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EFFECT OF DIFFERENT HYBRIDS, SPACING AND FERTILIZER DOSES ALONG WITH THEIR INTERACTION (2 WAY) ON GROWTH AND YIELD OF BROCCOLI (*Brassica oleracea* var. *italica* L.)

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ABSTRACT
The present study was conducted to evaluate the effect of different hybrids, spacing and fertilizer doses along with their interaction (2 way) on growth and yield of broccoli (Brassica oleracea var. italica L.) at Department of Horticulture, Eternal University, Baru Sahib (Sirmaur). The experiment was conducted using a Factorial Randomized Block Design with three replications. The research trial consisted of three different hybrids (Saki, Diana, Besty), three spacings levels (60 × 30 cm, 60 × 45 cm and 60 × 60 cm) and three different fertilizer doses (75% RDF, 100% RDF, 125% RDF). The experimental results revealed that hybrid, spacing, fertilizer and their interaction showed significant effect on the vegetative characters and yield of broccoli. Among different hybrid, H_3 (besty) recorded maximum plant height, plant spread, leaf area, stem girth and stem diameter. Whereas, number of leaves per plant and curd yield/m^2 found under hybrid H_2 (diana). In case of spacing levels, maximum plant height and curd yield/m^2 was observed under spacing S_1 (60 × 30 cm). Whereas, S_3 (60 × 60 cm) recorded maximum plant spread, number of leaves per plant, leaf area, stem girth and stem diameter. Among different fertilizer doses, maximum value of all vegetative and yield parameters was found from the highest dose of fertilizer F_3 (125% RDF) in both the years and pooled data. In respect of F×H interaction maximum plant height, plant spread, leaf area, stem girth and stem diameter were found under F_3H_3. Whereas, F_3H_2 recorded highest number of leaves per plant and curd yield/m^2. For F×S interaction maximum plant spread, number of leaves per plant, leaf area, stem girth and stem diameter were found under F_3S_3. Whereas, F_3S_1 recorded highest plant height and curd yield/m^2. In case of H×S interaction, H_3S_1 recorded highest plant height, curd yield/m^2 was recorded highest under H_2S_1 and maximum number of leaves per plant was found under H_2S_3. Whereas, maximum plant spread, leaf area, stem girth and stem diameter were obtained from the treatment combinations H_3S_3.
Keywords: *Broccoli, Fertilizer, Growth, Hybrid, Interaction, Spacing, Yield*

INTRODUCTION

Broccoli (*Brassica oleracea* var. *italica* L.) is one of the winter vegetable crops, which is more nutritious and profitable than other cole crops (Thomson and Kelly, 1985). It belongs to family Cruciferae with the chromosome number (2n=18) (Kumar *et al.* 2021). In India, broccoli is typically referred to as "green sprouting broccoli" or "calabrese". It is also known as heading or Italian or winter broccoli (Tejaswini *et al.* 2018). There are green, white and purple-coloured cultivars of broccoli which are highly nutritious (Thapa *et al.* 2016). There are two kinds of Broccoli: Headed Broccoli and Sprouting Broccoli (green and purple). The most popular variety of broccoli is called heading, it is similar to cauliflower and produces a big, central head while italian or sprouting broccoli produces several florets or little heads, but not a solid head. Tender sections of the higher stem and immature, completely differentiated flower buds make up the plant's edible component (Abhijithnaik *et al.* 2022). All cole crops grow best in hardy and cool weather (Quratul *et al.* 2016). In world the area under cultivation of broccoli is 1.12 million hectare with annual production of 20.88 million tonnes (Anonymous, 2015). In India broccoli are grown over an area of 369

thousand ha with annual production 6745 thousand tonnes (Anonymous, 2015). Sprouting broccoli is widely grown in Himachal Pradesh. India is world's 2nd largest broccoli producer (Kumar *et al.* 2021). In India, it is used as a fresh vegetable. It is eaten as a cooked vegetable, along with being a mixed vegetable and added to soup. It is usually boiled, but may be consumed raw as salad. It is also used to prepare curry, pie and casserole etc. If broccoli is boiled for longer than 10 minutes, the vegetable loses a lot of its anticancer properties. However, other methods of preparation like steaming, frying and microwaving had no impact on the constituent compounds (Jeffery, 2005). Broccoli is an important health food as it has antioxidant properties and it contains a lot of "sulphoraphane," which may lower the chance of developing cancer and also beneficial in heart disease (Kumar *et al.* 2021). Compared to other Cole crops, broccoli is the most nutrient dense. It has 22 times more vitamin A than cabbage and 130 more than cauliflower (Rana, 2008).Hybrids respond differently under different climatic conditions. It is very important to identify the hybrids that are suitable for a particular agro-climatic region. It is sold at higher rate due to availability of many hybrids in the market having different quality features, farmers are unable to decide which hybrid to purchase as there is no standard package of practices regarding the same, farmers are unable to decide the hybrid in a particular agro-climatic zone (Gosavi and Bhagat 2009). The identification of suitable hybrids is of prime significance for the effective cultivation of any type of crop in any area (Bhangre *et al.* 2011). There are no recommendations regarding the suitability of a particular hybrid for a specific region. As a result, in order to help growers, a specific recommendation must be made in order to produce scientific evidence about the compatibility of particular types during a particular season (Singh *et al.* 2006, Yadav *et al.* 2016).Spacing is another important component that is going to affect the growth, yield and quality of broccoli (Amare and Gebremedhin, 2020). Proper spacing allows more amount of sunlight, provides proper nutrients to the plants and better yield and better quality of broccoli (Meena et al. 2022). It is very important to grow broccoli at suitable planting distance. Larger plants grow more vigorously and produce of greater quality when they are spaced farther apart, but plants that are close together compete more with one another for nutrients, air and light (Singh *et al.* 2012). Plant need nitrogen as a primary and vital ingredient at every stage of their development. Phosphorus is a primary nutrient for plants. Potassium is a vital nutrient for plants, as it has multiple contributing roles. Potassium helps control how much water the plant takes in and its distribution, which lessens the effects of dryness (Rani *et al.* 2021). One of the most vital components in increasing crop productivity is plant nutrition. As a cole crop, in terms of plant nutrition, broccoli is a major feeder. As a result, nitrogen, phosphorus and potassium effect the meristematic activity, mineral fertilizer increases broccoli growth and output (Thapa *et al.* 2016). So, farmer is unable to decide which spacing suits best for a particular hybrid. We are also going to optimize the used of the fertilizer. By giving the optimum dosage of fertilizer, we could avoid the wastage of fertilizer by means of leaching and avoiding any toxic effect on the soil environment and also saves the money of farmer as less fertilizer leads to decrease in cost price of produce. Keeping these things in our mind we had planned the research so that farmers must know the best hybrid, suitable spacing and optimum fertilizer dose providing us the maximum yield and profit.

Materials and Methods

2.1 Experimental site

The present study was carried out in two consecutive years 2023-2024 and 2024-2025 at Chhapang Research Farm, Department of Horticulture, Dr. Khem Singh Gill Akal College of Agriculture, Eternal University, Baru Sahib, Sirmaur, Himachal Pradesh. The experimental site was located at an altitude of 912 m high from mean sea level at altitude of 30°44'20" North and a longitude of 77°18'53" East. The experimental site has blazing summers and frigid winters because it is located in a semi-temperate, semi-humid mid hill agroclimatic zone of Himachal Pradesh. The area of experiment had an average temperature among 2023 ranges from 11.58°C - 25.66°C with relative humidity ranges from 61.48% - 78.40% and a rainfall ranges from 0 mm - 0.27 mm. While during 2024, temperature ranges from 13.48°C - 27.56°C with relative humidity ranges from 63.38% - 80.30% and a rainfall ranges from 0.04 mm - 0.47 mm. The details are mentioned in table 2.1.

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Selection of hybrid

Selection of hybrid is an important component in experiment. We had used three hybrids of private sectors which are mostly being grown by the farmers of Sirmaur district. We had used the hybrids Saki, Diana and Besty in the research. Saki is a hybrid broccoli variety from Sakata. It's known for its compact heads, tender florets and early maturity. Diana broccoli hybrid is a broccoli variety from Kalash that produces large heads and is a great producer. It is sweet, crunchy and hardy. Besty is a hybrid broccoli variety from Syngenta that is known for its high yield and compact green curds.

Table 2.1. Average monthly climate records

Months	Year	Temperature (°C)			RH (%)	Rainfall (mm)
		Minimum	Maximum	Mean		
September	2023	19.64	31.64	25.66	78.40	0.27
	2024	21.54	33.54	27.56	80.30	0.47
October	2023	12.89	28.14	20.53	68.96	0.16
	2024	14.79	30.04	22.43	70.86	0.36
November	2023	9.18	24.13	16.67	69.96	0.01
	2024	11.08	26.03	18.57	71.86	0.02
December	2023	5.17	20.54	12.87	66.74	0
	2024	7.07	22.44	14.77	68.64	0.04
January	2024	3.94	19.17	11.58	61.48	0.05
	2025	5.84	21.07	13.48	63.38	0.07

2.3 Raising of nursery and transplanting

Broccoli seedlings were raised in 3 different seed beds having dimension of 1 m × 1 m. The soil was properly prepared and transformed into a loose, friable state to achieve good tilth. In each seedbed, we had sown 1000 hybrids seeds each on 1st September 2023 and 2024, the seeds were placed in the seedbeds. Seeds were sown and completed light soil was applied over them. To give seedlings a healthy environment for growth, weeding and light watering were done as needed in the nursery beds. Healthy and uniform seedlings that were 30 to 35 days old were transplanted into the experimental plots in the afternoon after uprooting from the seed bed during the morning hours. The seedlings were transplanted on 4th October 2023 and 30th September 2024, and all of these kept at a depth of 2 cm. To reduce harm to the roots, the seedbed was irrigated before the seedlings were pulled out from nursery beds. After transplanting the light irrigation was done twice a day during the initial days.

2.4 Experimental details

We had used three different hybrids *viz.*, (Saki, Diana, Besty), three spacing levels namely (60 × 30 cm, 60 × 45 cm, 60 × 60 cm) and three different fertilizer doses (75% RDF, 100% RDF, 125% RDF). The experiment was laid out in Factorial Randomized Block Design with three replications. The plot size was 1.8m × 1.8m. There were 27 treatment combinations. The details are mentioned in table 2.2.

2.5 Measurement of vegetative and yield parameters

1. Plant height (cm): It was measured from the bottom to the top of the tallest leaf on five randomly chosen plants using metre scale in centimetre and their average value was determined.

2. Plant spread (cm): It was measured at the time of harvest, recording polar and equatorial diameter of the plant and average was worked out in centimetre.

3. Number of leaves per plant: Five randomly collected plants leaves were counted at harvest. The average of these counts was then taken.

4. Leaf area (cm^2): The fourth leaf from the top of each sample plants was collected and it was measured by using leaf area metre. The average was calculated and expressed in cm^2.

5. Stem girth (cm): The girth of stem of individual sample plants was recorded at the base of each individual plant and expressed in centimetre.

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6. Stem diameter (cm): The central stem was cut off, at which point the diameter of the stem was measured. The stem's diameter was measured in 3 dimensions by scale, with the mean of the 3 figures being converted to centimetres (cm).

7. Curd yield/m^2 (kg): In each treatment combinations, yield from all plants from all the pickings was calculated.

Table 2.2. Details of the treatment combinations : The details of the treatment combinations used in experiment are given below.

Treatment Code	Treatment combinations	Treatment details
T_1	$H_1S_1F_1$	Saki + 60 × 30 cm + 75 % RDF
T_2	$H_1S_1F_2$	Saki + 60 × 30 cm + 100 % RDF
T_3	$H_1S_1F_3$	Saki + 60 × 30 cm + 125 % RDF
T_4	$H_1S_2F_1$	Saki + 60 × 45 cm + 75 % RDF
T_5	$H_1S_2F_2$	Saki + 60 × 45 cm + 100 % RDF
T_6	$H_1S_2F_3$	Saki + 60 × 45 cm + 125 % RDF
T_7	$H_1S_3F_1$	Saki + 60 × 60 cm + 75 % RDF
T_8	$H_1S_3F_2$	Saki + 60 × 60 cm + 100 % RDF
T_9	$H_1S_3F_3$	Saki + 60 × 60 cm + 125 % RDF
T_{10}	$H_2S_1F_1$	Diana + 60 × 30 cm + 75 % RDF
T_{11}	$H_2S_1F_2$	Diana + 60 × 30 cm + 100 % RDF
T_{12}	$H_2S_1F_3$	Diana + 60 × 30 cm + 125 % RDF
T_{13}	$H_2S_2F_1$	Diana + 60 × 45 cm + 75 % RDF
T_{14}	$H_2S_2F_2$	Diana + 60 × 45 cm + 100 % RDF
T_{15}	$H_2S_2F_3$	Diana + 60 × 45 cm + 125 % RDF
T_{16}	$H_2S_3F_1$	Diana + 60 × 60 cm + 75 % RDF
T_{17}	$H_2S_3F_2$	Diana + 60 × 60 cm + 100 % RDF
T_{18}	$H_2S_3F_3$	Diana + 60 × 60 cm + 125 % RDF
T_{19}	$H_3S_1F_1$	Besty + 60 × 30 cm + 75 % RDF
T_{20}	$H_3S_1F_2$	Besty + 60 × 30 cm + 100 % RDF
T_{21}	$H_3S_1F_3$	Besty + 60 × 30 cm + 125 % RDF
T_{22}	$H_3S_2F_1$	Besty + 60 × 45 cm + 75 % RDF
T_{23}	$H_3S_2F_2$	Besty + 60 × 45 cm + 100 % RDF
T_{24}	$H_3S_2F_3$	Besty + 60 × 45 cm + 125 % RDF
T_{25}	$H_3S_3F_1$	Besty + 60 × 60 cm + 75 % RDF
T_{26}	$H_3S_3F_2$	Besty + 60 × 60 cm + 100 % RDF
T_{27}	$H_3S_3F_3$	Besty + 60 × 60 cm + 125 % RDF

Fig 1 Overall view of experimental trial

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2.6 Statistical analysis

Analysis of variance and means comparison from each treatment combination by using general linear model. Mean values were compared using DMRT at a significance level 0.05 using SPSS version 20.00.

1. Results and Discussion

3.1 Effect of different hybrids on vegetative and yield characters

Different characters like plant height, plant spread, number of leaves per plant, leaf area, stem girth, stem diameter and curd yield/m^2 were analysed by LSD at 5% level of significance.

Table 3.1. Effect of different hybrids on vegetative and yield characters

Source	Dependent Variable	Hybrid	2023	2024	Pooled
			Mean	Mean	Mean
Hybrid	Plant height	H_1	56.19	62.83	59.51
		H_2	49.07	50.60	49.83
		H_3	60.60	63.99	62.30
	Plant spread	H_1	65.43	67.99	66.71
		H_2	69.61	70.59	70.10
		H_3	75.80	78.93	77.37
	Number of leaves per plant	H_1	18.40	22.51	20.45
		H_2	18.91	23.04	20.97
		H_3	16.93	19.78	18.35
	Leaf area	H_1	409.25	425.68	417.47
		H_2	411.59	456.08	433.83
		H_3	424.26	461.53	442.89
	Stem girth	H_1	7.45	10.13	8.79
		H_2	7.61	11.16	9.39
		H_3	8.19	12.15	10.17
	Stem diameter	H_1	4.47	4.70	4.59
		H_2	4.44	4.74	4.59
		H_3	4.56	4.93	4.75
	Curd yield/m^2	H_1	2.62	3.23	2.93
		H_2	2.96	3.49	3.23
		H_3	1.67	2.35	2.01

*H_1- Saki, H_2- Diana, H_3- Besty

Table 3.2. Tests of between subjects

Source	Dependent Variable	2023		2024		Pooled	
		F Cal	p Value	F Cal	p Value	F Cal	p Value
Hybrid	Plant height	107.164	.000	345.750	.000	383.408	.000
	Plant spread	40.066	.000	180.228	.000	139.822	.000
	Number of leaves per plant	74.163	.000	126.586	.000	199.342	.000
	Leaf area	4.449	.016	94.550	.000	38.985	.000
	Stem girth	52.244	.000	147.871	.000	185.308	.000
	Stem diameter	3.414	.040	13.007	.000	13.808	.000
	Curd yield/m^2	78.548	.000	126.307	.000	199.639	.000

All the hybrids of broccoli exhibited significant variation in their performance in terms of yield attributes. In 2023, 2024 and pooled data for hybrid, all vegetative characters were highly significant as value of p was less than 0.05. The details are mentioned in table 3.2. The result of the experiment revealed that maximum value of plant height (60.60 cm, 63.99 cm, 62.30 cm), plant spread (75.80 cm, 78.93 cm, 77.37 cm), maximum leaf area (424.26 cm^2, 461.53 cm^2, 442.89 cm^2), stem girth (8.19 cm, 12.15 cm, 10.17 cm) and stem diameter (4.56 cm, 4.93 cm, 4.75 cm) were recorded hybrid H_3. Whereas, hybrid H_2 recorded maximum number of leaves per plant (18.91, 23.04, 20.97) and highest curd yield/m^2 (2.96 kg, 3.49 kg, 3.23 kg). This is due to presence of some enzymes in the hybrid which could have led to enhanced cell

division, cell enlargement eventually resulting in the maximum value of characters in the hybrids. The similar results were also found by Bhangre et al. 2011, Giri et al. 2013, Zaki et al. 2015, Tejaswini et al. 2018, Hossain et al. 2020, Singh et al. 2021, Kumar et al. 2021, Verma et al. 2022, Verma et al. 2023, Yadav et al. 2023 and Kaur and Rampal (2024). The details are mentioned in table 3.1.

In case of multiple comparisons, among different hybrids (H_1- Saki, H_2- Diana, H3- Besty) there were significant difference among different hybrids. Maximum difference was recorded between hybrid H_3 (besty) with hybrid H_2 (diana) for plant height. Highest difference was observed between besty with saki for plant spread, diana with besty for number of leaves per plant, besty with saki for leaf area, stem girth and stem diameter. Whereas, maximum difference was recorded between diana with besty for curd yield/m^2. It depicts that hybrid H_3 (Besty) is having maximum difference from either of the two hybrids which means that hybrid H_3 recorded maximum value with respect to vegetative and quantitative characters. Which could probably due to presence of favourable genes that could have interacted with the favourable environment condition prevailing at that time which might have led to maximum cell division, enlargement ultimately leading to maximum vegetative and yield characters. Results with similar to Bhangre et al. 2011, Giri et al. 2013, Zaki et al. 2015, Tejaswini et al. 2018, Hossain et al. 2020, Singh et al. 2021, Kumar et al. 2021, Verma et al. 2022, Verma et al. 2023, Yadav et al. 2023 and Kaur and Rampal (2024). The details are mentioned in table 3.3.

Table 3.3. Multiple comparisons of hybrids for different vegetative and yield characters

LSD			2023			2024			Pooled		
Dependent Variable	(I) H	(J) H	Mean Difference (I-J)	Std. Error	Sig.	Mean Difference (I-J)	Std. Error	Sig.	Mean Difference (I-J)	Std. Error	Sig.
Plant height	H_1	H_2	7.119*	.7872	.000	12.230*	.5780	.000	9.667*	.4827	.000
		H_3	-4.415*	.7872	.000	-1.163*	.5780	.049	-2.785*	.4827	.000
	H_2	H_1	-7.119*	.7872	.000	-12.230*	.5780	.000	-9.667*	.4827	.000
		H_3	-11.533*	.7872	.000	-13.393*	.5780	.000	-12.452*	.4827	.000
	H_3	H_1	4.415*	.7872	.000	1.163*	.5780	.049	2.785*	.4827	.000
		H_2	11.533*	.7872	.000	13.393*	.5780	.000	12.452*	.4827	.000
Plant spread	H_1	H_2	-4.181*	1.1470	.001	-2.596*	.7179	.001	-3.389*	.6839	.000
		H_3	-10.370*	1.1470	.000	-10.937*	.7179	.000	-10.663*	.6839	.000
	H_2	H_1	4.181*	1.1470	.001	2.596*	.7179	.001	3.389*	.6839	.000
		H_3	-6.189*	1.1470	.000	-8.341*	.7179	.000	-7.274*	.6839	.000
	H_3	H_1	10.370*	1.1470	.000	10.937*	.7179	.000	10.663*	.6839	.000
		H_2	6.189*	1.1470	.000	8.341*	.7179	.000	7.274*	.6839	.000
Number of leaves per plant	H_1	H_2	-.511*	.1823	.007	-.526*	.2208	.021	-.515*	.1492	.001
		H_3	1.470*	.1823	.000	2.730*	.2208	.000	2.104*	.1492	.000
	H_2	H_1	.511*	.1823	.007	.526*	.2208	.021	.515*	.1492	.001
		H_3	1.981*	.1823	.000	3.256*	.2208	.000	2.619*	.1492	.000
	H_3	H_1	-1.470*	.1823	.000	-2.730*	.2208	.000	-2.104*	.1492	.000
		H_2	-1.981*	.1823	.000	-3.256*	.2208	.000	-2.619*	.1492	.000
Leaf area	H_1	H_2	-2.333	5.7459	.686	-30.415*	2.8976	.000	-16.374*	3.2206	.000
		H_3	-14.996*	5.7459	.012	-35.848*	2.8976	.000	-25.411*	3.2206	.000
	H_2	H_1	2.333	5.7459	.686	30.415*	2.8976	.000	16.374*	3.2206	.000
		H_3	-12.663*	5.7459	.032	-5.433	2.8976	.066	-9.037*	3.2206	.007
	H_3	H_1	14.996*	5.7459	.012	35.848*	2.8976	.000	25.411*	3.2206	.000
		H_2	12.663*	5.7459	.032	5.433	2.8976	.066	9.037*	3.2206	.007
Stem girth	H_1	H_2	-.159*	.0790	.049	-1.030*	.1158	.000	-.581*	.0736	.000
		H_3	-.726*	.0790	.000	-2.022*	.1158	.000	-1.378*	.0736	.000
	H_2	H_1	.159*	.0790	.049	1.030*	.1158	.000	.581*	.0736	.000
		H_3	-.567*	.0790	.000	-.993*	.1158	.000	-.796*	.0736	.000

	H_3	H_1	.726*	.0790	.000	2.022*	.1158	.000	1.378*	.0736	.000
		H_2	.567*	.0790	.000	.993*	.1158	.000	.796*	.0736	.000
Stem diameter	H_1	H_2	.037	.0467	.431	-.026	.0501	.607	-.011	.0337	.743
		H_3	-.078	.0467	.101	-.233*	.0501	.000	-.159*	.0337	.000
	H_2	H_1	-.037	.0467	.431	.026	.0501	.607	.011	.0337	.743
		H_3	-.115*	.0467	.017	-.207*	.0501	.000	-.148*	.0337	.000
	H_3	H_1	.078	.0467	.101	.233*	.0501	.000	.159*	.0337	.000
		H_2	.115*	.0467	.017	.207*	.0501	.000	.148*	.0337	.000
Curd yield/m^2	H_1	H_2	-.344*	.1074	.002	-.259*	.0857	.004	-.315*	.0633	.000
		H_3	.933*	.1074	.000	.889*	.0857	.000	.907*	.0633	.000
	H_2	H_1	.344*	.1074	.002	.259*	.0857	.004	.315*	.0633	.000
		H_3	1.278*	.1074	.000	1.148*	.0857	.000	1.222*	.0633	.000
	H_3	H_1	-.933*	.1074	.000	-.889*	.0857	.000	-.907*	.0633	.000
		H_2	-1.278*	.1074	.000	-1.148*	.0857	.000	-1.222*	.0633	.000

3.2 Effect of different spacing levels on vegetative and yield characters

In both the years and pooled data for spacing, all vegetative characters were highly significant. The results revealed that spacing level S_1 (60 × 30 cm) found maximum value of plant height (56.79 cm, 61.84 cm, 59.32 cm) and highest curd yield/m^2 (2.50 kg, 3.10 kg, 2.80 kg). This might be due to the cumulative effect of higher plant population per unit area, that had led to maximum plant height and highest curd yield/m^2. These findings are in close accordance with the findings of Agarwal et al. 2007, Rahman et al. 2007 in cauliflower, Saikia et al. 2010, Bhangre et al. 2011, Fabek et al. 2011, Hossain et al. 2011, Khatun et al. 2011, Solunke et al. 2011, Gogoi et al. 2016, Khatan et al. 2016, Vinod et al. 2017, Kaur et al. 2021 and Kande et al. 2024 in broccoli. Whereas, maximum plant spread (74.85 cm, 77.54 cm, 76.20 cm), highest number of leaves per plant (18.44, 22.41, 20.43), maximum leaf area (433.99 cm^2, 467.03 cm^2, 450.51 cm^2), stem girth (8.16 cm, 11.87 cm, 10.01 cm) and stem diameter (4.66 cm, 5.10 cm, 4.88 cm) were recorded under spacing S_3 (60 × 60 cm). This may be due to better availability of spacing, air, soil moisture, nutrient, sunlight, a smaller number of plants per plot and less competition among plants. The similar results were reported by Bhangre et al. 2001, Munro et al. 2007, Kumar et al. 2007, Saikia et al. 2010, Solunke et al. 2011, Thirupal et al. 2014, Roni et al. 2017, Kumar et al. 2021, Kaur et al. 2021 and Kande et al. 2024 in broccoli. The details are mentioned in table 3.4 & 3.5.

Table 3.4. Effect of different levels of spacing on vegetative and yield characters

Source	Dependent Variable	Spacing	2023	2024	Pooled
			Mean	Mean	Mean
Spacing	Plant height	S_1	56.79	61.84	59.32
		S_2	56.72	60.09	58.40
		S_3	52.34	55.49	53.92
	Plant spread	S_1	65.95	68.19	67.07
		S_2	70.06	71.78	70.92
		S_3	74.85	77.54	76.20
	Number of leaves per plant	S_1	17.69	21.55	19.62
		S_2	18.10	21.37	19.73
		S_3	18.44	22.41	20.43
	Leaf area	S_1	386.89	428.90	407.90
		S_2	424.22	447.36	435.79
		S_3	433.99	467.03	450.51
	Stem girth	S_1	7.49	10.79	9.14
		S_2	7.60	10.79	9.20
		S_3	8.16	11.87	10.01
	Stem diameter	S_1	4.43	4.56	4.50
		S_2	4.38	4.71	4.54

		S_3	4.66	5.10	4.88
	Curd yield/m^2	S_1	2.50	3.10	2.80
		S_2	2.49	3.08	2.78
		S_3	2.27	2.90	2.58

*S_1- 60 × 30 cm, S_2- 60 × 45 cm, S_3- 60 × 60 cm

Table 3.5. Tests of between subjects

Source	Dependent Variable	2023		2024		Pooled	
		F Cal	p Value	F Cal	p Value	F Cal	p Value
Spacing	Plant height	20.551	.000	67.556	.000	74.863	.000
	Plant spread	29.204	.000	122.833	.000	99.061	.000
	Number of leaves per plant	9.764	.000	12.884	.000	19.648	.000
	Leaf area	42.177	.000	92.106	.000	109.962	.000
	Stem girth	44.236	.000	56.120	.000	92.304	.000
	Stem diameter	21.665	.000	66.355	.000	75.510	.000
	Curd yield/m^2	3.089	.054	4.109	.022	7.193	.002

Among different spacing levels (S_1- 60 × 30 cm, S_2- 60 × 45 cm, S_3- 60 × 60 cm), there were significant difference among S_1 with S_2 and S_3, S_2 with S_3, here maximum difference was recorded between S_1 with S_3 for plant height. Highest difference was observed between S_3 with S_1 for plant spread, number of leaves per plant, leaf area and stem girth. Whereas, maximum difference was recorded between S_3 with S_2 for stem diameter and S_1 with S_3 for curd yield/m^2. It is evident from the pair wise comparisons that in all the characters maximum difference is coming with respect to spacing level S_3 which means that S_3 recorded maximum value of different vegetative and yield characters which might be due to more terminal increase in closer spaced plant. Wider spacing, which might be due to more availability of sunlight, nutrients and water. Results with similar to Tejaswini et al. 2018. While spacing level S_1 recorded maximum yield/m^2 because of a greater number of plants in the plot and cumulative effect of all the plants could have led to maximum yield/m^2 in particular spacing level. The details are mentioned in table 3.6.

Table 3.6. Multiple comparisons of spacing for different vegetative and yield characters

LSD			2023			2024			Pooled		
Dependent Variable	(I) S	(J) S	Mean Difference (I-J)	Std. Error	Sig.	Mean Difference (I-J)	Std. Error	Sig.	Mean Difference (I-J)	Std. Error	Sig.
Plant height	S_1	S_2	.074	.7872	.925	1.759*	.5780	.004	.904	.4827	.067
		S_3	4.452*	.7872	.000	6.352*	.5780	.000	5.400*	.4827	.000
	S_2	S_1	-.074	.7872	.925	-1.759*	.5780	.004	-.904	.4827	.067
		S_3	4.378*	.7872	.000	4.593*	.5780	.000	4.496*	.4827	.000
	S_3	S_1	-4.452*	.7872	.000	-6.352*	.5780	.000	-5.400*	.4827	.000
		S_2	-4.378*	.7872	.000	-4.593*	.5780	.000	-4.496*	.4827	.000
Plant spread	S_1	S_2	-4.107*	1.1470	.001	-3.593*	.7179	.000	-3.848*	.6839	.000
		S_3	-8.900*	1.1470	.000	-9.352*	.7179	.000	-9.115*	.6839	.000
	S_2	S_1	4.107*	1.1470	.001	3.593*	.7179	.000	3.848*	.6839	.000
		S_3	-4.793*	1.1470	.000	-5.759*	.7179	.000	-5.267*	.6839	.000
	S_3	S_1	8.900*	1.1470	.000	9.352*	.7179	.000	9.115*	.6839	.000
		S_2	4.793*	1.1470	.000	5.759*	.7179	.000	5.267*	.6839	.000
Number of leaves per plant	S_1	S_2	-.407*	.1823	.030	.185	.2208	.405	-.122	.1492	.416
		S_3	-.744*	.1823	.000	-.859*	.2208	.000	-.811*	.1492	.000
	S_2	S_1	.407*	.1823	.030	-.185	.2208	.405	.122	.1492	.416
		S_3	-.337	.1823	.070	-1.044*	.2208	.000	-.689*	.1492	.000
	S_3	S_1	.744*	.1823	.000	.859*	.2208	.000	.811*	.1492	.000

		S_2	.337	.1823	.070	1.044*	.2208	.000	.689*	.1492	.000
Leaf area	S_1	S_2	-37.333*	5.7459	.000	-18.441*	2.8976	.000	-27.896*	3.2206	.000
		S_3	-47.107*	5.7459	.000	-38.122*	2.8976	.000	-42.611*	3.2206	.000
	S_2	S_1	37.333*	5.7459	.000	18.441*	2.8976	.000	27.896*	3.2206	.000
		S_3	-9.774	5.7459	.095	-19.681*	2.8976	.000	-14.715*	3.2206	.000
	S_3	S_1	47.107*	5.7459	.000	38.122*	2.8976	.000	42.611*	3.2206	.000
		S_2	9.774	5.7459	.095	19.681*	2.8976	.000	14.715*	3.2206	.000
Stem girth	S_1	S_2	-.107	.0790	.179	.004	.1158	.975	-.044	.0736	.548
		S_3	-.656*	.0790	.000	-1.078*	.1158	.000	-.859*	.0736	.000
	S_2	S_1	.107	.0790	.179	-.004	.1158	.975	.044	.0736	.548
		S_3	-.548*	.0790	.000	-1.081*	.1158	.000	-.815*	.0736	.000
	S_3	S_1	.656*	.0790	.000	1.078*	.1158	.000	.859*	.0736	.000
		S_2	.548*	.0790	.000	1.081*	.1158	.000	.815*	.0736	.000
Stem diameter	S_1	S_2	.067	.0467	.159	-.152*	.0501	.004	-.059	.0337	.084
		S_3	-.230*	.0467	.000	-.552*	.0501	.000	-.400*	.0337	.000
	S_2	S_1	-.067	.0467	.159	.152*	.0501	.004	.059	.0337	.084
		S_3	-.296*	.0467	.000	-.400*	.0501	.000	-.341*	.0337	.000
	S_3	S_1	.230*	.0467	.000	.552*	.0501	.000	.400*	.0337	.000
		S_2	.296*	.0467	.000	.400*	.0501	.000	.341*	.0337	.000
Curd yield/m^2	S_1	S_2	.026	.1074	.810	.000	.0857	1.000	.019	.0633	.771
		S_3	.241*	.1074	.029	.196*	.0857	.026	.219*	.0633	.001
	S_2	S_1	-.026	.1074	.810	.000	.0857	1.000	-.019	.0633	.771
		S_3	.215	.1074	.050	.196*	.0857	.026	.200*	.0633	.003
	S_3	S_1	-.241*	.1074	.029	-.196*	.0857	.026	-.219*	.0633	.001
		S_2	-.215	.1074	.050	-.196*	.0857	.026	-.200*	.0633	.003

3.3 Effect of different fertilizer doses on vegetative and yield characters

Among the different fertilizer levels, in 2023 the result revealed that plant height, number of leaves per plant, leaf area, stem girth, stem diameter and curd yield/m^2 were significant whereas plant spread was non significant as the value of p is more than 0.05. In 2024 and pooled data, all characters were responded significantly as the value of p was less than 0.05. The details are mentioned in table 3.8.

Table 3.7. Effect of different fertilizer doses on vegetative and yield characters

ource	Dependent Variable	ertilizer	023	024	ooled
			Mean	Mean	Mean
ertilizer	lant height	$_1$	4.20	7.40	5.80
		$_2$	3.47	9.25	6.36
		$_3$	8.18	0.77	9.47
	lant spread	$_1$	9.40	0.37	9.89
		$_2$	0.44	3.25	1.84
		$_3$	1.01	3.89	2.45
	umber of leaves per plant	$_1$	7.72	1.51	9.61
		$_2$	8.22	1.65	9.94
		$_3$	8.29	2.17	0.23
	eaf area	$_1$	04.27	41.55	22.91
		$_2$	17.64	42.59	30.11
		$_3$	23.18	59.14	41.16
	tem girth	$_1$	.57	0.60	.08
		$_2$	.75	1.27	.51
		$_3$	.92	1.58	.75

	tem diameter	₁	.43	.63	.53
		₂	.45	.77	.61
		₃	.59	.97	.78
	urd yield/m²	₁	.73	.41	.07
		₂	.07	.78	.42
		₃	.46	.89	.67

*F_1- 75% RDF, F_2- 100% RDF, F_3- 125% RDF

Table 3.8. Tests of between subjects

Source	Dependent Variable	2023		2024		Pooled	
		F Cal	p Value	F Cal	p Value	F Cal	p Value
Fertilizer	Plant height	20.282	.000	17.852	.000	35.071	.000
	Plant spread	0.977	.383	19.412	.000	8.474	.001
	Number of leaves per plant	6.822	.002	5.049	.010	9.875	.000
	Leaf area	6.451	.003	24.688	.000	19.840	.000
	Stem girth	10.948	.000	36.565	.000	44.485	.000
	Stem diameter	7.028	.002	23.628	.000	26.558	.000
	Curd yield/m^2	147.393	.000	210.049	.000	353.980	.000

For both the years and pooled data, among various levels of fertilizer doses, F_3 (125% RDF) recorded maximum value of plant height (58.18 cm, 60.77 cm, 59.47 cm), plant spread (71.01 cm, 73.89 cm, 72.45 cm), higher number of leaves per plant (18.29, 22.17, 20.23), maximum leaf area (423.18 cm^2, 459.14 cm^2, 441.16 cm^2), maximum stem girth (7.92 cm, 11.58 cm, 9.75 cm), stem diameter (4.59 cm, 4.97 cm, 4.78 cm) and highest curd yield/m^2 (3.46 kg, 3.89 kg, 3.67 kg). It might be due to more vegetative growth, development, photosynthesis, dry matter synthesis and translocation to storage organ that might had led to an increase in all the above mention parameters that attribute to increase the final curd yield/m^2. These findings are very similar to those of Moniruzzaman et al. 2007, Supe and Marbhal 2008, Prasad et al. 2009 in chinese cabbage, Giri et al. 2013, Kumar et al. 2013, Singh et al. 2015 in broccoli, Haque et al. 2015 in cabbage, Neethu et al. 2015, Roni et al. 2017, Mohanta et al. 2018 in broccoli, Priyanka et al. 2023, Akanksha et al. 2023, Chalabi and Ibraheem 2024 in broccoli. The details are mentioned in table 3.7.

Among different fertilizer levels (F_1- 75% RDF, F_2- 75% RDF, F_3- 75% RDF), there were significant difference among F_1 with F_2 and F_3, F_2 with F_3, here maximum difference was recorded between F_3 with F_2 for plant height. Highest difference was observed between F_3 with F_1 for plant spread, number of leaves per plant, leaf area, stem girth, stem diameter and curd yield/m^2. Which could probably due to larger amount of nutrient available to the plant in the fertilizer level of F_3 which could have been utilized by the plants for synthesis of photosynthates leading to best result. The results with similar to Roni et al. 2017 and Abhijithnaik et al. 2022. The details are mentioned in table 3.9.

Table 3.9. Multiple comparisons of fertilizer for different vegetative and yield characters

LSD			2023			2024			Pooled		
Dependent Variable	(I) F	(J) F	Mean Difference (I-J)	Std. Error	Sig.	Mean Difference (I-J)	Std. Error	Sig.	Mean Difference (I-J)	Std. Error	Sig.
Plant height	F_1	F_2	-.726	.7872	.361	-1.844*	.5780	.002	-.570	.4827	.243
		F_3	-3.978*	.7872	.000	-3.367*	.5780	.000	-3.681*	.4827	.000
	F_2	F_1	.726	.7872	.361	1.844*	.5780	.002	.570	.4827	.243
		F_3	-4.704*	.7872	.000	-1.522*	.5780	.011	-3.111*	.4827	.000
	F_3	F_1	3.978*	.7872	.000	3.367*	.5780	.000	3.681*	.4827	.000
		F_2	4.704*	.7872	.000	1.522*	.5780	.011	3.111*	.4827	.000
Plant spread	F_1	F_2	-1.033	1.1470	.372	-2.878*	.7179	.000	-1.952*	.6839	.006
		F_3	-1.607	1.1470	.167	-3.522*	.7179	.000	-2.567*	.6839	.000
	F_2	F_1	1.033	1.1470	.372	2.878*	.7179	.000	1.952*	.6839	.006

		F_3	-.574	1.1470	.619	-.644	.7179	.373	-.615	.6839	.373
	F_3	F_1	1.607	1.1470	.167	3.522*	.7179	.000	2.567*	.6839	.000
		F_2	.574	1.1470	.619	.644	.7179	.373	.615	.6839	.373
Number of leaves per plant	F_1	F_2	-.504*	.1823	.008	-.144	.2208	.516	-.348*	.1492	.023
		F_3	-.570*	.1823	.003	-.663*	.2208	.004	-.630*	.1492	.000
	F_2	F_1	.504*	.1823	.008	.144	.2208	.516	.348*	.1492	.023
		F_3	-.067	.1823	.716	-.519*	.2208	.023	-.281	.1492	.065
	F_3	F_1	.570*	.1823	.003	.663*	.2208	.004	.630*	.1492	.000
		F_2	.067	.1823	.716	.519*	.2208	.023	.281	.1492	.065
Leaf area	F_1	F_2	-13.378*	5.7459	.024	-1.033	2.8976	.723	-7.215*	3.2206	.029
		F_3	-18.919*	5.7459	.002	-17.585*	2.8976	.000	-18.248*	3.2206	.000
	F_2	F_1	13.378*	5.7459	.024	1.033	2.8976	.723	7.215*	3.2206	.029
		F_3	-5.541	5.7459	.339	-16.552*	2.8976	.000	-11.033*	3.2206	.001
	F_3	F_1	18.919*	5.7459	.002	17.585*	2.8976	.000	18.248*	3.2206	.000
		F_2	5.541	5.7459	.339	16.552*	2.8976	.000	11.033*	3.2206	.001
Stem girth	F_1	F_2	-.189*	.0790	.020	-.663*	.1158	.000	-.407*	.0736	.000
		F_3	-.352*	.0790	.000	-.978*	.1158	.000	-.652*	.0736	.000
	F_2	F_1	.189*	.0790	.020	.663*	.1158	.000	.407*	.0736	.000
		F_3	-.163*	.0790	.044	-.315*	.1158	.009	-.244*	.0736	.002
	F_3	F_1	.352*	.0790	.000	.978*	.1158	.000	.652*	.0736	.000
		F_2	.163*	.0790	.044	.315*	.1158	.009	.244*	.0736	.002
Stem diameter	F_1	F_2	-.011	.0467	.813	-.130*	.0501	.012	-.096*	.0337	.006
		F_3	-.141*	.0467	.004	-.330*	.0501	.000	-.252*	.0337	.000
	F_2	F_1	.011	.0467	.813	.130*	.0501	.012	.096*	.0337	.006
		F_3	-.130*	.0467	.007	-.200*	.0501	.000	-.156*	.0337	.000
	F_3	F_1	.141*	.0467	.004	.330*	.0501	.000	.252*	.0337	.000
		F_2	.130*	.0467	.007	.200*	.0501	.000	.156*	.0337	.000
Curd yield/m^2	F_1	F_2	-.330*	.1074	.003	-.374*	.0857	.000	-.348*	.0633	.000
		F_3	-1.726*	.1074	.000	-1.485*	.0857	.000	-1.604*	.0633	.000
	F_2	F_1	.330*	.1074	.003	.374*	.0857	.000	.348*	.0633	.000
		F_3	-1.396*	.1074	.000	-1.111*	.0857	.000	-1.256*	.0633	.000
	F_3	F_1	1.726*	.1074	.000	1.485*	.0857	.000	1.604*	.0633	.000
		F_2	1.396*	.1074	.000	1.111*	.0857	.000	1.256*	.0633	.000

3.4 Effect of fertilizer × hybrid on vegetative and yield characters

In 2023, 2024 and pooled data for Fertilizer × Hybrid, all vegetative characters were significant**.** The result revealed that maximum value of plant height (63.82 cm, 66.86 cm, 65.34 cm), plant spread (79.02 cm, 82.72 cm, 80.87 cm), maximum leaf area (444.01 cm^2, 479.17 cm^2, 461.59 cm^2), stem girth (8.38 cm, 12.66 cm, 10.52 cm) and stem diameter (4.71 cm, 5.02 cm, 4.86 cm) were observed under F_3H_3. Which might to be interaction of some favourable genes which might be favouring the absorption of nutrients at higher fertilizer dose and have resulting in maximum absorption of nutrients by the plants. Whereas, F_3H_2 recorded maximum number of leaves per plant (19.13, 23.61, 21.37) and highest curd yield/m^2 (4.11 kg, 4.45 kg, 4.28 kg). This might be due to the availability of greater amount of nutrient to the plant, favourable genes which might to be governing the characters. Similar findings have also been reported by Giri et al. 2013, Zaki et al. 2015, Hossain et al. 2020, Singh et al. 2021 and Abhijithnaik et al. 2022. The details are mentioned in table 3.10 & 3.11.

Table 3.10. Effect of Fertilizer × Hybrid on vegetative and yield characters

Fertilizer * Hybrid			**2023**	**2024**	**Pooled**
Dependent Variable	**F**	**H**	**Mean**	**Mean**	**Mean**
Plant height	F_1	H_1	55.59	62.27	58.93

		H_2	48.90	48.63	48.77
		H_3	58.11	61.31	59.71
	F_2	H_1	55.11	62.64	58.88
		H_2	45.44	51.29	48.37
		H_3	59.87	63.81	61.84
	F_3	H_1	57.86	63.58	60.72
		H_2	52.85	51.88	52.37
		H_3	63.82	66.86	65.34
Plant spread	F_1	H_1	66.28	66.32	66.30
		H_2	66.10	69.07	67.58
		H_3	75.83	75.72	75.78
	F_2	H_1	65.70	70.60	68.15
		H_2	73.06	70.80	71.93
		H_3	72.56	78.34	75.45
	F_3	H_1	64.32	67.06	65.69
		H_2	69.69	71.90	70.79
		H_3	79.02	82.72	80.87
Number of leaves per plant	F_1	H_1	17.65	21.78	19.72
		H_2	18.70	23.27	20.99
		H_3	16.80	19.47	18.14
	F_2	H_1	19.05	22.99	21.02
		H_2	18.89	22.23	20.56
		H_3	16.73	19.74	18.24
	F_3	H_1	18.49	22.76	20.62
		H_2	19.13	23.61	21.37
		H_3	17.24	20.14	18.69
Leaf area	F_1	H_1	400.87	404.13	402.50
		H_2	400.06	461.33	430.70
		H_3	411.88	459.20	435.54
	F_2	H_1	421.19	425.52	423.35
		H_2	414.85	456.04	435.45
		H_3	416.87	446.21	431.54
	F_3	H_1	405.70	447.39	426.54
		H_2	419.84	450.87	435.36
		H_3	444.01	479.17	461.59
Stem girth	F_1	H_1	7.17	9.08	8.13
		H_2	7.33	10.78	9.06
		H_3	8.21	11.93	10.07
	F_2	H_1	7.40	10.47	8.93
		H_2	7.89	11.47	9.68
		H_3	7.98	11.86	9.92
	F_3	H_1	7.78	10.85	9.31
		H_2	7.62	11.24	9.43
		H_3	8.38	12.66	10.52
Stem diameter	F_1	H_1	4.32	4.40	4.36
		H_2	4.46	4.60	4.53
		H_3	4.52	4.90	4.71
	F_2	H_1	4.41	4.76	4.58
		H_2	4.50	4.68	4.59

		H_3	4.45	4.88	4.66
	F_3	H_1	4.69	4.94	4.81
		H_2	4.37	4.94	4.66
		H_3	4.71	5.02	4.86
Curd yield/m²	F_1	H_1	1.66	2.43	2.04
		H_2	2.23	2.81	2.52
		H_3	1.31	1.99	1.65
	F_2	H_1	2.13	2.94	2.53
		H_2	2.54	3.21	2.88
		H_3	1.53	2.18	1.86
	F_3	H_1	4.09	4.32	4.20
		H_2	4.11	4.45	4.28
		H_3	2.18	2.89	2.53

Table 3.11. Tests of between subjects

Source	Dependent Variable	2023		2024		Pooled	
		F Cal	p Value	F Cal	p Value	F Cal	p Value
Hybrid * Fertilizer	Plant height	2.751	.038	2.749	.038	3.406	.015
	Plant spread	5.288	.001	8.490	.000	8.316	.000
	Number of leaves per plant	3.775	.009	4.740	.002	7.180	.000
	Leaf area	2.661	.043	20.215	.000	7.460	.000
	Stem girth	6.674	.000	10.294	.000	13.966	.000
	Stem diameter	5.992	.000	3.922	.007	5.520	.001
	Curd yield/m²	10.747	.000	8.130	.000	19.627	.000

3.5 Effect of fertilizer × spacing on vegetative and yield characters

The results revealed that in both the years and pooled data for Fertilizer × Spacing, all vegetative and yield characters were highly significant. The experimental result revealed that F_3S_1 recorded maximum value of plant height (60.44 cm, 64.18 cm, 62.31 cm) and highest curd yield/m² (3.84 kg, 4.18 kg, 4.01 kg). This might be due to more terminal increase in closer spaced plant, where lateral growth is more along with more availability of plants. These findings are in close accordance with the findings of Tejaswini et al. 2018. Whereas, maximum plant spread (76.19 cm, 81.10 cm, 78.64 cm), maximum number of leaves per plant (18.91, 22.92, 20.91), leaf area (441.80 cm², 473.07 cm², 457.44 cm²), stem girth (8.61 cm, 12.80 cm, 10.71 cm) and stem diameter (4.75 cm, 5.18 cm, 4.96 cm) were observed under treatment combination F_3S_3. Higher vegetative growth of broccoli plant under wider spacing with higher dose of fertilizer, in the investigation may be because of wider spacing provided less competition for sunlight and nutrients which ultimately resulted in more growth of plants by receiving maximum sun light and more photosynthesis as well as less interplant competition for nutrient and availability of more nutrients could have led to maximum value of these characters. The similar results were reported by Ahmed et al. 2011, Roni et al. 2017, Abhijithnaik et al. 2022 and Verma et al. 2023. The details are mentioned in table 3.12 & 3.13.

Table 3.12. Effect of fertilizer × spacing on vegetative and yield characters

Fertilizer * Spacing			2023	2024	Pooled
Dependent Variable	F	S	Mean	Mean	Mean
Plant height	F_1	S_1	53.42	58.42	55.92
		S_2	59.53	60.48	60.01
		S_3	49.65	53.31	51.48
	F_2	S_1	56.51	62.93	59.72
		S_2	51.60	58.66	55.13
		S_3	52.31	56.16	54.23
	F_3	S_1	60.44	64.18	62.31
		S_2	59.02	61.12	60.07

		S_3	55.07	57.01	56.04
Plant spread	F_1	S_1	68.50	65.64	67.07
		S_2	66.12	68.24	67.18
		S_3	73.59	77.22	75.41
	F_2	S_1	63.97	70.91	67.44
		S_2	72.58	74.53	73.56
		S_3	74.77	74.30	74.54
	F_3	S_1	65.38	68.01	66.69
		S_2	71.47	72.57	72.02
		S_3	76.19	81.10	78.64
Number of leaves per plant	F_1	S_1	17.70	21.71	19.71
		S_2	17.70	21.05	19.37
		S_3	17.76	21.76	19.76
	F_2	S_1	17.93	20.90	19.42
		S_2	18.09	21.49	19.79
		S_3	18.65	22.56	20.60
	F_3	S_1	17.44	22.04	19.74
		S_2	18.51	21.56	20.03
		S_3	18.91	22.92	20.91
Leaf area	F_1	S_1	366.14	422.93	394.53
		S_2	427.70	442.52	435.11
		S_3	418.98	459.22	439.10
	F_2	S_1	397.41	418.87	408.14
		S_2	414.32	440.11	427.22
		S_3	441.19	468.79	454.99
	F_3	S_1	397.12	444.91	421.01
		S_2	430.63	459.45	445.04
		S_3	441.80	473.07	457.44
Stem girth	F_1	S_1	7.21	10.59	8.90
		S_2	7.62	10.34	8.98
		S_3	7.88	10.87	9.37
	F_2	S_1	7.66	10.69	9.18
		S_2	7.62	11.17	9.40
		S_3	7.98	11.93	9.95
	F_3	S_1	7.59	11.09	9.34
		S_2	7.57	10.86	9.22
		S_3	8.61	12.80	10.71
Stem diameter	F_1	S_1	4.47	4.37	4.42
		S_2	4.21	4.48	4.35
		S_3	4.62	5.05	4.83
	F_2	S_1	4.41	4.49	4.45
		S_2	4.31	4.75	4.53
		S_3	4.63	5.08	4.85
	F_3	S_1	4.41	4.83	4.62
		S_2	4.62	4.89	4.75
		S_3	4.75	5.18	4.96
Curd yield/m^2	F_1	S_1	1.61	2.39	2.00
		S_2	2.11	2.78	2.45
		S_3	1.48	2.06	1.77

	F_2	S_1	2.05	2.73	2.39
		S_2	2.22	2.97	2.59
		S_3	1.93	2.64	2.29
	F_3	S_1	3.84	4.18	4.01
		S_2	3.14	3.48	3.31
		S_3	3.39	4.01	3.70

Table 3.13. Tests of between subjects

Source	Dependent Variable	2023		2024		Pooled	
		F Cal	p Value	F Cal	p Value	F Cal	p Value
Spacing * Fertilizer	Plant height	10.657	.000	6.316	.000	17.769	.000
	Plant spread	4.169	.005	16.919	.000	8.255	.000
	Number of leaves per plant	3.497	.013	2.784	.036	3.720	.010
	Leaf area	3.232	.019	2.762	.037	3.943	.007
	Stem girth	7.182	.000	10.203	.000	12.581	.000
	Stem diameter	4.527	.003	3.044	.025	3.098	.023
	Curd yield/m^2	5.946	.001	15.315	.000	18.505	.000

3.6 Effect of hybrid × spacing on vegetative and yield characters

The interaction Hybrid × Spacing, for all vegetative and yield characters were responded significantly in both the years and pooled data. The result revealed that H_3S_1 recorded maximum value of plant height (63.36 cm, 67.00 cm, 65.18 cm) because of presence of genes in hybrid H_3 and closer plant spacing increases the plant height which might the accelerating the process of cell division, cell enlargement along with presence of gene in hybrid provided by the soil at F_3 concentration i.e. 125% RDF might have led to greater number of leaves per plant. These results were in conformity with the results of Bhangre et al. 2011, Gurjeet (2016) in broccoli, Moniruzzaman et al. 2011 in cabbage and Tejaswini et al. 2018.

Table 3.14. Effect of hybrid × spacing on vegetative and yield characters

Hybrid * Spacing			2023	2024	Pooled
Dependent Variable	H	S	Mean	Mean	Mean
Plant height	H_1	S_1	53.86	64.16	59.01
		S_2	58.36	65.11	61.73
		S_3	56.35	59.22	57.78
	H_2	S_1	53.16	54.38	53.77
		S_2	50.76	50.97	50.86
		S_3	43.28	46.46	44.87
	H_3	S_1	63.36	67.00	65.18
		S_2	61.04	64.18	62.61
		S_3	57.40	60.80	59.10
Plant spread	H_1	S_1	63.77	64.03	63.90
		S_2	65.44	67.31	66.38
		S_3	67.09	72.63	69.86
	H_2	S_1	64.11	67.23	65.67
		S_2	68.88	71.63	70.26
		S_3	75.86	72.90	74.38
	H_3	S_1	69.97	73.30	71.63
		S_2	75.84	76.40	76.12
		S_3	81.60	87.09	84.35
Number of leaves per plant	H_1	S_1	18.18	21.59	19.88
		S_2	18.87	22.78	20.83
		S_3	18.14	23.16	20.65

	H_2	S_1	18.54	23.59	21.07
		S_2	18.67	21.89	20.28
		S_3	19.51	23.63	21.57
	H_3	S_1	16.36	19.47	17.91
		S_2	16.76	19.43	18.09
		S_3	17.67	20.45	19.06
Leaf area	H_1	S_1	358.67	390.89	374.78
		S_2	431.04	420.75	425.89
		S_3	438.05	465.40	451.73
	H_2	S_1	390.72	437.99	414.35
		S_2	423.13	463.56	443.34
		S_3	420.92	466.70	443.81
	H_3	S_1	411.28	457.83	434.55
		S_2	418.49	457.77	438.13
		S_3	443.00	468.98	455.99
Stem girth	H_1	S_1	7.36	9.60	8.48
		S_2	7.19	9.34	8.26
		S_3	7.80	11.46	9.63
	H_2	S_1	7.29	10.75	9.02
		S_2	7.45	11.09	9.27
		S_3	8.09	11.65	9.87
	H_3	S_1	7.81	12.02	9.92
		S_2	8.18	11.94	10.06
		S_3	8.57	12.49	10.53
Stem diameter	H_1	S_1	4.51	4.53	4.52
		S_2	4.45	4.47	4.46
		S_3	4.46	5.09	4.78
	H_2	S_1	4.22	4.45	4.34
		S_2	4.45	4.77	4.61
		S_3	4.65	5.00	4.83
	H_3	S_1	4.55	4.70	4.63
		S_2	4.24	4.88	4.56
		S_3	4.88	5.21	5.05
Curd yield/m^2	H_1	S_1	2.37	3.17	2.77
		S_2	3.02	3.53	3.28
		S_3	2.48	2.99	2.74
	H_2	S_1	3.20	3.74	3.47
		S_2	2.79	3.33	3.06
		S_3	2.90	3.40	3.15
	H_3	S_1	1.94	2.38	2.16
		S_2	1.66	2.37	2.01
		S_3	1.42	2.31	1.86

Table 3.15. Tests of between subjects

Source	Dependent Variable	2023		2024		Pooled	
		F Cal	p Value	F Cal	p Value	F Cal	p Value
Hybrid * Spacing	Plant height	11.168	.000	3.296	.018	13.360	.000
	Plant spread	2.934	.029	12.189	.000	5.128	.001
	Number of leaves per plant	5.612	.001	7.288	.000	8.359	.000
	Leaf area	7.758	.000	25.569	.000	21.315	.000

	Stem girth	2.512	.053	11.359	.000	7.851	.000
	Stem diameter	12.528	.000	3.631	.011	6.557	.000
	Curd yield/m^2	5.297	.001	5.329	.001	9.656	.000

Whereas, maximum plant spread (81.60 cm, 87.09 cm, 84.35 cm), leaf area (443.00 cm^2, 468.98 cm^2, 455.99 cm^2), stem girth (8.57 cm, 12.49 cm, 10.53 cm) and stem diameter (4.88 cm, 5.21 cm, 5.05 cm) were observed under treatment combination H_3S_3. H_2S_3 recorded maximum number of leaves per plant (19.51, 23.63, 21.57). The wider plant spacing due to the availability of more space and light, less competition for nutrients. The crop might have a greater number of leaves per plant, maximum plant spread, leaf area, stem girth and stem diameter and also due to genetic makeup of the variety. These findings are in accordance with the findings of Hill (2000) in Chinese cabbage, Singh (2005) in cauliflower, Agarkar et al. 2010 in broccoli, Bhangre et al. 2011, Solunke et al. 2011, Vinod et al. 2017, Singh et al. 2021, Kumar et al. 2021, Verma et al. 2022, Verma et al. 2023 and Yadav et al. 2023. Whereas, highest curd yield/m^2 (3.20 kg, 3.74 kg, 3.47 kg) was observed under H_2S_1. This was due to the reality that as plant spacing decreases, total plant population increases and this in turn contributes to increase in total curd yield. The current result agreed with works of Hossain et al. 2011. The details are mentioned in table 3.14 & 3.15.

CONCLUSION

Among different hybrid H_3 (Besty), spacing level S_3 (60 × 60 cm) and fertilizer level F_3 (125% RDF) recorded maximum plant spread, leaf area, stem girth and stem diameter. Whereas hybrid H_2, spacing level S_1 and fertilizer doses F_3 observed maximum curd yield/m^2. Among different interaction F_3H_3, F_3S_3, H_3S_3 recorded maximum plant spread, leaf area, stem girth and stem diameter. Whereas, F_3H_2, F_3S_1, H_2S_1 observed maximum curd yield/m^2. Hence hybrid H_3, spacing level S_3 and fertilizer doses F_3 must be recommended to farmers.

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