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SD Deshmukh
M.Sc. (Horti) Department of Horticulture (Vegetable Science), VNMKV, Parbhani, Maharashtra, India

VS Khandare
Head of Department, Department of Horticulture, VNMKV, Parbhani, Maharashtra, India

SM Kadam
M. Sc. (Horti) Department of Horticulture (Vegetable Science), College of Agriculture Latur, Maharashtra, India

KB Nagargoje
M.Sc. (Horti) Department of Horticulture (Vegetable Science), VNMKV, Parbhani, Maharashtra, India

GH Rathod
M.Sc. (Agri) Department of Genetics and plant breeding, VNMKV, Parbhani, Maharashtra, India

Corresponding Author:
SD Deshmukh
M.Sc. (Horti) Department of Horticulture (Vegetable Science), VNMKV, Parbhani, Maharashtra, India

Evaluation of high-yielding F_4 progenies of chilli (*Capsicum annuum* L.) for cultivation under Marathwada agro-climatic conditions in Maharashtra, India

SD Deshmukh, VS Khandare, SM Kadam, KB Nagargoje and GH Rathod

Abstract
This study identifies high-yielding F_4 chilli genotypes suitable for Marathwada agro-climatic conditions in Maharashtra, India. Focused on addressing low productivity challenges, the research evaluates 13 F_4 progenies and three standard checks for growth, yield, and disease resistance. Progenies PBNC-15, PBNC-16, and PBNC-17 stand out for green fruit yields, with PBNC-16 showing the highest overall yield. PBNC-14 exhibits the highest capsaicin content, contributing to the hot flavour. Noteworthy resistance to thrips, murda complex, and powdery mildew is observed in various progenies. The study recommends adopting PBNC-15, PBNC-16, and PBNC-17 for commercial cultivation in Maharashtra due to their exceptional performance in yield and resistance attributes, offering the potential to enhance chilli productivity in the region.

Keywords: Chilli, F_4 progenies, high-yielding, Marathwada agro-climatic conditions, pest and diseases

Introduction
The chili or hot pepper (*Capsicum annuum* var. annuum L.) is acknowledged as a significant economic and popular vegetable crop within India. It is cultivated for its green fruits, utilized as a vegetable, and its red form, employed as a spice. Belonging to the Solanaceae family, chili originated in New Mexico, Guatemala, and Bulgaria in Latin America. In India, chili cultivation spans approximately 7.43 lakh ha., with an annual production of 19.14 lakh tonnes and a productivity rate of 2576 kg/ha (first advance estimate, 2021-22). Maharashtra, with an area of 99.50 lakh ha., is a key region for chili cultivation, contributing to an annual production of 42.43 MT (Anon., 2021-22) [3].
The major chili-cultivating districts in Maharashtra include Dhule, Jalgaon, Satara, Nagpur, Kolhapur, Yewatmal, Aurangabad, and Sangli. Parbhani and Hingoli districts dominate chili cultivation in Marathwada, with substantial cultivation also occurring in Latur, Jalna, and Aurangabad. The prevalence of local cultivars is attributed to regional preferences, emphasizing the necessity for developing varieties with high yield potential, disease and pest resistance, and suitability for specific agro-climatic conditions to enhance the average yield nationwide.
Chilies serve as a rich source of vitamins A, C, and E, as well as potassium and folic acid, with low sodium and cholesterol content. The red coloration is attributed to capsanthin pigment, while the pungency arises from capsaicin, a crystalline, acrid, volatile alkaloid found in the fruit's placenta and pericarp. Capsaicin holds prophylactic and therapeutic uses in both allopathic and ayurvedic medicine. Furthermore, chilies yield oleoresin, a concentrated flavor extract with diverse applications in the processed food and beverage industries. Given its utility in pharmaceutical formulations and processed products, oleoresin derived from dried and ground chilies is gaining industrial significance due to its consistent quality, extended shelf life, microbial absence, and economical freight costs, particularly in export markets.
The Marathwada region exhibits a diverse array of chili types characterized by variations in fruit size, shape, and growth habits. Despite this diversity, there is a notable lack of systematic research on the selection and evaluation of suitable chili types. Consequently, there exists a compelling need to assess chili types in Marathwada for quality, yield, growth performance, and resilience against biotic and abiotic stressors. In this context, the present research endeavors to evaluate the F_4 Progenies of Chilli (*Capsicum annuum* L.) cultivated under Marathwada Agro-climatic Conditions.

Materials and Methods

The field experiment transpired at the experimental farms of the Horticulture Research Scheme (Vegetable), College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, during the Kharif season of 2021-22. The experimental materials encompassed thirteen F_4 progenies and three standard checks, all sourced from the Horticulture Research Scheme (Vegetable), Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. A Randomized Block Design was employed in the experimental layout, comprising 13 F_4 progenies and 3 standard checks, with two replications. Each F_4 progeny was treated as an individual treatment and was randomly replicated. Planting was executed in five rows, each containing eight plants, with a spacing of 60 cm x 45 cm.

To ensure uniformity, 40-day-old seedlings with an average height of 15 cm were meticulously selected and immersed in a solution composed of 10 ml of Trichoderma and 25g of Carbendazim in 10 liters of water. This treatment aimed to mitigate the risk of pests and diseases. Subsequently, chili seedlings were transplanted with a spacing of 60 x 45 cm. A random sampling technique was employed, selecting five plants from each treatment in all replications for in-depth studies on vegetative growth, yield characteristics, and the incidence of diseases and pests. Growth parameters, including plant height (cm), number of primary branches per plant, and plant spread (cm^2), as well as yield parameters such as the number of fruits per plant and fruit yield per plant (g), were recorded. Quality parameters, including the number of seeds per fruit and capsaicin content (%), were also documented. Simultaneously, instances of Thrips infestation, leaf curl incidence, and powdery mildew incidence (%) were recorded, recognizing that pest and disease damage can significantly impact fruit yield and quality.

The statistical analysis followed standard methods outlined by Panse and Sukhatme (1985) [11]. Standard errors (S.E.) of means were calculated, and critical differences (CD) at a 5% significance level were determined when the results exhibited significance. The data for individual plant characteristics were subjected to the method of analysis of variance, commonly applicable to the randomized block design.

Results and Discussion

The research was conducted to assess the comparative performance of F_4 progenies concerning growth, yield, and yield-attributing characteristics. The objective was to identify high-yielding F_4 progenies suitable for Marathwada agroclimatic conditions. Growth parameters, including plant height, number of primary branches per plant, plant spread, and plant growth habit, play pivotal roles in determining plant vigor, which, in turn, influences the biological yield of the crop. Significance variations were observed in all the growth parameters, and the corresponding data are presented in Table 1. Plant height is a crucial growth character in chilli, as it directly impacts crop yield through its influence on plant vigor. The data in Table 1 revealed a range in plant height from 61.17 cm to 79.96 cm, with a general mean of 71.26 cm. The highest plant height (79.96 cm) was recorded in F_4 progeny PBNC-19, which was comparable to progeny PBNC-16 (78.85 cm). In contrast, the lowest plant height (61.17 cm) was observed in F_4 progeny PBNC-15. The variation in plant height can be attributed primarily to genetic potential, as suggested by Aloni *et al*. (1999) [19], but environmental factors, especially temperature within the optimal range of around 25°C, also play a significant role, as noted by Abdullah *et al*. (2003) [1]. Sreelathakumary & Rajamony (2004) [15] also observed variations in plant height among chilli cultivars.

The number of primary branches per plant is directly related to plant spread, influencing decisions on plant spacing and overall crop management for maximizing fruit yield. The data on the number of primary branches among different chilli F_4 progenies are presented in Table 1. The number of primary branches varied significantly, ranging from 5.06 to 13.52, with a general mean of 8.37. Progeny PBNC-16 exhibited the maximum number of primary branches (13.52), comparable to progeny PBNC-15 (12.23), while progeny PBNC-19 displayed the minimum number of primary branches (5.06).

The variability observed in the number of primary branches per plant is likely attributed to the inherent characteristics of the progenies, interactions with the environment, and soil factors. This finding aligns with similar results reported by Amit *et al*. (2014) [2] and Vijaya *et al*. (2014) [17], indicating that genetic and environmental factors contribute to the variation in this growth parameter.

The data concerning plant spread in the North-South (N-S) direction at various growth stages are detailed in Table 1. Significant differences were noted among the F_4 progenies in terms of plant spread (N-S). Progeny PBNC-15 exhibited the highest plant spread (N-S) at all growth stages (34.36 cm, 38.08 cm, 59.04 cm, and 66.65 cm at 30, 60, 90, and 120 days after transplanting (DAT), respectively), comparable to progeny PBNC-16 (32.32 cm, 37.05 cm, 57.35 cm, and 64.84 cm at 30, 60, 90, and 120 DAT, respectively) and PBNC-17 (30.04 cm, 62.82 cm at 30 and 120 DAT, respectively). PBNC-18 also displayed significant plant spread (N-S) at 60 and 90 DAT (36.57 cm, 57.27 cm). Conversely, progeny PBNC-10 recorded the least plant spread (N-S) at early growth stages (13.36 cm, 19.94 cm, and 39.46 cm at 30, 60, and 90 DAT, respectively), while PBNC-7 exhibited the least plant spread (N-S) at 120 DAT.

The data on plant spread in the East-West (E-W) direction at different growth stages are presented in Table 1. There were significant variations among the progenies in terms of plant spread (E-W). Progeny PBNC-16 displayed the highest plant spread (E-W) at all growth stages (31.37 cm, 39.35 cm, 63.27 cm, and 68.43 cm at 30, 60, 90, and 120 DAT, respectively), comparable to progeny PBNC-17 (36.70 cm, 61.93 cm, 66.26 cm at 60, 90, and 120 DAT, respectively) and PBNC-15 (29.77 cm, 37.55 cm, 62.04 cm at 30, 60, 90 DAT, respectively). Progeny PBNC-10 recorded the least plant spread (E-W) at all growth stages (14.84 cm, 23.43 cm, 35.68 cm, and 49.43 cm at 30, 60, 90, and 120 DAT, respectively). The broad range of variation in plant spread may be attributed to the direct effects of soil and agro-climatic conditions, as well as the indirect effects of the number of branches per plant. These findings align with the observations of Mahantesh *et al*. (2013) [9] and Sharma *et al*. (2015) [13], confirming the significant influence of environmental and genetic factors on plant spread.

The number of fruits per plant stands as a pivotal yield attributing character, and the identification of promising lines in the present investigation underscores the need for reinforcing the selection process. The data presented in Table 2 illustrates that the mean value for the number of fruits per plant exhibited a range from 139.00 to 462.00, with a mean of 275.10. Progeny PBNC-16 displayed the highest number of fruits per plant (462.00), on par with progeny PBNC-15 (442.50) and PBNC-17 (412.50), while the lowest number of fruits (139.00) was observed in progeny PBNC-11. This variation can be primarily attributed to the genetic makeup of the plants. These results align with Mohanty (2003) [10], who reported the highest number of fruits per plant (233.97) in the X-235 genotype of chilli. The findings are further supported by the studies of Amit *et al*. (2014) [2] and Jyothi *et al*. (2011) [7].

The data in Table 2 also indicates a significant difference in fruit yield per plant. Progeny PBNC-16 recorded the highest fruit yield per plant (1903.38 g), on par with progeny PBNC-15 (1901.93 g) and PBNC-17 (1844.92 g), while progeny PBNC-19 exhibited the lowest fruit yield per plant (1011.23 g). The determination of fruit yield per plant is crucial in the selection of chilli progenies, as it reflects the adaptability and performance of the progenies under diverse environmental conditions (Sileshi, 2011). This may be attributed to the inherent genetic nature of the hybrid and the presence of a higher number of fruits per plant, greater fruit weight, and a comparatively higher number of primary and secondary branches. These findings align with the conclusions of Jamal *et al*. (2015) [6] and Zhani *et al*. (2015) [18], who proposed that the highest yield is often associated with the highest number of fruits per plant. The data further reveals that the mean value for the number of seeds per fruit ranged from 77.59 to 103.33, with a mean of 92.29. Progeny PBNC-20 exhibited the highest number of seeds per fruit (103.33), on par with PBNC-14 (101.97), while progeny PBNC-7 recorded the lowest number of seeds per fruit (77.59), followed by PBNC-13 (84.25). Variations in the number of seeds per fruit in chili were also observed by Chattopadhyay *et al*. (2011) and Dhaliwal *et al*. (2014). The data in Table 2 presents the mean values for capsaicin content, ranging from 0.20 to 0.66 percent, with an overall mean of 0.38 percent. Progeny PBNC-14 exhibited the significantly highest capsaicin content at 0.66 percent, on par with PBNC-20 at 0.64 percent. Conversely, progeny PBNC-7 displayed the significantly lowest capsaicin content at 0.20 percent. Notably, capsaicin percentage is a crucial determinant of the hot flavour in chili and holds significance for market value and industrial applications. The observed variation may be attributed to the presence of gene-modifying factors influencing pungency, as well as the ratio of placental tissue to seed and pericarp. Lekshmi and Sreelathakumary (2016) [8] also reported a capsaicin range of 0.10-0.88 percent in chili.

The data on pest and disease reactions of chili progenies are presented in Table 3. Thrips infestation ranged from 5.68 to 25.41 percent, with a mean infestation of 12.47 percent. Progeny PBNC-16 exhibited the minimum thrips infestation at 5.68 percent, while PBNC-18 recorded the maximum infestation at 25.41 percent.

The evaluation against murda complex under natural disease pressure conditions revealed varying levels of disease infection among the thirteen F_4 hybrids and three check varieties. Promising F_4 hybrids with a resistant reaction against the murda complex were PBNC-15, PBNC-16, PBNC-10, and PBNC-17, with disease infection percentages of 6.48, 5.12, 6.50, and 6.49, respectively. Additionally, four F_4 hybrids exhibited moderate resistance, while eleven F4 hybrids displayed moderate susceptibility to the murda complex. This study aligns with the findings of other scientists such as Tewari *et al*. (1985) [16] and Babu *et al*. (2002) [4], who documented the resistance of chili varieties to murda complex incidence.

The comparative performance of different chili F_4 progenies to powdery mildew infection is summarized in Table 3. Among the thirteen F_4 progenies and three standard checks screened, five progenies (PBNC-6, PBNC-10, PBNC-15, PBNC-16, PBNC-17) were found to be resistant to powdery mildew, with disease infection percentages of 8.40, 8.70, 8.37, 7.12, and 8.39, respectively. Additionally, six progenies exhibited moderate resistance, and three progenies displayed moderate susceptibility. One progeny, PBNC-13, was identified as susceptible to powdery mildew infection.

In the evaluation of fifteen F_4 progenies for their reaction to powdery mildew incidence under field conditions, five progenies (PBNC-16, PBNC-15, PBNC-17, PBNC-10, and PBNC-6) were found to be resistant, six progenies showed moderate resistance, one progeny was susceptible, and three progenies were most susceptible. The percentage of powdery mildew infection was lowest in PBNC-16 (7.12%) and highest in PBNC-11 (24.73%). The observed resistance to powdery mildew infection in chili aligns with findings reported by other scientists such as Souza and Cafe-Filho (2003) [14] and Rajesh *et al*. (2015) [12].

Table 1: Growth parameters recorded in different chilli progenies in the study.

Genotypes	Plant Height (cm)	Number of primary branches per plant	Plant spread (NORTH-SOUTH)	Plant spread (EAST-WEST)
PBNC-6	72.17	7.33	58.05	59.09
PBNC-7	73.46	8.77	47.86	61.31
PBNC-10	69.39	7.42	57.78	49.43
PBNC-11	75.46	7.97	54.21	59.37
PBNC-13	62.06	7.77	54.3	59.65
PBNC-14	69.55	7.87	62.09	56.65
PBNC-15	61.17	12.23	66.65	62.44
PBNC-16	78.85	13.52	64.84	68.43
PBNC-17	61.67	8.05	62.82	66.26
PBNC-18	71.29	7.18	56.48	63.48
PBNC-19	79.96	5.06	63.65	60.45
PBNC-20	67.4	8.01	63.85	64
BSS 273	77.47	7.85	56.77	65.21
BSS 355	71.26	8.56	63.22	63.42
BSS-378	77.85	8.08	56.6	53.41
Mean	71.26	8.37	59.27	60.84
Range	61.17-79.96	5.06-13.52	47.86-66.65	49.43-68.43
Result	SIG	SIG	SIG	SIG
SE(m)	0.33	0.4	0.64	0.72
CD	1	1.22	1.95	2.22

Table 2: Yield parameter and fruit quality parameters recorded in different chilli progenies in the study.

Genotype	No. of fruit per plant	Green fruit yield per planr (g)	Capsaicin (%)	No. of seed per fruit
PBNC-6	255	1155.01	0.3	93.77
PBNC-7	222.5	1303.02	0.2	77.59
PBNC-10	157.5	1284.66	0.36	86.16
PBNC-11	139	1411.02	0.48	94.3
PBNC-13	346	1564.82	0.31	84.25
PBNC-14	263	1638.31	0.66	101.97
PBNC-15	442.5	1901.93	0.31	98.78
PBNC-16	462	1903.38	0.3	89.16
PBNC-17	412.5	1844.92	0.4	99.12
PBNC-18	153.5	1051.16	0.34	99.51
PBNC-19	124.5	1011.23	0.38	89.27
PBNC-20	231.5	1303.4	0.64	103.33
BSS 273	374	1663.28	0.52	89.38
BSS 355	393	1739.1	0.32	87.56
BSS-378	350	1633.05	0.27	90.31
Mean	275.1	1493.88	0.38	92.29
Range	139.00 - 462.00	1011.23 - 1903.38	0.20 - 0.66	77.59 - 103.33
Result	SIG	SIG	SIG	NS
SE(m)	22.32	35.49	0.008	0.64
CD	68.08	108.7	0.026	1.95

Table 3: Reaction of chilli progenies against incidence of leaf curl (%), incidence of powdery mildew and thrips under field Condition.

Genotype	Incidence of leaf curl (%)			Incidence of powdery mildew			Incidence of thrips
	Percent of disease infection	Grade	Reaction	Percent of disease infection	Grade	Reaction	Mean
PBNC-6	10.27	2	MR	8.4	1	R	14.67
PBNC-7	9.80	2	MR	15.70	2	MR	6.69
PBNC-10	6.50	1	R	8.70	1	R	7.03
PBNC-11	11.50	2	MR	24.73	3	MS	9.05
PBNC-13	10.73	2	MR	38.40	4	S	6.92
PBNC-14	11.55	2	MR	13.40	2	MR	12.13
PBNC-15	6.48	2	MR	8.37	2	MR	6.78
PBNC-16	5.12	2	MS	7.12	2	MR	5.68
PBNC-17	6.49	1	R	8.39	4	S	6.90
PBNC-18	21.70	3	MS	12.56	2	MR	25.22
PBNC-19	24.50	3	MS	18.40	3	MS	25.41
PBNC-20	15.71	2	MR	12.40	2	MR	10.77
BSS 273	15.13	2	MR	12.30	2	MR	16.45
BSS 355	10.80	2	MR	20.21	3	MS	8.77
BSS-378	26.60	3	MS	12.56	2	MR	24.66
Mean	12.85	-	-	14.77	-	-	12.47
Range	-	-	-	-	-	-	5.68-25.41
Result	-	-	-	-	-	-	SIG
SE(m)	-	-	-	-	-	-	0.27
CD	-	-	-	-	-	-	0.83

Conclusion

In conclusion, the study focused on addressing the challenge of relatively low productivity in chilli cultivation in Maharashtra. The introduction of F_4 hybrids, characterized by genetic superiority, high yield, and resistance to pests and diseases, emerged as a promising strategy to enhance chilli productivity. Among the thirteen F_4 progenies and three checks evaluated, PBNC-15, PBNC-16, and PBNC-17 demonstrated outstanding green fruit yields, with PBNC-16 standing out with the highest yield at 923.75 q/ha. These superior F_4 progenies are recommended for commercial cultivation in the Maharashtra region, given their exceptional performance. The genetic traits of high yield and resistance make them valuable assets for elevating chilli productivity. The adoption of these F_4 hybrids holds the potential to contribute significantly to increased chilli yields, aligning with the broader goal of enhancing agricultural productivity in Maharashtra.

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