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Research Article

Harnessing parent-offspring regression analysis to develop high-yielding submergence tolerant lines of *Oryza sativa* L.

S. Viswabharathy [1], Thiyagarajan Thulasinathan[2], Samuthirapandi Subburaj[1], F D. Prisca Seeli[1], Bharathi Ayyenar[2], Rohit Kambale[2], Vignesh Mohanavel[2], Veera Ranjani Rajagopalan[2], Sudha Manickam[2], P. Jeyakumar[3], S. Manonmani [4], T. Kalaimagal[5*] and M. Raveendran[6]

[1]Department of Genetics and Plant Breeding, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore-641 003.
[2]Department of Plant Biotechnology, Centre for Plant Molecular Biology and biotechnology, Tamil Nadu Agricultural University, Coimbatore-641 003.
[3]Directorate of Planning and Monitoring, Tamil Nadu Agricultural University, Coimbatore-641 003.
[4]Department of Rice, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore-641 003.
[5]Department of Oil Seeds, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore-641 003.
[6]Directorate of Research, Tamil Nadu Agricultural University, Coimbatore-641 003.
*E-Mail: kalaimagal.t@gmail.com

Abstract
Given the urgency of rising sea levels and the need to sustain food production, developing flood-tolerant crops is essential. The aim of this study was to assess the genetic potential of the cross CO51x13-6 (NIL of CO43Sub1) in the BC_2F_4 and BC_2F_5 generations using Parent Offspring regression analysis. Significant variation was observed across a wide range of traits in both generations. The distribution of important traits, including plant height, number of productive tillers per plant, panicle length, and single plant yield, showed a positively skewed and platykurtic curve in both generations, indicating the influence of multiple genes. The correlation and regression coefficients were highly significant for all the recorded traits in this study. The traits with the highest narrow sense heritability were days to fifty percent flowering, followed by stem diameter and spikelet fertility, suggesting that these traits can be effectively utilized for selecting superior genotypes in the early generations.

Keywords*:* Submergence, parent offspring regression, Skewness, kurtosis, intergenerational correlation, Rice

INTRODUCTION

The ability to be grown anywhere, from very high elevations down below sea level, makes rice incredibly unique. According to FAOSTAT 2021, Asia produces 89.9% of the world's rice, with China producing the most (212.84 million tonnes), followed by India (195.43 million tonnes), Bangladesh (56.94 million tonnes), Indonesia (54.42 million tonnes), and Vietnam (43.85 million tonnes). Over 700 million people in South Asia's rice-growing regions live in poverty (Oladosu *et al.,* 2020). According to Godfray *et al.* (2010), current agriculture faces a significant challenge in raising potential yields due to the growing submergence threat brought on by global

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warming and the necessity to feed the growing human population. Thereby, designing crops that can tolerate submergence is necessary to address this issue. Marker-assisted selection (MAS) has substantially improved the accuracy in the transfer of genes causing flood tolerance, allowing for the minimising of undesired traits like low yield during non-stress situations (Bailey-Serres *et al.,* 2010, Tester and Langridge 2010). A more effective approach of submergence tolerance breeding in rice is made possible by the accessible nature of elite lines with heritable target gene and the assessment of the stability of the introgressed gene validated in stress and non-stress conditions for quantitative traits contributing to yield. Therefore, in order to achieve the goal of yield improvement under submergence, selection for high yield combined with the target QTL in the earlier segregating generations is required. A potent paradigm for examining the intricate genetic architecture of phenotypic traits is quantitative genetics (Kruuk *et al.,* 2002, de Villemereuil *et al.,* 2013). Natural selection only affects an individual's phenotype; in contrast, the affected individual primarily transmits genotypes to their progeny. Therefore, a crucial question for understanding evolution in nature is how genotype shapes phenotype (Ridley., 2003). The proportion of trait variance that may be understood via genetic factors is known as broad sense or true heritability (Hill and Mackay 2004). The primary thrust of our investigation, parent-offspring (PO) regression, produces outcomes that are logically closest to the aforementioned concept. The most prevalent biometrical genetics approach for calculating heritability is PO regression. The slope of the linear regression line between parent and offspring trait values is used as an estimate for heritability in PO regression, which distinguishes the character's values in parents to characters' values in those they produce (Bachmann *et al.,* 2017). To get an idea of the association and heritability of the variables impacting yield in the segregating population of rice introgressed with submergence QTL, parent offspring regression analysis was implemented in our present investigation.

MATERIALS AND METHODS

The purpose of the current study was to examine the genetic potential of the cross CO 51 x 13-6 (NIL of CO 43 Sub1) in the BC_2F_4 and BC_2 F_5 generations during the Navarai season (Jan.-Apr. 2020) and from August to the middle of November 2022 at Paddy Breeding Station, AC&RI, Coimbatore, Tamil Nadu, India. Regular cultural practises and plant protection techniques that were based on necessity were implemented. Female parent was a popular variety, CO 51 with short duration (105-110 days), medium slender, moderate resistance to pests (BPH and GLH), disease (blast), as well as higher yield and cooking quality compared to the control ADT 43 (Robin *et al.,* 2019). Although this mega variety that can be grown in Tamil Nadu's main growing seasons (*Kar, Kuruvai, Sornavari, and Navarai*), it is extremely vulnerable to flooding. Sub1 QTL was introgressed using CO 43 Sub1's near isogenic line (13-6). A total of 225 progenies from 15 families of BC_2F_4 underwent foreground selection for Sub1 QTL using the INDEL marker, ART5. Among those, 72 homozygous progenies with good yield performance were forwarded to the next generation (BC_2F_5). Twelve biometrical traits *viz.,* DFF: Days to fifty percent flowering (days); NPT: number of productive tillers per plant; PL: panicle length (cm); FLL: flag leaf length (cm); FG: number of filled grains per panicle; CG: number of chaffy grains per panicle; TG: total grains per panicle; SF: spikelet fertility; HSW: hundred seed weight; SD: stem diameter (mm); SPY: single plant yield (g) were recorded on five plants and their average values of these traits were employed for the analysis that followed. Using Origin software version 10, intergenerational correlation and parent progeny regression studies were performed. To explore gene interactions, skewness and kurtosis were calculated using the average data in Microsoft Excel and graphs created with the R software.

Narrow sense heritability (Smith and Kinman, 1965)

$$h^2 = \frac{b_{yx}}{2r_{xy}} x\ 100$$

b_{yx} b_{yx}:	regression coefficient of BC_2F_5 progeny means on BC_2F_4 parental values for respective characters
r_{xy} r_{xy}:	Intergenerational correlation coefficient between the parent "x" and its offspring "y"

RESULTS AND DISCUSSION

Selection of superior plants is made possible by the diversity among the separating generations. In BC_2F_4 and BC_2F_5 generation, broad range of variation were observed. For the parents, BC_2 F_4 (**Table 1**), and BC_2 F_5 (**Table 2**) generations, mean and range values for the various characteristics were obtained. In BC_2F_4 generation, the days to fifty percent flowering ranged from 95-100 days. Plant height ranged from 78 to 113 cm, number of productive tillers from 14 to 43. Regarding the single plant yield, the range was 25 to 65 g. Whereas in BC_2F_5 generation, the range of single plant yield was 25.3 to 66.3 g. The value of plant height ranged from 71.6 – 102.6 cm and the number of productive tillers from 17 to 42. The progeny No. 12 x 9-7-6-12-3-38, showed maximum single plant yield in both the generations and it also has outperformed both the parents. In both generations, the average values for days to 50% flowering fell in the middle of the parents' range. The mean value of hundred seed weight was similar to CO 51 parent in both the generations. Spikelet fertility mean in both the generations was similar to 13-6 (donor parent). Stem diameter mean in BC_2F_4 and BC_2F_5 generations was intermediate between both the parents.

Table 1. Performance of yield and its associated traits in in BC$_2$ F$_4$ progenies

S. No	Plant No.	DFF	PH	NPT	PL	FLL	FG	CG	TG	SF	HSW	SD	SPY
1	12 x 9-7-6-12-3-1	95	99.5	25.0	25.2	28.4	151.3	21.9	173.2	87.3	1.7	6.4	49.0
2	12 x 9-7-6-12-3-2	95	100.0	24.0	24.0	30.9	142.4	17.7	160.1	88.9	1.7	5.2	47.0
3	12 x 9-7-6-12-3-3	99	110.0	35.0	23.6	28.0	157.9	22.9	180.8	87.4	1.6	5.5	51.0
4	12 x 9-7-6-12-3-4	99	108.0	43.0	22.3	23.3	143.8	22.7	166.5	86.4	1.0	5.5	25.0
5	12 x 9-7-6-12-3-5	99	98.5	20.0	21.3	22.1	140.2	17.4	157.5	89.0	1.7	6.2	46.0
6	12 x 9-7-6-12-3-6	98	100.0	30.0	22.6	24.3	133.6	23.1	156.7	85.2	1.8	7.6	44.0
7	12 x 9-7-6-12-3-7	97	98.0	28.0	23.4	30.6	159.1	13.5	172.6	92.2	1.7	5.8	42.0
8	12 x 9-7-6-12-3-8	97	100.0	31.0	21.6	25.1	144.7	10.5	155.2	93.3	1.6	6.0	44.0
9	12 x 9-7-6-12-3-9	97	100.0	34.0	22.3	24.7	139.0	28.8	167.8	82.8	1.5	6.7	43.0
10	12 x 9-7-6-12-3-10	97	93.0	40.0	23.4	30.2	95.4	37.8	133.2	71.6	1.7	6.5	58.0
11	12 x 9-7-6-12-3-11	97	88.0	27.0	23.6	30.4	145.9	23.9	169.8	86.0	1.5	6.2	47.0
12	12 x 9-7-6-12-3-12	97	90.0	24.0	24.5	29.1	111.3	36.4	147.7	75.4	1.7	5.9	41.0
13	12 x 9-7-6-12-3-13	97	90.0	27.0	21.6	26.6	173.3	48.7	222.0	78.1	1.1	5.6	39.0
14	12 x 9-7-6-12-3-14	99	111.0	20.0	23.6	28.3	127.6	21.6	149.2	85.5	1.8	6.4	42.0
15	12 x 9-7-6-12-3-15	99	109.0	25.0	22.1	24.6	177.5	35.5	213.0	83.4	1.7	5.0	42.0
16	12 x 9-7-6-12-3-16	99	94.0	34.0	24.3	30.5	144.9	43.7	188.6	76.8	1.7	6.4	50.0
17	12 x 9-7-6-12-3-17	99	96.0	35.0	23.9	28.8	129.9	28.1	158.0	82.2	1.7	6.6	51.0
18	12 x 9-7-6-12-3-18	99	95.0	35.0	24.0	26.8	126.1	36.5	162.6	77.6	1.7	6.8	56.0
19	12 x 9-7-6-12-3-19	98	103.0	31.0	23.5	26.7	159.5	31.4	190.9	83.6	1.7	7.4	44.0
20	12 x 9-7-6-12-3-20	98	111.0	25.0	22.8	20.2	143.7	21.7	165.4	86.9	1.5	7.2	42.0
21	12 x 9-7-6-12-3-21	100	113.0	33.0	23.6	26.5	198.1	36.7	234.8	84.4	1.6	6.3	49.0
22	12 x 9-7-6-12-3-22	100	99.0	26.0	22.6	28.3	119.8	47.1	166.9	71.8	1.7	6.6	41.0
23	12 x 9-7-6-12-3-23	100	98.5	23.0	23.6	31.2	137.9	76.9	214.9	64.2	1.7	6.5	44.0
24	12 x 9-7-6-12-3-24	96	94.0	28.0	24.8	25.1	240.3	44.6	285.0	84.3	1.7	4.4	53.0
25	12 x 9-7-6-12-3-25	96	90.0	30.0	22.6	20.4	122.9	29.5	152.4	80.7	1.7	6.7	53.0
26	12 x 9-7-6-12-3-26	96	89.0	24.0	25.8	34.5	138.3	49.5	187.8	73.6	1.7	5.7	54.0
27	12 x 9-7-6-12-3-27	96	90.0	35.0	21.7	26.2	102.9	31.4	134.3	76.6	1.6	6.4	53.0
28	12 x 9-7-6-12-3-28	96	94.0	22.0	24.6	25.9	108.5	24.2	132.6	81.8	1.3	4.9	63.0
29	12 x 9-7-6-12-3-29	96	90.0	21.0	22.6	24.1	105.6	11.1	116.7	90.5	1.5	6.7	62.0
30	12 x 9-7-6-12-3-30	96	89.0	25.0	22.3	22.2	149.4	42.6	192.0	77.8	1.5	4.4	56.0
31	12 x 9-7-6-12-3-31	96	90.0	25.0	21.8	26.3	166.0	40.6	206.5	80.4	1.2	6.4	50.0
32	12 x 9-7-6-12-3-32	96	90.0	23.0	23.4	20.4	109.0	28.9	137.9	79.0	1.4	6.4	49.0
33	12 x 9-7-6-12-3-33	96	110.0	22.0	21.6	22.4	119.3	19.6	138.9	85.9	1.7	5.4	62.0
34	12 x 9-7-6-12-3-34	96	104.0	22.0	21.8	25.2	119.0	41.8	160.8	74.0	1.8	6.1	50.0
35	12 x 9-7-6-12-3-35	96	102.0	22.0	24.2	21.0	131.1	56.4	187.5	69.9	1.7	6.3	53.0
36	12 x 9-7-6-12-3-36	96	99.0	24.0	22.4	21.8	108.2	54.6	162.9	66.4	1.3	7.3	53.0
37	12 x 9-7-6-12-3-37	96	110.0	27.0	21.8	21.8	139.0	17.2	156.2	89.0	1.8	5.2	59.0
38	12 x 9-7-6-12-3-38	96	109.0	23.0	24.6	24.8	116.6	27.3	143.9	81.0	1.6	5.6	65.0
39	12 x 9-7-6-12-3-39	96	92.0	25.0	25.3	28.7	134.7	57.0	191.7	70.3	1.6	6.2	52.0
40	12 x 9-7-6-12-3-40	96	109.0	24.0	21.5	24.1	111.2	20.9	132.1	84.2	1.7	6.3	65.0
41	12 x 9-7-6-12-3-41	97	92.0	22.0	25.2	38.7	135.3	43.6	178.9	75.6	1.8	5.4	40.0
42	12 x 9-7-6-12-3-42	97	81.0	21.0	21.9	30.5	157.7	9.0	166.7	94.6	1.2	5.8	40.0
43	12 x 9-7-6-12-3-43	97	78.0	32.0	23.0	27.8	123.9	19.3	143.2	86.5	1.6	4.9	39.0
44	12 x 9-7-6-12-3-44	97	96.0	21.0	23.4	29.8	129.9	42.5	172.4	75.3	1.8	6.5	40.0
45	12 x 9-7-6-12-3-45	97	99.0	29.0	21.5	23.2	145.7	26.7	172.5	84.5	1.5	6.0	46.0
46	12 x 9-7-6-12-3-46	98	91.0	38.0	21.6	22.7	101.0	18.6	119.6	84.5	1.6	6.2	51.0

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Table 1. Continued...

S. No	Plant No.	DFF	PH	NPT	PL	FLL	FG	CG	TG	SF	HSW	SD	SPY
47	12 x 9-7-6-12-3-47	98	97.0	20.0	24.6	26.1	123.6	39.6	163.2	75.7	1.8	5.6	40.0
48	12 x 9-7-6-12-3-48	98	99.0	32.0	24.8	28.2	122.8	25.9	148.7	82.6	1.8	6.5	40.0
49	12 x 9-7-6-12-3-49	98	91.0	25.0	26.4	27.6	104.7	72.2	176.9	59.2	1.7	6.8	40.0
50	12 x 9-7-6-12-3-50	97	83.0	20.0	23.6	29.7	150.2	41.2	191.3	78.5	0.7	6.0	46.7
51	12 x 9-7-6-12-3-51	97	81.0	18.0	24.8	29.5	118.8	37.4	156.2	76.1	1.7	5.9	41.7
52	12 x 9-7-6-12-3-52	97	86.0	28.0	22.6	26.7	130.1	59.3	189.4	68.7	1.6	5.2	50.0
53	12 x 9-7-6-12-3-53	97	86.0	24.0	24.3	29.6	110.8	27.6	138.4	80.1	1.6	5.8	40.0
54	12 x 9-7-6-12-3-54	97	94.0	18.0	22.7	30.3	115.6	26.3	141.9	81.4	1.6	6.0	51.3
55	12 x 9-7-6-12-3-55	97	92.0	29.0	23.4	25.6	102.4	51.4	153.8	66.6	1.6	6.6	41.0
56	12 x 9-7-6-12-3-56	97	90.0	19.0	20.9	22.1	113.0	16.2	129.1	87.5	1.5	6.3	47.5
57	12 x 9-7-6-12-3-57	97	86.0	18.0	23.2	28.7	137.2	51.9	189.1	72.6	1.6	6.0	45.6
58	12 x 9-7-6-12-3-58	97	87.0	18.0	24.2	29.4	130.0	33.8	163.8	79.3	1.8	5.3	44.0
59	12 x 9-7-6-12-3-59	97	86.0	14.0	26.7	28.7	102.4	20.2	122.6	83.5	1.6	5.6	42.0
60	12 x 9-7-6-12-3-60	100	100.0	20.0	22.4	22.3	111.4	19.8	131.2	84.9	1.6	6.2	40.0
61	12 x 9-7-6-12-3-61	100	102.0	18.0	24.2	29.5	127.0	33.7	160.7	79.0	1.7	5.6	39.0
62	12 x 9-7-6-12-3-62	100	105.0	26.0	25.0	28.0	118.9	18.8	137.7	86.4	1.1	5.8	58.0
63	12 x 9-7-6-12-3-63	100	95.0	25.0	22.4	25.6	134.0	17.6	151.6	88.4	1.7	6.2	45.0
64	12 x 9-7-6-12-3-64	100	97.0	30.0	23.1	24.1	137.6	29.4	167.0	82.4	1.7	7.0	47.0
65	12 x 9-7-6-12-3-65	100	99.0	24.0	24.0	27.2	111.6	20.3	132.0	84.6	1.7	6.8	44.0
66	12 x 9-7-6-12-3-66	99	80.0	30.0	20.9	31.7	110.7	26.7	137.4	80.6	1.7	5.8	53.0
67	12 x 9-7-6-12-3-67	99	89.0	25.0	22.8	30.0	134.7	23.1	157.7	85.4	1.6	6.3	41.0
68	12 x 9-7-6-12-3-68	99	87.0	18.0	23.5	27.9	148.0	39.4	187.4	79.0	1.6	7.5	44.0
69	12 x 9-7-6-12-3-69	99	92.0	28.0	22.4	29.6	150.3	45.8	196.1	76.7	1.7	6.9	42.0
70	12 x 9-7-6-12-3-70	99	90.0	28.0	22.7	30.8	106.2	36.6	142.7	74.4	1.3	7.5	42.0
71	12 x 9-7-6-12-3-71	97	89.0	26.0	21.8	23.3	155.3	32.4	187.8	82.7	1.6	6.6	49.0
72	12 x 9-7-6-12-3-72	96	99.0	19.0	22.6	24.3	143.7	26.0	169.7	84.7	1.6	5.9	34.0
	MEAN	97.5	95.5	25.8	23.2	26.8	132.9	32.4	165.3	80.7	1.6	6.1	47.1
	CO 51	84	88.6	21.0	23.4	26.8	153.0	11.0	164.0	93.3	1.9	5.3	33.2
	13-6	100	102.0	30.0	20.6	25.1	176.0	33.0	209.0	84.2	2.2	7.1	38.0

DFF: Days to fifty percent flowering (days); NPT: number of productive tillers per plant; PL: panicle length (cm); FLL: flag leaf length (cm); FG: number of filled grains per panicle; CG: number of chaffy grains per panicle; TG: total grains per panicle; SF: spikelet fertility; HSW: hundred seed weight; SD: stem diameter (mm); SPY: single plant yield (g).

The variation in the segregating generations is analysed using skewness and kurtosis (Nadarajan *et al.,* 2016). The third degree statistic tool used to find how the genes interact is skewness. Skewness values less than zero imply duplicate interactions for the particular features, but values greater than zero indicate the presence of complementary interactions (Choo and Reinbergs, 1982). Based on the skewness value, the traits can be classified into three types *viz.,* positively skewed ($\beta 1 > 0$), negatively skewed ($\beta 1 < 0$) and symmetrical distribution ($\beta 1 = 0$). Positive skewness was witnessed for DFF (0.39), PH (0.25), NPT (0.63), PL (0.41), FLL (0.30), FG (1.53), CG (0.85), TG (1.22) and SPY (0.34) in BC$_2$F$_4$ generation followed by SF (-0.66), HSW (-2.09) and SD (-0.18) showing negative skewness (**Table 3**). In BC$_2$F$_5$ generation, negative skewness was observed in PH (-1.05), SF (-0.74), HSW (-0.80) and stem diameter (-0.33), whereas the positive skewness was observed for the following traits *viz.,* DFF (0.31), NPT (0.68), PL (0.18), FLL (0.31), FG (1.58), CG (0.92), TG (1.31) and SPY (0.30).

Based on the kurtosis value, which depends on the distribution curve, three forms of kurtosis were identified. Kurtosis value of 1 indicates mesokurtic behaviour. Leptokurtic is defined as having a kurtosis value > 1 and Platykurtic as having a kurtosis value < 1. According to leptokurtic and platykurtic curves, a trait is influenced by, respectively, a smaller and greater number of genes (Aananthi, 2018). In BC$_2$F$_4$ generation, leptokurtic curve

Table 2. Performance of yield and its associated traits in BC_2 F_5 progenies

S. No	Plant No	DFF	PH	NPT	PL	FLL	FG	CG	TG	SF	HSW	SD	SPY
1	12 x 9-7-6-12-3-1	96	92.0	24.0	23.2	26.3	148.0	23.0	171.0	86.5	1.7	5.9	48.2
2	12 x 9-7-6-12-3-2	97	93.7	23.0	23.0	29.9	138.0	18.0	156.0	88.5	1.8	7.3	46.9
3	12 x 9-7-6-12-3-3	102	99.3	36.0	22.4	26.8	152.0	23.0	175.0	86.9	1.7	6.3	52.8
4	12 x 9-7-6-12-3-4	101	98.3	42.0	21.6	22.6	149.0	22.0	171.0	87.1	1.7	8.1	25.3
5	12 x 9-7-6-12-3-5	103	90.7	19.0	20.3	21.1	146.0	17.0	163.0	89.6	1.7	5.7	46.0
6	12 x 9-7-6-12-3-6	104	97.3	28.0	21.9	23.6	129.3	24.3	153.7	84.2	2.0	5.8	44.3
7	12 x 9-7-6-12-3-7	99	94.3	29.0	22.6	29.9	156.0	13.0	169.0	92.3	1.7	6.1	43.9
8	12 x 9-7-6-12-3-8	99	94.3	29.0	20.6	24.0	144.0	10.0	154.0	93.5	1.7	6.7	41.9
9	12 x 9-7-6-12-3-9	100	97.7	32.0	21.5	23.9	144.0	28.3	172.3	83.6	1.8	6.2	44.7
10	12 x 9-7-6-12-3-10	98	78.3	36.0	21.5	28.3	97.0	38.0	135.0	71.9	1.8	6.1	58.6
11	12 x 9-7-6-12-3-11	98	80.0	26.0	21.9	28.7	148.0	23.0	171.0	86.5	1.7	4.7	48.0
12	12 x 9-7-6-12-3-12	100	71.7	22.0	22.0	26.6	112.0	37.0	149.0	75.2	1.7	6.4	41.6
13	12 x 9-7-6-12-3-13	100	87.3	28.0	20.4	25.4	167.0	49.0	216.0	77.3	1.6	6.2	39.6
14	12 x 9-7-6-12-3-14	103	96.0	21.0	21.1	25.8	132.0	22.0	154.0	85.7	1.8	6.6	40.9
15	12 x 9-7-6-12-3-15	102	96.0	26.0	20.8	23.3	177.0	34.0	211.0	83.9	1.7	7.0	42.2
16	12 x 9-7-6-12-3-16	100	88.0	32.0	21.6	27.8	146.7	42.0	188.7	77.7	1.8	6.0	52.3
17	12 x 9-7-6-12-3-17	101	96.3	33.0	22.7	27.5	127.0	27.0	154.0	82.5	1.9	5.9	51.3
18	12 x 9-7-6-12-3-18	100	98.3	33.0	22.6	25.4	124.0	35.0	159.0	78.0	1.8	4.9	53.4
19	12 x 9-7-6-12-3-19	99	89.7	29.0	22.5	25.7	160.0	31.0	191.0	83.8	1.8	6.9	44.6
20	12 x 9-7-6-12-3-20	99	91.3	22.0	21.7	19.1	150.0	21.7	171.7	87.4	1.9	6.7	42.6
21	12 x 9-7-6-12-3-21	102	91.0	34.0	22.9	25.8	195.0	38.0	233.0	83.7	1.7	6.6	49.8
22	12 x 9-7-6-12-3-22	103	88.3	25.0	21.6	27.4	119.0	47.0	166.0	71.7	1.7	6.8	41.2
23	12 x 9-7-6-12-3-23	104	74.3	22.0	21.1	28.7	136.0	79.0	215.0	63.3	1.8	6.4	45.3
24	12 x 9-7-6-12-3-24	99	84.7	27.0	21.2	21.5	246.0	44.0	290.0	84.8	1.7	4.6	54.7
25	12 x 9-7-6-12-3-25	98	88.3	30.0	21.6	19.3	125.7	29.7	155.3	80.9	1.9	7.0	54.7
26	12 x 9-7-6-12-3-26	98	78.0	23.0	22.0	30.7	138.0	49.0	187.0	73.8	1.8	5.7	55.3
27	12 x 9-7-6-12-3-27	99	84.3	33.0	19.6	24.1	100.0	31.0	131.0	76.3	1.7	6.3	51.6
28	12 x 9-7-6-12-3-28	98	93.3	22.0	21.8	23.1	104.0	25.0	129.0	80.6	1.5	4.8	61.8
29	12 x 9-7-6-12-3-29	99	95.7	20.0	20.9	22.3	105.0	11.0	116.0	90.5	1.6	6.6	61.8
30	12 x 9-7-6-12-3-30	98	95.3	23.0	20.4	20.4	150.0	43.0	193.0	77.7	1.7	4.3	53.4
31	12 x 9-7-6-12-3-31	98	96.0	22.0	22.3	26.8	164.0	42.0	206.0	79.6	1.7	6.6	50.0
32	12 x 9-7-6-12-3-32	98	99.7	23.0	20.6	17.6	114.0	29.7	143.7	79.4	1.7	6.7	48.8
33	12 x 9-7-6-12-3-33	99	102.7	22.0	20.2	21.0	120.0	19.0	139.0	86.3	1.8	5.5	59.2
34	12 x 9-7-6-12-3-34	98	98.7	21.0	20.1	23.5	116.0	40.0	156.0	74.4	1.8	6.3	50.5
35	12 x 9-7-6-12-3-35	99	102.0	22.0	22.2	19.0	128.0	58.0	186.0	68.8	1.8	6.4	55.1
36	12 x 9-7-6-12-3-36	97	98.7	23.0	20.5	19.9	104.0	54.0	158.0	65.8	1.4	7.2	53.1
37	12 x 9-7-6-12-3-37	99	101.0	28.0	20.8	20.8	140.0	18.0	158.0	88.6	1.8	5.5	58.1
38	12 x 9-7-6-12-3-38	100	99.7	21.0	22.2	22.4	116.0	27.0	143.0	81.1	1.6	5.7	66.0
39	12 x 9-7-6-12-3-39	101	96.3	24.0	21.4	24.8	140.0	58.0	198.0	70.7	1.6	6.3	51.3
40	12 x 9-7-6-12-3-40	99	95.7	24.0	19.3	21.9	109.0	21.7	130.7	83.4	1.9	6.4	66.4
41	12 x 9-7-6-12-3-41	99	91.3	23.0	22.5	36.0	132.0	42.0	174.0	75.9	1.8	5.5	41.9
42	12 x 9-7-6-12-3-42	103	86.0	19.0	19.0	27.6	156.0	9.0	165.0	94.5	1.3	6.0	38.1
43	12 x 9-7-6-12-3-43	99	88.3	32.0	19.3	24.1	125.0	20.0	145.0	86.2	1.6	4.8	40.2
44	12 x 9-7-6-12-3-44	102	89.7	18.0	22.1	28.5	136.0	42.0	178.0	76.4	1.9	6.4	38.6
45	12 x 9-7-6-12-3-45	103	97.0	27.0	20.3	22.0	143.0	28.0	171.0	83.6	1.5	6.2	48.1
46	12 x 9-7-6-12-3-46	100	96.7	39.0	20.4	21.5	103.0	19.0	122.0	84.4	1.8	6.4	48.8

Table 2. Continued...

S. No	Plant No	DFF	PH	NPT	PL	FLL	FG	CG	TG	SF	HSW	SD	SPY
47	12 x 9-7-6-12-3-47	100	96.3	19.0	21.5	22.9	119.7	39.3	159.0	75.3	1.8	5.5	38.8
48	12 x 9-7-6-12-3-48	99	100.7	30.0	21.8	25.2	118.0	26.0	144.0	81.9	1.6	6.4	41.2
49	12 x 9-7-6-12-3-49	99	95.3	25.0	22.0	23.3	100.0	72.0	172.0	58.1	1.9	6.9	41.3
50	12 x 9-7-6-12-3-50	98	95.0	19.0	22.5	28.7	151.7	42.7	194.3	78.0	1.6	5.8	46.9
51	12 x 9-7-6-12-3-51	99	96.0	17.0	21.5	26.3	123.0	36.3	159.3	77.2	1.8	5.7	39.9
52	12 x 9-7-6-12-3-52	101	95.0	27.0	21.1	25.2	133.0	60.0	193.0	68.9	1.9	5.6	52.0
53	12 x 9-7-6-12-3-53	102	96.3	22.0	19.6	24.9	106.7	29.0	135.7	78.6	1.8	6.0	38.6
54	12 x 9-7-6-12-3-54	99	95.3	17.0	20.1	27.7	120.0	26.7	146.7	81.8	1.8	6.3	50.3
55	12 x 9-7-6-12-3-55	103	91.0	28.0	21.3	23.5	104.0	54.0	158.0	65.8	1.9	6.7	41.8
56	12 x 9-7-6-12-3-56	102	90.3	18.0	19.8	21.1	110.0	16.0	126.0	87.3	1.6	6.4	48.9
57	12 x 9-7-6-12-3-57	99	90.3	17.0	20.6	26.1	144.0	52.0	196.0	73.5	1.9	6.1	47.4
58	12 x 9-7-6-12-3-58	99	88.7	18.0	21.5	26.7	134.7	32.7	167.3	80.5	1.9	5.5	42.3
59	12 x 9-7-6-12-3-59	99	86.7	17.0	23.4	25.4	103.0	21.0	124.0	83.1	2.1	5.8	40.8
60	12 x 9-7-6-12-3-60	102	94.7	19.0	20.1	20.0	114.0	20.7	134.7	84.7	1.7	6.4	39.9
61	12 x 9-7-6-12-3-61	103	96.0	17.0	22.4	27.7	127.3	34.3	161.7	78.8	1.8	5.5	40.5
62	12 x 9-7-6-12-3-62	102	95.7	24.0	21.0	24.0	116.7	18.0	134.7	86.6	1.9	6.0	57.5
63	12 x 9-7-6-12-3-63	102	92.0	24.0	21.7	24.9	131.7	18.0	149.7	88.0	1.9	6.4	43.2
64	12 x 9-7-6-12-3-64	101	93.0	32.0	20.3	21.4	143.7	28.0	171.7	83.7	1.6	7.0	47.2
65	12 x 9-7-6-12-3-65	103	94.0	23.0	22.0	25.2	115.3	21.0	136.3	84.6	1.8	6.9	46.1
66	12 x 9-7-6-12-3-66	100	95.3	31.0	18.9	29.7	114.7	27.0	141.7	80.9	1.9	5.7	55.5
67	12 x 9-7-6-12-3-67	100	87.3	24.0	20.1	27.3	138.0	22.0	160.0	86.3	1.6	6.4	40.1
68	12 x 9-7-6-12-3-68	102	88.7	17.0	21.3	25.7	142.0	38.0	180.0	78.9	1.6	7.3	43.0
69	12 x 9-7-6-12-3-69	100	88.3	26.0	20.4	27.6	150.0	44.0	194.0	77.3	1.7	6.8	42.4
70	12 x 9-7-6-12-3-70	100	86.0	28.0	20.3	28.4	110.0	38.0	148.0	74.3	1.4	7.4	40.7
71	12 x 9-7-6-12-3-71	103	80.3	24.0	19.4	20.9	152.0	32.0	184.0	82.6	1.7	6.7	49.7
72	12 x 9-7-6-12-3-72	99	87.0	18.0	20.9	22.7	148.0	25.0	173.0	85.5	1.6	5.8	35.3
	MEAN	100.125	92.2	25.0	21.2	24.8	133.1	32.4	165.5	80.6	1.7	6.2	47.3
	CO 51	**92**	**82.3**	**19.0**	**21.3**	**24.7**	**188.0**	**31.0**	**219.0**	**85.8**	**1.9**	**5.4**	**32.0**
	13 – 6	**112**	**88.0**	**26.0**	**19.6**	**24.1**	**182.0**	**29.0**	**211.0**	**86.3**	**2.2**	**7.6**	**34.0**

DFF: Days to fifty percent flowering (days); NPT: number of productive tillers per plant; PL: panicle length (cm); FLL: flag leaf length (cm); FG: number of filled grains per panicle; CG: number of chaffy grains per panicle; TG: total grains per panicle; SF: spikelet fertility; HSW: hundred seed weight; SD: stem diameter (mm); SPY: single plant yield (g).

was observed for the traits days to fifty percent flowering (-1.03), number of filled grains per panicle (4.82), total grains per panicle (3.23) and hundred seed weight (4.91) whereas the platykurtic curve was observed for plant height (-0.47), number of productive tillers per plant (0.28), panicle length (-0.28), flag leaf length (0.58), chaffy grains per panicle (0.70), spikelet fertility (0.46), stem diameter (0.15) and single plant yield (054) (**Fig. 1**). Similarly, in the BC_2F_5 generation, plant height (1.21), number of filled grains per panicle (5.70), total grains per panicle (3.88) and hundred seed weight (1.72) showed leptokurtic curve but days to fifty percent flowering (-0.80), number of productive tillers per plant (0.10), panicle length (-0.64), flag leaf length (0.58), chaffy grains per panicle (0.93), spikelet fertility (0.74), stem diameter (0.65) and single plant yield (0.47) showed platykurtic curve (**Fig. 2**).

In the present study, positively skewed and platykurtic curve was observed for plant height, number of productive tillers per plant, panicle length, flag leaf length, number of chaffy grains per panicle and single plant yield in BC_2F_4 generation whereas days to fifty percent flowering, number of productive tillers per plant, panicle length, flag leaf length, number of chaffy grains per panicle and single plant yield in BC_2F_5 generation. This suggests that a large number of genes with dominance-based gene interactions control these traits. Faster genetic progress in these characters can be achieved by intense selection. Hosagoudar and Shashidhar (2018) and Harijan *et al.* (2021) found similar results for days to flowering, the number of tillers, days to maturity, and yield per plant. Also days to fifty percent flowering and chaffy grains per panicle by Seeli *et al.* (2021).

Table 3. Skewness and Kurtosis values for yield and yield contributing traits in BC$_2$ F$_4$ and BC$_2$ F$_5$ progenies

Traits	BC2F4		BC2F5	
	Skewness	Kurtosis	Skewness	Kurtosis
DFF	0.39	-1.03	0.31	-0.80
PH	0.25	-0.47	-1.05	1.21
NPT	0.63	0.28	0.68	0.10
PL	0.41	-0.28	-0.18	-0.64
FLL	0.30	0.58	0.31	0.58
FG	1.53	4.82	1.58	5.70
CG	0.85	0.70	0.92	0.93
TG	1.22	3.23	1.31	3.88
SF	-0.66	0.46	-0.74	0.74
HSW	-2.09	4.91	-0.80	1.72
SD	-0.18	0.15	-0.33	0.65
SPY	0.34	0.54	0.30	0.47

DFF: Days to fifty percent flowering (days); NPT: number of productive tillers per plant; PL: panicle length (cm); FLL: flag leaf length (cm); FG: number of filled grains per panicle; CG: number of chaffy grains per panicle; TG: total grains per panicle; SF: spikelet fertility; HSW: hundred seed weight; SD: stem diameter (mm); SPY: single plant yield (g).

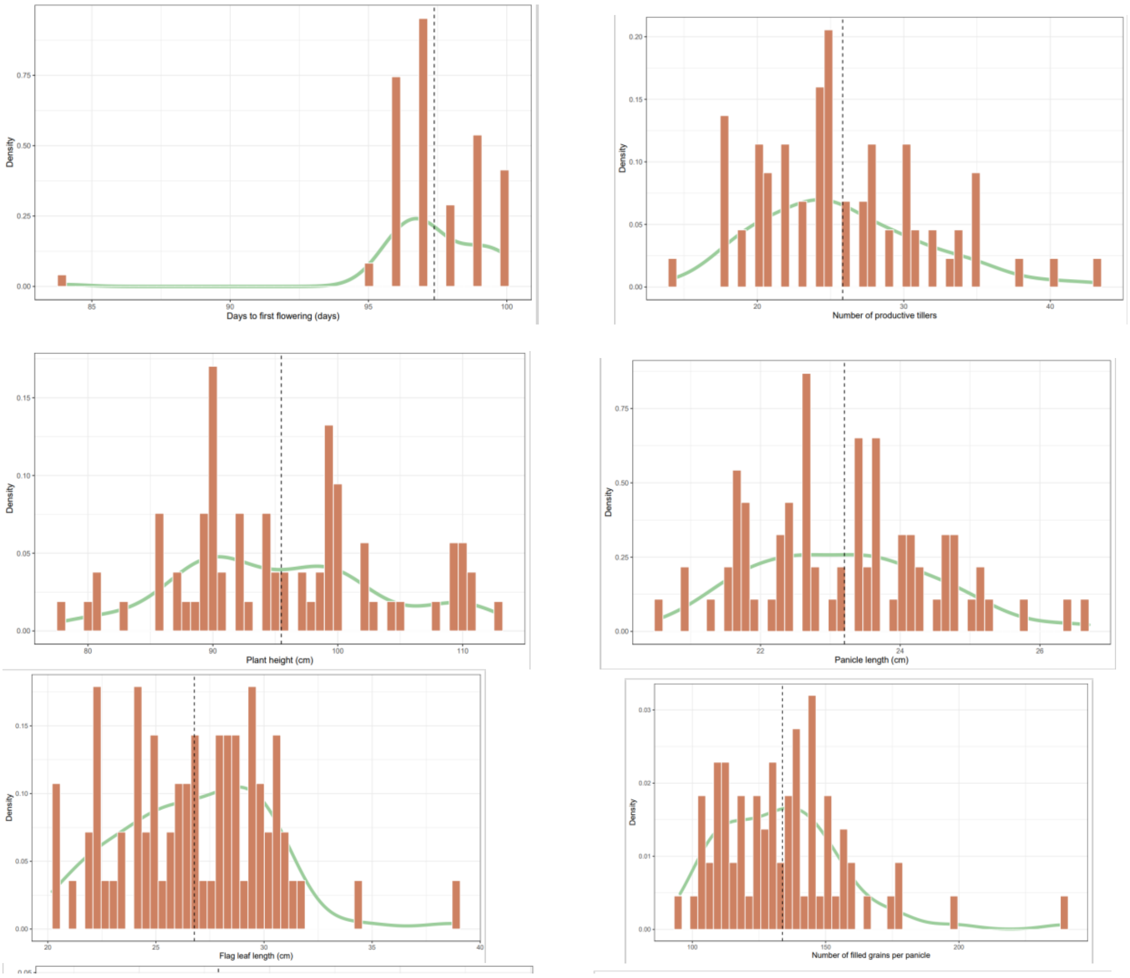
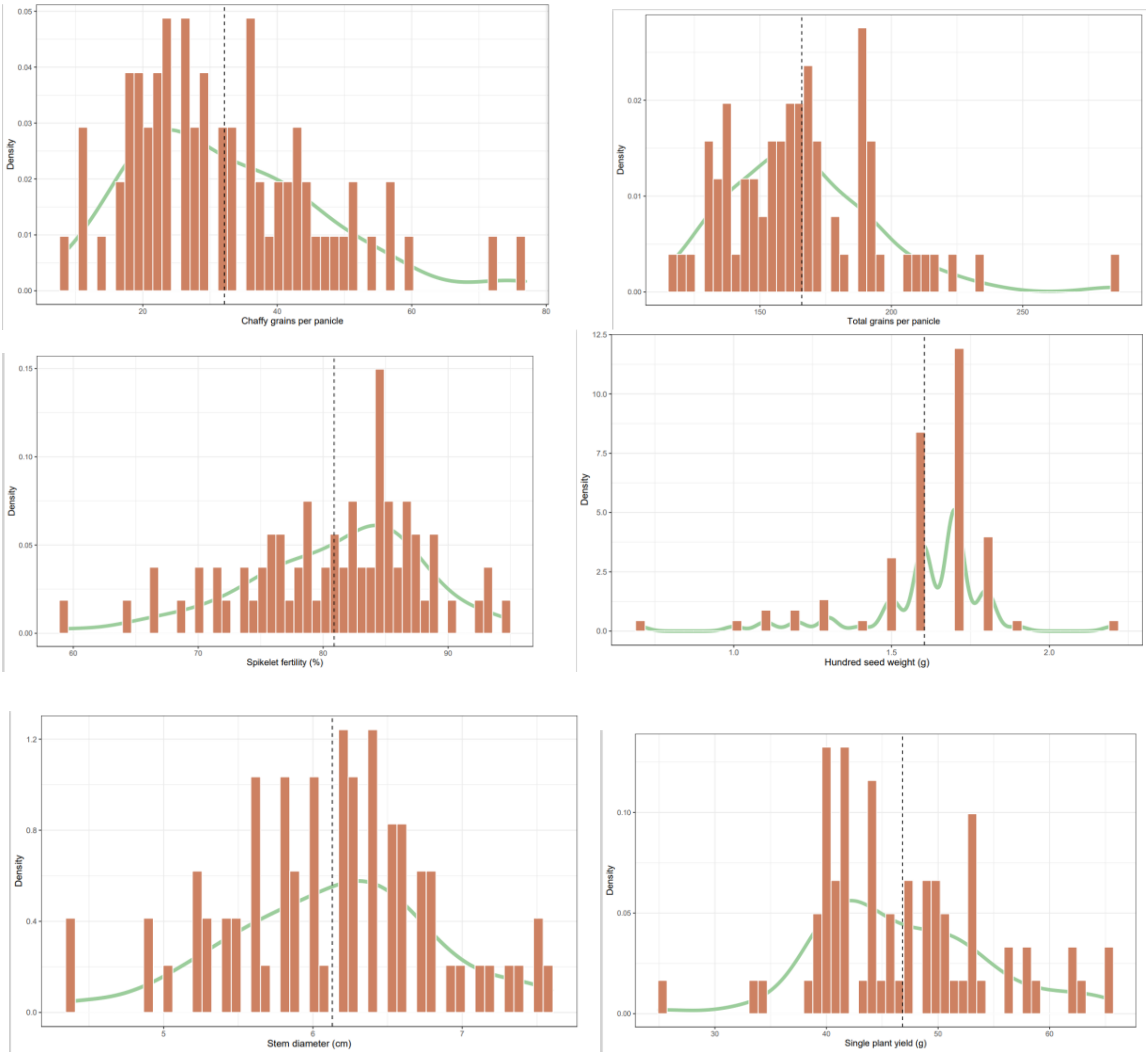


Fig. 1. Frequency distribution patterns of different traits in the BC$_2$F$_4$ generation

Fig. 1. Continued..



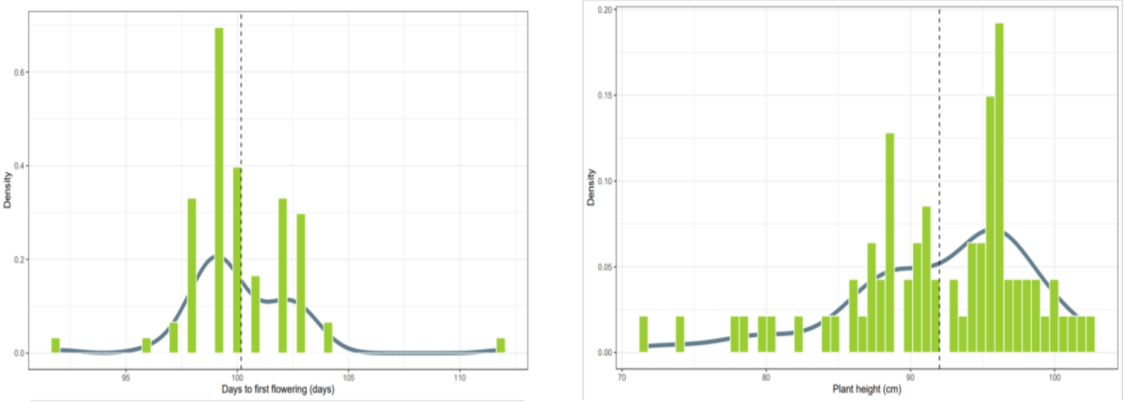


Fig. 2. Frequency distribution patterns of different traits in the BC_2F_5 generation

Fig. 2. Continued..

The negatively skewed and platykurtic curve was observed for stem diameter and spikelet fertility in both BC_2F_4 and BC_2F_5 generation. Many genes with duplicate gene action are responsible for these traits. Genetic gain for stem diameter and spikelet fertility can be increased by mild selection.

The mean values of BC_2F_5 individuals on BC_2F_4 for all the yield contributing traits were used to estimate the parent progeny regression analysis. The findings revealed an elevated association between the characteristics in the BC_2F_4 and BC_2F_5 generation. Regression coefficients were highly significant ($p<0.01$) for days to fifty percent flowering, plant height, number of productive tillers per plant, panicle length, flag leaf length, number of filled grains per panicle, number of chaffy grains per panicle, total grains per panicle, spikelet fertility, stem diameter and single plant yield. The maximum regression coefficient was observed for spikelet fertility (1.01) followed by filled grains per panicle (0.99), total grains per panicle (0.99), single plant yield (0.98), number of productive tillers per plant (0.97), flag leaf length (0.90), days to fifty percent flowering (0.87), panicle length (0.64) and stem diameter (0.57) indicating that selection of these traits at the early generation helps in obtaining plants with higher yield and good agronomic performance (**Table 4**). Similar findings were made regarding all yield contributing traits in drought study by Seeli *et al.* (2021), Blessy *et al.* (2022), single plant yield by Anilkumar and Ramalingam (2011), days to 50% flowering, plant height, and the number of productive tillers by Kavithamani *et al.* (2013), and panicle length by Lalitha *et al.* (2018). Greater genetic influence and fewer environmental influences are indicated by higher regression values (Palanisamy, 2018). In this work, regression estimates showed that these features were less affected by the environment and that selection based on their phenotypes in these generations was heritable. The parent-progeny regression technique is used to determine the narrow-sense heritability of variables that result from additive genetic variance (Rani *et al.,* 2021). For all the characteristics included in this analysis, the correlation coefficient was highly significant. Intergenerational correlation studies aid in determining the degree to which the trait's genetic potential will be passed on to succeeding generations. In the present study, intergenerational correlation was maximum for three traits number of chaffy grains per panicle (0.99), total grains per panicle (0.99) and spikelet fertility (0.99) followed by number of filled grains per panicle (0.98), single plant yield (0.98), number of productive tillers per panicle (0.97), flag leaf length (0.95), days to fifty percent flowering (0.66), panicle length (0.64), stem diameter (0.56), hundred seed weight (0.46) and plant height (0.38) showing all the traits having high heritability. Similar positive and significant results for plant height, the number of filled grains per panicle, hundred grain weight and panicle length were obtained by Seeli *et al.* (2021). Number of productive tillers, panicle length and single plant yield by Govintharaj *et al.* (2018).

Narrow sense heritability estimated based on parent progeny regression recorded high heritability for days to fifty percent flowering (65.6 %). Moderate heritability was observed in spikelet fertility (50.7 %) followed by stem diameter (50.7 %), number of filled grains per panicle (50.3 %), number of chaffy grains per panicle (50.3 %),

Table 4. Intergenerational correlation and regression values for the yield and yield contributing traits in BC_2F_4 and BC_2F_5 progenies

Traits	Correlation coefficient	Regression coefficient	Heritability
DFF	0.66**	0.87**	65.6
PH	0.38**	0.38**	38.4
NPT	0.97**	0.97**	49.4
PL	0.64**	0.64**	40.7
FLL	0.95**	0.9**	47.1
FG	0.98**	0.99**	50.3
CG	0.99**	1.01**	50.3
TG	0.99**	0.99**	49.9
SF	0.99**	1.01**	50.7
HSW	0.46**	0.32**	35.1
SD	0.56**	0.57**	50.7
SPY	0.98**	0.98**	50

*, ** significant at $P<0.01$ and $P<0.05$ respectively. DFF: Days to fifty percent flowering (days); NPT: number of productive tillers per plant; PL: panicle length (cm); FLL: flag leaf length (cm); FG: number of filled grains per panicle; CG: number of chaffy grains per panicle; TG: total grains per panicle; SF: spikelet fertility; HSW: hundred seed weight; SD: stem diameter (mm); SPY: single plant yield (g).

single plant yield (50 %), total grains per panicle (49.9 %), number of productive tillers per plant (49.4 %), flag leaf length (47.1%), panicle length (40.7 5), plant height (38.4 %) and hundred seed weight (35.1 %). Similar results were obtained by Kavithamani *et al.* (2013). Maximum heritability for days to fifty percent flowering was observed by Seeli *et al.* (2021) and Blessy *et al.* (2022).

Most of the submergence-tolerant cultivars identified, such as FR13A, FR43B, Kurkarupan, and Goda heenati, have shown limited agronomic performance and are not suitable for large-scale cultivation (Neeraja *et al.,* 2007). Consequently, these cultivars are crossed with high-yielding varieties to improve submergence tolerance while maintaining favourable agronomic characteristics for widespread cultivation. Therefore, it is crucial to carefully evaluate the segregating generations derived from these crosses to ensure enhanced submergence tolerance without compromising the high-yield potential of the varieties. In the present study, traits such as flowering, number of productive tillers, and grain yield exhibited high heritability, correlation, and regression coefficients, indicating their suitability for selecting superior genotypes in the early generations. Furthermore, the most promising lines among the segregants can serve as valuable donors for incorporating submergence tolerance into elite cultivars.

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