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Evaluation of CGMS-based chilli F_1 hybrids for morphometric, fruit quality and yield traits

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ABSTRACT

Chilli is a significant vegetable cum spice crop having broader applications in the food, phytogenic feed, cosmeceutical and pharmaceutical industries. To meet the demand, there is a need to develop F_1 hybrids with tolerance/ resistance to major threatening diseases and higher yields. The present investigation was conducted to study the diversity of morphometric, fruit quality and yield traits and their reaction to chilli leaf curl disease among thirteen CGMS-based high-yielding F_1 hybrids. The hybrids Arka Nihira, Arka Yashasvi, H-25, H-26, and Arka Tanvi excelled for most of the traits contributing to yield enhancement. The yield increment potential in these hybrids is attributed to high morphometric and fruit biometric. In relation to the local check (HPH-3351), hybrid Arka Nihira exhibited enhanced green fruit yield by about sixty-two per cent. The cluster plot partitioned these hybrids into four primary groups, revealing genetic similarities and differences among the hybrids. Further, a character association study indicates that traits such as days to 50 per cent flowering, plant spread, fruit girth, and the number of fruits per plant can be leveraged as indirect selection indices for green fruit yield while selecting a commercial hybrid cultivar in chilli breeding programs. The hybrids, Arka Nihira and Arka Tanvi, in particular, have the potential to be commercial cultivars in terms of yield, agronomic characteristics, and leaf curl disease tolerance in shallow basaltic soils of the Deccan plateau of India.

Key words: *Capsicum annuum* L., Character association, Diversity, Fruit yield, Leaf curl virus.

INTRODUCTION

Chilli is an important vegetable cum spice crop grown in diverse agro-climatic regions of the world. Chilli is valued for its manifold uses like pungency due to capsaicin, nutrition, and rich in pigment capsanthin as a colouring agent. The products like dried fruit, powder, pickles and oleoresin are exported on a larger scale from India (Thakur *et al*., 17). India stands second in dry chilli production, producing 1.28 million tons annually, followed by China with 0.25 million tons. On the other hand, fresh pepper is mainly cultivated in China, Mexico, Turkey, Indonesia, Spain, the USA, Nigeria, and India. China tops the list with an annual production of over 12.55 million tons, followed by Mexico with about 2.03 million tons (FAOSTAT, 4). Dry chilli accounts for 31% of India's total spice export value. The preference for chilli varies globally based on fruit-bearing habits and fruit types. Efforts are being made to develop F_1 hybrids that offer multiple benefits, including early maturity, high yield, superior quality, disease tolerance, and broader adaptability.

The F_1 hybrid development for the traits of interest from consumer and industrial perspectives is the primary objective in chilli. Recently, chilli F_1 hybrid CH-27 (Dhaliwal *et al*., 2) developed at PAU, Ludhiana, India and Arka Tejasvi, Arka Tanvi, Arka Saanvi, Arka Yashasvi and Arka Gagan with chilli leaf curl virus resistance were developed at ICAR-IIHR for commercial cultivation (ICAR-IIHR, 7). The performance of chilli hybrids and genotypes can differ based on agro-climatic conditions, as observed in previous studies. Selecting suitable hybrids for specific regions and segments of chilli is crucial. Despite its semi-arid climate and poor soil fertility, the Deccan plateau has the potential for chilli cultivation (Wakchaure *et al*., 19). However, yields in these regions may be affected by low rainfall, high temperatures, and the incidence of pests, particularly those transmitting the chilli leaf curl virus. Exploiting host plant resistance is a practical and eco-friendly approach to combat pests and diseases. Therefore, evaluating newly developed hybrids is essential to identify disease-resistant varieties and assess genetic variability. Evaluating productive and superior hybrids at various locations is necessary to obtain information for cultivar recommendations and chilli breeding programs (Martinez *et al*., 12).

The present study aims to assess the diversity and character associations in CGMS-based chilli hybrids grown in shallow basaltic soils of the semi-arid Deccan plateau in India, with the goal of improving

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the productivity of green and red chilli F_1 hybrids for economic yields.

MATERIALS AND METHODS

The experiment was conducted at ICAR-NIASM, Baramati, Pune district of Maharashtra, India, from August 2021 to January 2022. This region falls under the agroecological region Deccan Plateau, hot and semi-arid climate 100 (AER-6), and agro-climatic zone AZ-95, i.e., the scarcity zone of Maharashtra. The soil of the experimental site was gravelly loamy sand texture with 70.56-82.32% sand, 13.21-19.32% silt, and 9.21-16.21% clay content.

Thirteen CGMS-based chilli F_1 hybrids were recently developed using the diverse set of inbred lines by ICAR-IIHR, Bengaluru. The commercial hybrid HPH-3351 (Syngenta Pvt. Ltd., India) was used as a local check. The nursery was raised in cocopeat medium. Forty-day-old seedlings were transplanted in a randomized complete block design with four replicates with 30 plants in replication with spacing at 90 cm x 60 cm on raised beds irrigated through furrows. The standard recommended package of practices was followed for raising the crop.

The observations were recorded for morphological, fruit quality, physio-biochemical, and yield traits. Plant height, spread, and stem girth were measured 120 days after transplanting. Parameters such as fruit length, girth, pedicel length, and dry recovery percentage were measured using selected uniform fruits with a digital vernier calliper. The dry recovery percentage was measured by estimating the difference in red fruit's fresh and dry weight and expressed in cents. The average fruit weight, number, and yield data were recorded separately for green and red fruits. Red fruits were harvested when they reached uniform red colouration. Fruit yield and number were calculated based on combined harvests, and average fruit weight was derived.

The data about chilli leaf curl disease infestation (PDI) were recorded at 120 days after transplanting, and the number of plants infected was scored based on the appearance of symptoms among the total transplanted and expressed in the per cent (Srivastava *et al.*, 16). Statistical analysis was done using SPSS Ver. 20 package. DMRT was applied for pairwise comparisons of means. Clustering analysis was performed using the K-means clustering algorithm, and Pearson's correlation coefficients were generated among the characters using the R studio Corrplot package.

RESULTS AND DISCUSSION

Significant variation was observed for almost all the morphological traits except the primary branches because all the hybrids are genetically diverse from each other (Table 1). The days to 50 % flowering is a crucial trait to determine the earliness; except for

Table 1. Mean performance of chilli hybrids for morphometric traits.

Hybrid	Days to 50% flowering	Plant height (cm)	Primary branches (Nos.)	Plant spread (N-S)	Plant spread (E-W)	Stem girth (mm)
Arka Dhriti	33.33^{abc}	77.55^{ef}	9.78	66.93^{abc}	82.37^{ab}	18.12^{bc}
Arka Gagan	34.33^{ab}	77.72^{ef}	9.56	63.51^{bc}	67.71^{cde}	18.35^{bc}
Arka Nihira	33.33^{abc}	86.02^{cde}	9.55	70.10^{abc}	83.44^{ab}	19.93^{abc}
Arka Saanvi	33.67^{ab}	94.03^{bc}	10.78	75.45^{ab}	78.20^{bc}	18.27^{bc}
Arka Tanvi	33.67^{ab}	90.7^{bcd}	9.67	81.16^{a}	81.36^{abc}	19.23^{abc}
Arka Tejasvi	34.00^{ab}	79.73^{ef}	10.44	64.24^{bc}	73.21^{b-e}	18.81^{bc}
Arka Yashasvi	35.00^{a}	104.25^{a}	10.67	82.22^{a}	92.20^{a}	22.04^{a}
H-07	34.00^{ab}	91.01^{bcd}	9.78	72.71^{abc}	69.70^{b-e}	21.04^{ab}
H-20	33.67^{ab}	94.98^{abc}	10.45	57.72^{c}	73.90^{bcd}	21.17^{ab}
H-25	34.00^{ab}	82.74^{def}	9.55	69.11^{abc}	71.03^{b-e}	20.87^{abc}
H-26	34.00^{ab}	83.15^{def}	9.56	70.52^{abc}	74.13^{bcd}	21.01^{ab}
H-43	31.67^{c}	82.80^{def}	10.33	62.30^{bc}	62.48^{de}	17.71^{c}
H-47	31.67^{c}	97.25^{ab}	10.45	66.96^{abc}	76.86^{bcd}	22.02^{a}
HPH-5531	32.67^{bc}	72.50^{f}	9.44	57.64^{c}	58.74^{e}	19.57^{abc}
SE(m)	0.89	3.25	0.45	4.78	4.31	0.92
LSD	1.62	9.50	NS	13.96	12.61	2.70

Mean values of four replicates within columns are separated using DMRT P ≤ 0.05. NS-Non-significant

H-43, H47 and HPH-5531, all hybrids were at par, which indicated they had early flowering. The hybrids Arka Yashasvi, Arka Tanvi, Arka Nihira, H25, and H26 had significantly higher morphometric traits like plant height, spread, and stem girth. Plant ideotype is crucial in determining if a cultivar is suitable for a particular purpose (Meena *et al*., 13). Further, the vigour of the hybrid is also indicated by the plant spread and primary branches, which results in a higher number of secondary and tertiary branches.

The hybrids evaluated differed significantly in terms of fruit length and fruit girth (Table 2). Fruit length was highest in the hybrid HPH-5531, followed by H-43, while fruit girth was highest in the hybrids H-26, H-07, Arka Nihira, and H-25. Fruit girth in chilli is a major contributing trait directly related to the fruit weight (Ben-Chaim and Paran, 1) and the final yield (do Rego *et al*., 2). Chilli fruit harvesting is highly labour-intensive and time-consuming (Shamshiri *et al*., 14), especially when the fruit pedicel length is short. Pedicel length significantly varied among the hybrids, with H-47 being the longest, followed by Arka Nihira, Arka Dhriti, H-07, and H-20. Due to their pedicel length, these hybrids are comparatively best suited for easy harvesting. From an industrial perspective, the most crucial product in chilli is dry chilli powder, and hybrids with the highest dry recovery percentage are ideal for dry powder recovery (Sreenivas *et al*., 15). In hybrids, the dry recovery percentage ranged from 18.44 to 29.99 per cent, with Arka Gagan having the highest dry recovery percentage.

Table 2. Performance of chilli hybrids for fruit quality attributes.

Hybrid	Fruit length (cm)	Fruit girth (mm)	Pedicel length (cm)	Dry recovery (%)
Arka Dhriti	7.78^{de}	8.20^{cd}	2.81^{b}	22.26^{c-f}
Arka Gagan	6.23^{g}	6.74^{f}	2.11^{f}	29.99^{a}
Arka Nihira	8.59^{cd}	10.63^{b}	2.85^{b}	19.36^{gh}
Arka Saanvi	8.37^{cd}	8.85^{c}	2.23^{ef}	20.54^{e-h}
Arka Tanvi	6.78^{efg}	8.18^{cd}	2.22^{ef}	24.85^{bc}
Arka Tejasvi	8.54^{cd}	8.22^{cd}	2.45^{de}	21.2^{d-g}
Arka Yashasvi	6.37^{fg}	8.51^{cd}	2.69^{bcd}	24.78^{bc}
H-07	7.16^{d-g}	10.00^{b}	2.74^{bc}	23.06^{b-e}
H-20	7.74^{def}	7.70^{de}	2.7^{bc}	24.49^{bc}
H-25	8.52^{cd}	9.99^{b}	2.53^{cd}	21.01^{d-h}
H-26	7.27^{d-g}	12.506^{a}	2.67^{bcd}	18.44^{h}
H-43	9.95^{b}	7.00^{ef}	2.77^{bc}	23.30^{bcd}
H-47	9.19^{bc}	6.11^{f}	3.25^{a}	25.00^{b}
HPH-5531	11.58^{a}	7.79^{de}	2.60^{bcd}	20.19^{fgh}
SE(m)	0.43	0.31	0.80	0.80
LSD	1.25	0.90	0.22	2.34

Mean values of four replicates within columns are separated using DMRT $P \leq 0.05$.

Yield is a dependent trait that several factors can influence. In chilli, green and red fruits have high demand; for instance, green fruits are used for fresh consumption, whereas red fruits are used for the processing industry. The chilli hybrids differed significantly in terms of green and red fruit yield (Table 3). Due to the highest fruit weight with maximum fruit number, the hybrid Arka Nihira had the highest green fruit yield (1.63 kg $plant^{-1}$), followed by Arka Yashasvi, H-25, H-26 and Arka Tanvi. In addition, the hybrid H-26 yielded higher red ripe fruit. The higher fruit yields in these hybrids were due to the increased plant height, spread (canopy volume/density), and higher NDVI during the cropping period, especially over check. Furthermore, higher fruit physical indices, notably fruit length and girth, are important contributors to these hybrids' overall yield. The red ripe fruit yield was recorded as the highest in H-26, with no significant variation from seven other hybrids.

Chilli leaf curl disease, caused by begomoviruses, seriously threatens chilli production in India. This disease severely infects the plants and produces symptoms like stunted growth, leaf chlorosis, curling and fruit size reduction. A sizable number of farmers have withdrawn chilli cultivation in India due to yield losses caused by this disease (Kumar *et al*. 11). In India, some resistant sources such as S-343 (Thakur *et al*., 19), DLS-Sel-10, WBC-Sel-5 and PBC 142 (Srivastava *et al*., 16) are reported. For Chilli leaf curl virus- Raichur isolates, three resistant accessions, IHR4615, IHR4630 and IHR4517, have been identified (Yadav *et al*. 20); the resistance was found to be monogenic dominant in nature. Such gene action can be easily explored by developing F_1 hybrids, and in this direction, F_1 hybrids with resistance to chilli leaf curl Raichur isolate. The performance and reaction to leaf curl disease of hybrids may vary across the locations based on climate and begomovirus variability. In the present study, the identified potential F_1 hybrids were evaluated to learn about their performance in terms of reaction to chilli leaf curl disease and, finally, the economic yield. The response of chilli hybrids to leaf curl virus disease varied significantly.

All hybrids were disease-free (symptom-free) up to 90 days after transplanting and further up to 120 days, except four hybrids, all were infected with the leaf curl virus (Fig. 1). In chilli leaf curl virus, tolerance can be conferred *via* mechanisms

Table 3. Performance of chilli hybrids for green and red fruit yield parameters.

Hybrid	Green fruit			Red ripe fruit		
	weight (g)	Numbers	Yield(kg)	weight (g)	Numbers	Yield(kg)
		(Plant^{-1})			(Plant^{-1})	
Arka Dhriti	2.28^{cd}	489.33^{bcd}	1.05^{de}	3.02^{de}	211.00^{bc}	0.64^{abc}
Arka Gagan	1.85^{e}	523.56^{bc}	0.86^{f}	2.05^{fg}	188.11^{bcd}	0.40^{d}
Arka Nihira	3.41^{a}	481.67^{bcd}	1.63^{a}	5.59^{a}	127.11^{e}	0.69^{ab}
Arka Saanvi	2.54^{c}	535.56^{bc}	1.19^{cd}	3.15^{de}	195.00^{bcd}	0.61^{abc}
Arka Tanvi	2.03^{de}	683.78^{a}	1.40^{b}	2.41^{efg}	277.44^{a}	0.7^{ab}
Arka Tejasvi	2.39^{cd}	422.11^{def}	1.03^{def}	2.69^{def}	215.67^{bc}	0.61^{abc}
Arka Yashasvi	2.05^{de}	693.67^{a}	1.46^{b}	2.46^{efg}	248.00^{ab}	0.64^{abc}
H-07	2.28^{cd}	559.78^{b}	1.34^{bc}	3.35^{cd}	163.66^{cde}	0.56^{bcd}
H-20	1.90^{e}	453.67^{cde}	0.93^{ef}	2.48^{efg}	193.78^{bcd}	0.49^{cd}
H-25	3.03^{b}	504.89^{bcd}	1.45^{b}	4.69^{b}	142.33^{de}	0.69^{ab}
H-26	3.36^{ab}	422.56^{def}	1.41^{b}	5.96^{a}	122.00^{e}	0.75^{a}
H-43	2.56^{c}	378.33^{efg}	0.92^{ef}	2.91^{de}	190.22^{bcd}	0.54^{bcd}
H-47	2.05^{de}	350.28^{fg}	0.61^{g}	1.88^{g}	205.33^{bc}	0.38^{d}
HPH-5531	3.15^{ab}	321.00^{g}	1.01^{def}	3.97^{c}	113.11^{e}	0.52^{bcd}
SE(m)	0.11	28.61	0.06	0.23	18.22	0.05
LSD	0.32	83.63	0.17	0.68	53.27	0.16

Mean values of four replicates within columns are separated using DMRT P ≤ 0.05

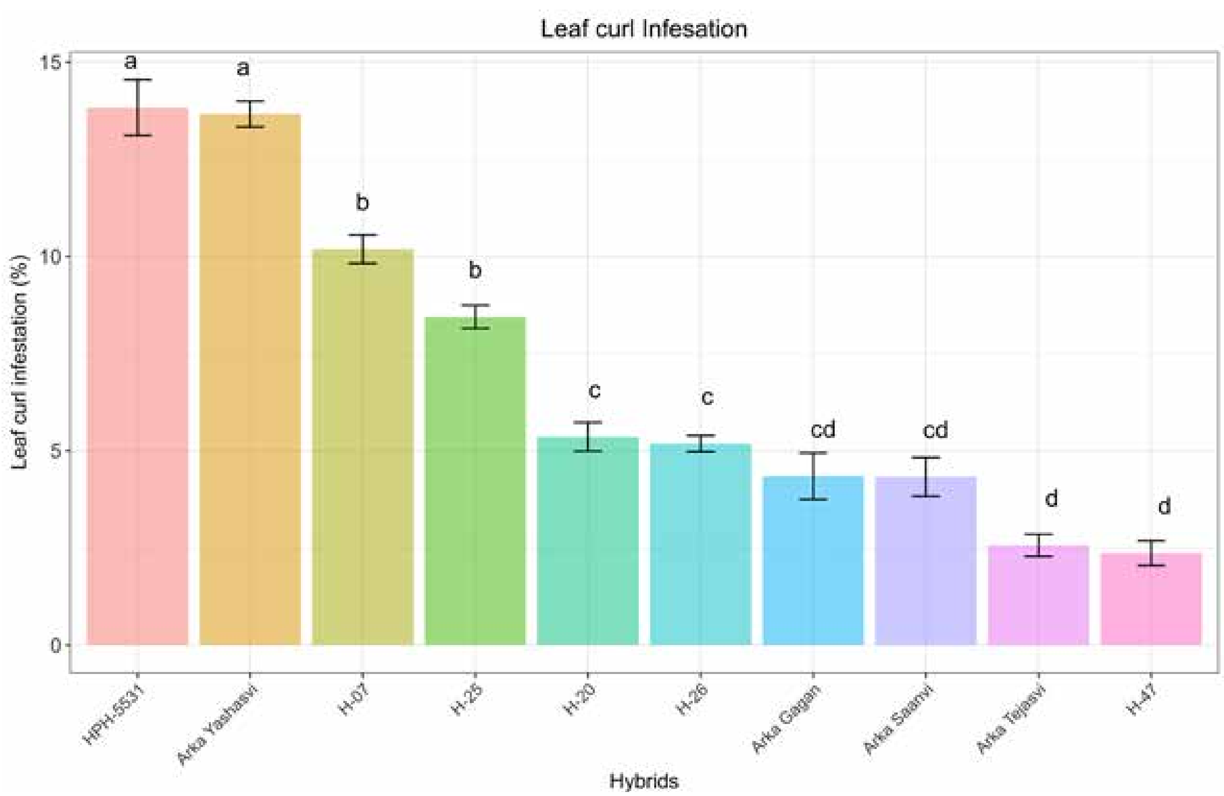

Fig. 1. Chilli leaf curl disease infestation 120 days after transplanting. Each bar represents the mean values of four replicates separated using DMRT P ≤ 0.05.

that alter viral concentration inside host cells and further limit virus mobility within cells, as well as activate the plant defence system (Hofmann *et al*. 6; Ishibashi *et al*., 8). Further, Thakur *et al*. (17) exclusively reviewed the impact of chilli leaf curl viral disease and highlighted that several genotypes and germplasm lines have been successfully developed employing the traditional breeding strategy, which is a significant breeding goal in tropical and sub-tropical regions around the world. Consequently, these conventionally bred hybrids Arka Nihira, Arka Yashasvi and Arka Tanvi, which had the least infestation, have the potential to impart tolerance to the chilli leaf curl disease and secure better yields in this region.

The K-means clustering results were used to determine genetic similarities and differences between the chilli hybrids (Fig. 2). The hybrids were divided into four groups. Cluster-1 has included hybrids Arka Dhriti, Arka Tejasvi, Arka Gagan, and H-20, which had medium fruit size with high yield potential. Further, Arka Nihira, H-07, H-25, and H-26 were four hybrids that were similar, having bullet-shaped fruits, notably the fruit girth, and were placed in cluster-2. In cluster-3, H-43, H-47, and H-3351, hybrids were positioned sharing similar traits like thin and long fruit. Cluster-4 had the hybrids (Arka Yashasvi, Arka Tanvi, and Arka Saanvi). As a result, hybrids in the same cluster have the most similarity for the multiple evaluated characteristics, whereas hybrids in separate clusters exhibit genetic variation that is directly proportional to their genetic diversity.

The character association through correlation coefficients measures the mutual relationship between different traits (Khapte *et al*., 10). The correlation coefficient results of the present investigation revealed that the green fruit yield in chilli hybrids was positively and significantly correlated with the number of days to fifty per cent flowering (DFF), plant spread, fruit girth, and the number of fruits per plant (Fig. 3). Therefore, these traits should be prioritized while identifying the hybrid for stable fruit yield and several reports earlier also highlighted the association of these traits with fruit yield (Janaki *et al*., 9). Additionally, the number of fruits per plant, an important yield-attributing trait, is positively and significantly correlated with DFF and plant spread, whereas average fruit weight is with fruit girth. A previous report by Hasanuzzaman *et al.* (5) highlighted that plant spread is associated with fruit yield and fruit weight with fruit girth (Ben-Chaim and Paran, 1) in chilli.

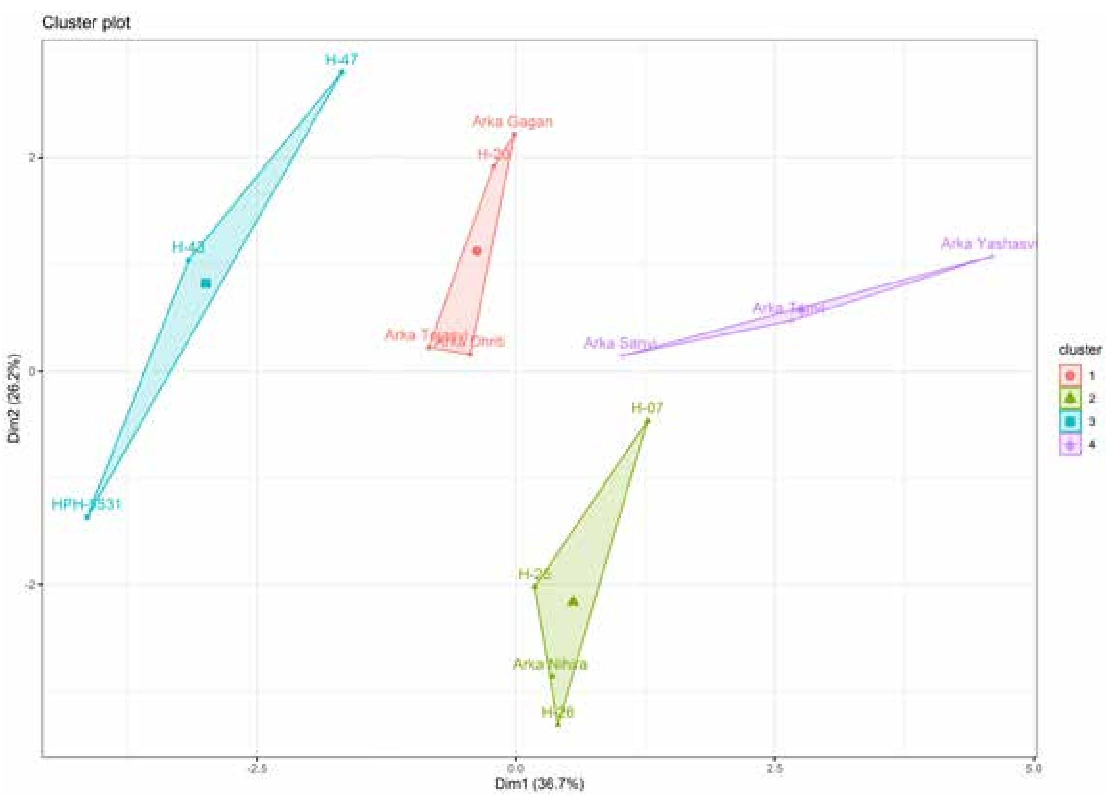

Fig. 2. K-means clustering of chilli hybrids grouped into four clusters represented by different colours based on evaluated traits.

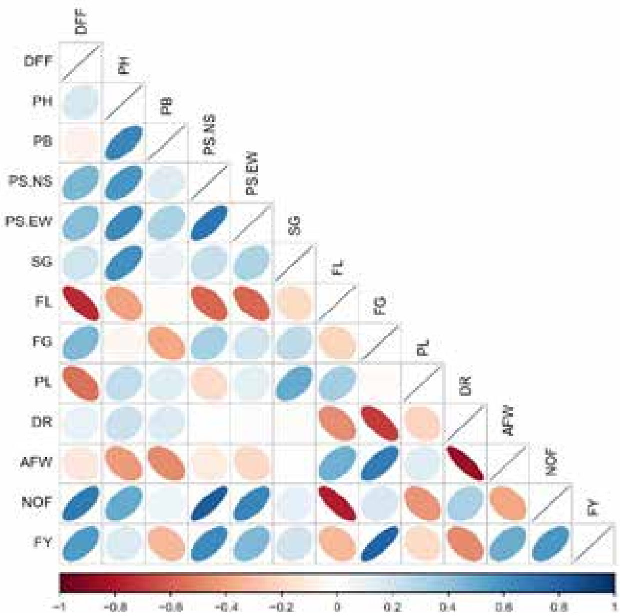

Fig. 3. Corrplot of combined Pearson's correlation coefficients among the different parameters in chilli hybrids. Positive and negative associations are presented in blue and red coloured ellipse, respectively. An absence of coloured ellipse represent no significant association at p-value < 0.005 among respective parameters. The intensity of colours of ellipse and the size of the circles indicate the proportion of Pearson's coefficients.

DFF-days to 50% flowering; PH-plant height; PB-primary branches; PS-plant spread; SG-stem girth; FL-fruit length; FG-fruit girth; PL-pedicel length; DR-dry recovery %; AFW-average fruit weight; NOF--number of fruits; FY-green fruit yield.

The evaluated hybrids displayed significant variations in morphometric and production traits. Promising hybrids such as Arka Nihira, Arka Yashasvi, H-25, H-26, and Arka Tanvi exhibited superior performance in yield improvement and fruit quality attributes, making them favourable choices for commercial cultivation. Key traits, including days to flowering, plant spread, fruit girth, and number of fruits per plant, were identified as reliable indicators for selecting high-yielding hybrid cultivars in chilli breeding programmes.

AUTHORS' CONTRIBUTION

Conceptualization of research (PSK, MRK, NP); Designing of the experiments (PSK, BKM, GCW, GS); Execution of field/lab experiments and data collection (PSK); Analysis of data and interpretation (PSK, NP, BKM, GCW); Preparation of the manuscript (PSK, MRK, NP).

DECLARATION

The authors declare no conflict of interest.

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