findings were in accordance with Radkov (1980) who inferred that accumulation of plus genes during F_2 and F_3 generations in French bean leads to evaluation of higher transgressive segregants for pod yield per plant. Results are also inconformity with Kshirsagar *et al*. (2013) reported transgressive segregation for average fruit weight and yield per plant in F_3 generation of two inter varietal crosses in tomato.

Pod dry weight

In terms of fresh pod weight, the cross IC 632962 × Arka Arjun exhibited maximum positive heterosis in the better parents (20.93% and 46.42%) and the standard parent (20.80% and 103.42%) for average pod dry weight and pod dry weight per plant, respectively. This cross combination also showed a high frequency of TGS (58.54% and 60.98% respectively) due to high heterosis and fixing of dominance x dominance and additive x additive interactions in F_2.

Number of seeds per pod

The data revealed negative or non-significant heterosis in the F_1 generation for the three crosses, indicating non-additive genetic effects for the number of seeds per pod. However, the cross IC 632962 × Arka Arjun exhibited the highest positive standard heterosis (32.04%) and the maximum frequency of TGS (39.02%) which attributed to accumulation of favourable genes or nonadditive gene actions or epistasis.

Seed index

The trait examined in the study showed negative or non-significant heterobeltiosis for seed index *i.e.*, hundred seed weight in all cross combination whereas, the cross-combination Arka Arjun × IC 632961 and IC 632962 × Arka Arjun exhibited positive heterosis (22.48% and 29.49% respectively) for the standard parent (Table 1). However, for TGS estimation, maximum frequency (43.59%) was reported in the cross IC 632961 × Arka Sukomal (Table 2). This indicated the recombination of genes from both the parents with positive effects resulted emergence of transgressive segregants in groundnut (Byadagi *et al*., 2019).

Seed yield

The data on seed yield per plant displayed maximum significant positive heterobeltiosis (33.82%) and economic heterosis (410.64%) in cross IC 632961 × Arka Arjun. On the other hand, IC 632961 × Arka Sukomal and Arka Arjun × IC 632961 displayed negative heterosis for better parent but displayed high economic heterosis (Table 1). TGS identification revealed maximum frequency of 64.62% witnessed in cross combination Arka Arjun × IC 632961 (Table 2). The results corroborated with finding of Radkov (1980) revealed higher transgressive segregants in seed yield per plant due to accumulation of plus genes in French bean during F_2 and F_3 generations. This indicating that the parents involved in developing F_3 families derived were differed for many genes which causes large amount of genetic variability for yield and its contributing traits (Shivakumar *et al*., 2013).

The results on heterobeltiosis corroborated with findings Chinapolaiah *et al*. (2019) who revealed high heterotic effect on plant traits such as days to 50% flowering, pod length, pod weight, dry pod yield per plant and seed yield per plant in velvet bean. Patil *et al*. (2012) revealed high heterosis in crosses of vegetable lab lab bean for number of pods and green pod yield per plant. The findings regarding transgressive segregants in French bean during the early segregating generation (F_2) align with the findings of previous studies conducted by various authors. Geneticists have proposed that when heterozygous hybrids are self-pollinated and progressed to subsequent segregating generations, they undergo a transition from heterozygosity to homozygosity. During this transition, a rare combination of genes inherited from both parents can contribute to the occurrence of transgressive segregations in later generations. The individuals receiving 'plus' alleles from both the parents or 'minus' alleles from both the parents are likely to have extreme phenotypes. Khrostovska *et al.* (1975) explained parents possess favourable alleles and genes governing economic traits witnessed transgressive segregation in pea crosses across eight segregating generations. Radkov (1980) considered pod weight and seed yield for estimation of TGS in F_2 and F_3 population of French bean. Monpara *et al*. (2004) conducted a study to investigate transgressive segregants in the F_2 generation of French bean for traits such as plant height, pods per plant and pod yield per plant. The researchers concluded that the emergence of transgressive segregants in these traits can be attributed to the contribution of different alleles from the parental lines. Maximum number of transgressive segregants was isolated for number of pods per plant and number of seeds per plant in F_2 and F_3 generation of chick peas (Sundaram *et al*., 2023). In an experiment, Basanagouda *et al*. (2022) revealed higher transgressive RILs in crosses of dolichos bean for the concerned traits like number of branches per plant, number of pods per plant and seed weight per plant.

Principal component analysis

Principal component analysis (PCA) is used for multivariate analysis to estimate and decompose complicated and large datasets. In this study, PCA was employed to investigate the pattern of variation in F_2 populations, including three parents and a standard check. The analysis was based on the correlation between the studied traits and the extracted

Table 3: Extracted eigenvalues and correlation values for yield and associated traits with the first three principal components.

Variables	Principles components		
	PC1	PC2	PC3
Extracted eigenvalues	6.524	2.839	1.427
Explained variance (%)	40.777	17.743	8.919
Cumulative variance (%)	40.777	58.521	67.439
Yield traits			
PH	-0.177	0.128	-0.183
LL	0.722	-0.201	-0.485
LW	0.677	-0.247	-0.462
LA	0.618	-0.267	-0.388
DF	-0.313	0.179	0.598
NIP	0.628	-0.528	0.262
PL	0.546	0.617	0.189
PW	0.44	0.694	-0.144
NPP	0.669	-0.616	0.241
APW	0.575	0.673	-0.033
PYP	0.881	-0.09	0.186
APW	0.69	0.445	-0.026
PDYP	0.878	-0.205	0.212
NSP	0.523	0.203	0.289
SI	0.559	0.553	-0.051
SYP	0.873	-0.22	0.294

clusters were assessed to understand the diversity of genotypes and their relationship with the observed traits. All the examined yield and yield-related traits were subjected to PCA, resulting in a total of 16 principal components (PCs). However, only five of these components were considered significant as they had eigenvalues greater than 1 (Table 3). The length and colour intensity of a vector in a biplot indicate, respectively, the quality's representation and its contribution to the principal components. In the biplot, the angles between the vectors derived from the midpoint demonstrate the independence or relationship between the qualities being studied for Groups I and III. Positive angles (between I and II) suggest a positive interaction, while negative angles (between I and IV) indicate a negative interaction. Additionally, the larger circles represent the centroids of the corresponding clusters (Fig 1). Taking into account PC1 and PC2 simultaneously, we identified three distinct sets of traits. Group I consisted of NIP and NIP, while group II included LL, LW, LA, PYP, SYP and PDWP. Group III comprised PL, PW, APW, NSP, HSW and APDW and group IV consisted of PH and DF (Fig 1). Notably, the PCA biplot revealed a strong association between group I and II traits, which had a significant contribution to PC1 and the individuals belonging to row clusters 1 and 4. The traits in group III had a greater impact on PC2 and showed a positive correlation with individuals scattered across clusters 1 to 3. On the other hand, the group IV traits (PH and DF) exhibited strong interactions with group I and II traits, indicating a negative correlation. The individuals scattered across clusters 2 to 4 were closely related to these traits (Fig 2). The results corroborated with findings of Reddy *et al*. (2021) for pod length, number of pods per plant, 10 pod weight (g), pod length (cm), number of seeds per pod and yield per plant.

Correlation studies for yield and component traits in F_2 plants

The correlation studies depicted that there is maximum significant positive correlation of pod yield per plant with

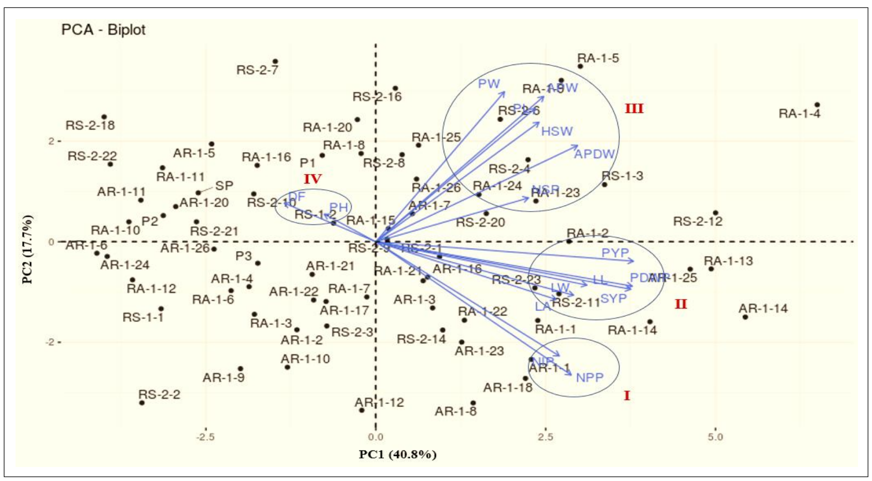

Fig 1: PCA-Biplot of F_2 segregating population, parent and standard check.

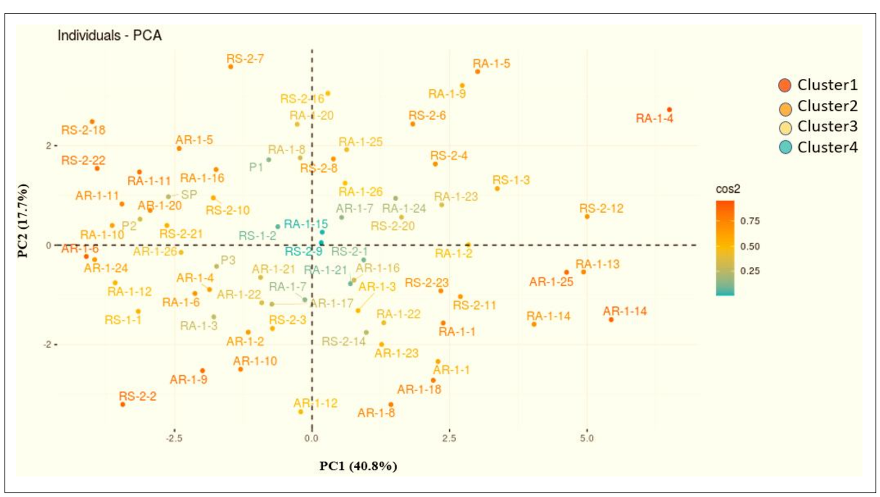

Fig 2: PCA showing clustering of F_2 segregating population, parent and standard check and traits contribution.

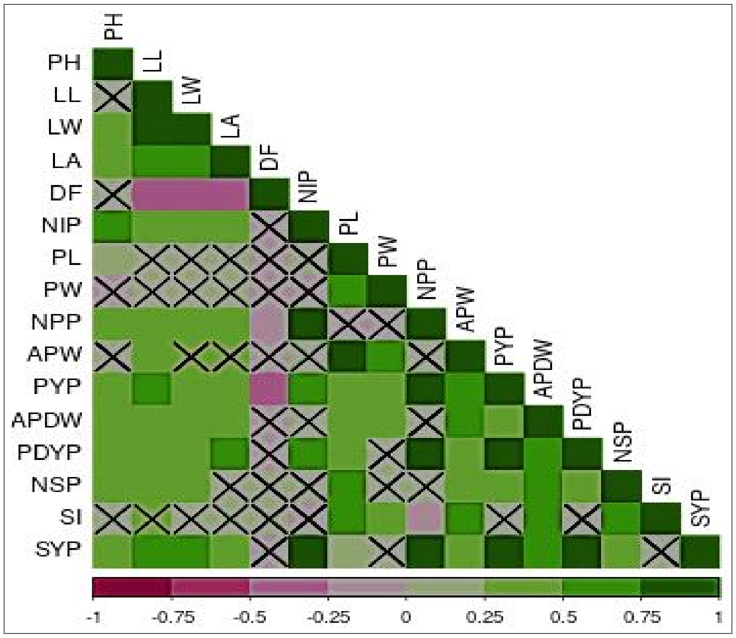

Fig 3: Correlation between yield and component traits.

NPP followed by NIP, APW, LA and other relevant traits under study except DF which had significant negative correlation (Fig 3). As far as seed yield per plant is concerned, it had strong correlation with PL, NPP, PYP and PDYP whereas, it has nonsignificant correlation with SI. Days to 50% flowering had nonsignificant negative correlation with most of yield associated traits.

CONCLUSION

Rare gene combination in segregating generations with additive gene action leads to extreme phenotypes which exceed parent value. The F_1 crosses derived from diverse parents of French bean (IC 632961, Arka Sukomal and Arka Arjun) witnessed a significant heterobeltiosis and standard heterosis for yield and yield attributing traits depicts that high genotypic coefficient of variation accompanied with high degree of heritability and genetic advance for the traits under investigation. Higher percentage of transgressive segregants (TGS) were resulted from all the three crosses and the most transgressive segregants for yield traits were observed in the cross IC 632961 × Arka Sukomal. Superior desirable transgressive segregants were witnessed for all sixteen yield and its component traits except leaf length in two cross combination Arka Arjun × IC 632961 and IC 632961 × Arka Arjun. The maximum per cent of transgressive segregation were yielded for number of inflorescences per plant (79.49%), followed by number of pods per plant (78.46), pod yield per plant (75.61%) in F_2 generation. Identification and isolation of such transgressive segregants which possess favourable alleles and genes governing traits of interest can be brought into a single or few genotype through stringent selection. Multivariate analysis inferred that the segregating populations derived showed remarkable variation for yield and its components traits and breeder can choose these lines for future crop improvement of French bean.

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Authors' contributions

Conceptualization of research (Meenu Kumari, Gouri Shankar Sahu, Gobinda Chandra Acharya, Pradyumna Tripathy and Kartik Pramanik); Designing of the experiments (Kartik Pramanik, Manasi Dash and Chinmaya Jena); Contribution of experimental materials (Meenu Kumari, G. C. Acharya and Kartik Pramanik); Execution of field/lab experiments and data collection (Kartik Pramanik, Chinmaya Jena); Analysis of data and interpretation (Kartik Pramanik and Manasi Dash); Preparation of the manuscript (Kartik Pramanik). Language editing and correction (Kartik Pramanik and Chinmaya Jena). All authors read and approved the final manuscript.

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The research design, data collection and analysis procedures were guided by established ethical principles. No ethical concerns arose during the course of this study.

Data availability

The data used to support the findings of the study are included within the article.

Consent to publish

All authors agree to publish the paper in Legume Research.

Conflict of interest

The authors declare that there is no conflict of interest.

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