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Studies of weather parameters on growth and development parameters of tomato and cauliflower under protected environment and open field

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Abstract
The present research work entitled "Studies of weather parameters on growth, and development traits and yield of tomato and cauliflower under protected environment and open field" was carried out in the Department of Agricultural Meteorology, College of Agriculture, IGKV, Raipur during Rabi 2023-24. Experiment was laid at the Centre of Excellence on Protected Cultivation and Precision Farming, IGKV, Raipur to evaluate the effect of weather parameters on growth, development, and quality of tomato and cauliflower under protected and open field conditions. A protected environment and adjacent open field were used to monitor microclimatic parameters, plant growth, yield attributes and quality traits. In tomato, protected environment conditions favoured higher plant height (249.3 cm), more number of leaves plant^{-1}(103 leaves plant^{-1}), higher number of fruits plant^{-1} (39 fruits plant^{-1}), and larger fruit length (8.1 cm) and breadth (8.2 cm), resulting in higher yields (44.80 t ha^{-1}). Growth parameters such as plant height (249.3 cm), number of leaves plant^{-1} (103 leaves plant^{-1}), days to first flowering (35 days), number of fruit clusters plant^{-1} (8.16 cluster plant^{-1}), number of fruits plant^{-1} (39 fruits plant^{-1}) of tomato were higher under the protected environment as compared to the open field. In tomato, parameters like plant height (cm), number of leaves plant^{-1}, and number of fruit plant^{-1} showed strong positive correlations with maximum and minimum temperatures and light intensity 07:00 hours and 14:00 hours under protected environmental conditions, while RH I and RH II exhibited a negative correlation. Yield attributes such as average fruit weight (67.12 g fruit^{-1}) and yield (44.80 t ha^{-1}) of tomato were higher under protected environment than crop grown in open field. Tomato yield under a protected environment was 1.74 times greater than in open field conditions. Similarly, cauliflower grown under a protected environment exhibited enhanced plant height (45.04 cm) and number of leaves plant^{-1} (19 leaves plant^{-1}), with early and consistent development of cauliflower crop. In cauliflower curd diameter (18.4 cm), average curd weight (0.720 kg curd^{-1}) and yield of cauliflower curd (35.56 t ha^{-1}) was found to be higher under protected environments, while cauliflower curd yield was 1.67 times higher under a protected environment than crop grown in open field. In cauliflower crop grown under open field plant height (cm) showed a significant positive correlation with RH I (r value 0.833*). Number of leaves plant^{-1}(r value 0.849*) shows a strong positive correlation with RH I under open field.

Keywords: Protected cultivation, microclimate, tomato, cauliflower, growth parameters, yield attributes, correlation analysis

Introduction
In the twenty-first century, agriculture which is the foundation of human civilization faces an unprecedented challenge i.e. climate change. The world's population is expanding, the climate is changing and arable land is becoming less available for cultivation resulting in serious risks of food security. Vegetable production in our country is significantly influenced by the seasonality and weather conditions. Extents of abundance and deficiency in production cause considerable fluctuations in the prices of vegetables. Protected cultivation is one of the option to cope with adverse effect of climate change with respect to vegetable production. Main purpose of protected cultivation is to create a favourable environment for the sustained growth of plant to realize its maximum potential even in adverse climatic conditions. Greenhouses, rain shelter, plastic tunnel, mulches, shade nets etc. are used as protective structures (Kumari *et al.* 2016) [13]. The three crucial factors that affect plant growth and development are climate, nutrition and water (Wang *et al*. 2003) [36]. All these factors can

easily be open conditions led via fertilization and irrigation, but light and temperature are quite difficult to manage (Wang *et al.* 2007) [37].

In protected environment, the natural environment is modified for optimum plant growth, which ultimately provides quality vegetables. Microclimate modification as per need of the plants an intended change in the soil-plant-atmosphere system, which prevents damage with the aim of attaining higher quality production. The main purpose of protected cultivation is to create a favorable environment for the sustained growth of plant to realize its maximum potential even in adverse climatic conditions (Job *et al.* 2018) [14]. Greenhouses are framed structures covered with transparent or translucent material and are large enough to grow crops under partial or full controlled environmental conditions, to obtain optimum growth and production. Greenhouses protect the crop from varied climatic conditions like wind, rainfall, excess solar radiation, extreme temperature conditions and incidence of pests and diseases. Plant response to specific environmental parameter is related to the physiological processes and to yield and quality. Since the microclimate (temperature, relative humidity, and light intensity) inside the structures influences the functional aspects of plant, emphasis is normally given to the maintenance of optimal level of factors for the successful and better productivity in the protective cultivation. Partial control of microclimatic condition, which have major influence on plant growth characteristics, can be achieved in poly greenhouses.

Tomato and cauliflower are two widely cultivated vegetable crops that are highly sensitive to fluctuations in environmental factors such as temperature, humidity, and light intensity. Their growth, development, yield and quality are significantly influenced by the microclimate in which they are cultivated. The major off-season vegetable crop that provides substantial profits to the farming community is the tomato. Both open and protected environments are suitable for its cultivation. But because to adverse conditions, its cultivation in an open field is not particularly profitable. Thus, there is a great deal of potential for tomato growing in polyhouses, particularly in Chhattisgarh. A lot of hybrid varieties are now being grown in open fields, but fewer types have been studied in protected environments. Growing tomatoes in a polyhouse offers an outstanding opportunity to gather high-quality product even during the off-season. Crop productivity and yield potential are significantly higher in polyhouses.

Tomato fruit, which belongs to the Solanaceae family, is edible and resembles a red berry. The scientific name is *Solanum lycopersicum*. Originating in South and Central America, the species. Tomato belongs to the Solanaceae family is one of most popular and nutritious vegetables worldwide. Globally, tomatoes are cultivated, with India being the world's second-largest producer. Bihar, Karnataka, Uttar Pradesh, Odisha, Andhra Pradesh, Maharashtra, Madhya Pradesh, and Assam are the principal states experiencing growth. In Chhattisgarh, the total area under tomato cultivation is about 61.215 thousand hectares in 2023-2024, and the production is 1035.33 metric tonnes (indiastat). Tomato requires a relatively cool and dry climate for high yield and premium quality. However, it is adapted to a wide range of climatic conditions from temperate to hot and humid tropical. Optimum temperature for most of the varieties lies between 21 and 24 °C. Plants can survive in a range of temperatures, but the plant tissues are damaged below 10 °C and above 38 °C. Tomato plants react to temperature variation during the life cycle form seed germination, seedling growth, flower and fruits and seeds set and fruits quality (job *et al.* 2018) [14]. The major cause of tomato availability in the summer is the high temperatures during the summer and heavy rains during rainy season. For tomatoes, a temperature of about 30 °C is optimum for blossom setting. Up to 35 °C, they can still keep their blossoms, but beyond that point, they will start to decline. Fruit production quickly declines at 30 °C for any period of time, since the blossoms drop off before they will produce a tomato (Ahammad *et al.* 2009) [4]. The way that different cultivars blossom and fruit under high temperatures (over 30 °C) varies greatly. In terms of acreage and production, tomatoes rank IInd among the most important vegetable crops in the nation.

The name cauliflower is derived from Latin word 'caulis' meaning cabbage and 'floris' meaning flower. An essential member of the Brassicaceae family, cauliflower (*Brassica oleracea* L. var. botrytis) has been appropriately known as an aristocrat of the cole family. Like all other crops in the family, cauliflower originated from a common ancestor, the wild cabbage (*Brassica oleracea* L. var. *sylvestris*), which is still found in western and southern Europe and North Africa. Native to the Mediterranean region, cauliflower was brought to India during the British era in 1822 from England. (Swarup and Chatterjee, 1972). In Chhattisgarh, the total area under cauliflower cultivation is about 24.25 thousand hectares in 2023-2024, and the production is 483.56 metric tonnes (indiastat). Since cauliflower is a thermo-sensitive crop, temperature affects the plant's ability to reproduce as well as grow. The period of curd initiation is strongly influenced by high temperatures during vegetative development (Wurr and Fellows, 1990) [39]. Increased temperature in the greenhouse during the winter months promotes crop maturity (Albright, 1997) [5]. For a high yield, higher temperatures during the cauliflower's vegetative growth increase the number of leaves overall, plant height, and curd growth (Uzen and Peken, 2000) [35].

In view of population explosion and shrinking of cultivable land for crops, there is an urgent need to enhance the productivity and quality of crops. Protected cultivation, in green houses, poly houses, net sheds etc, is one of the best alternatives to raise the high-quality vegetables, fruits as well as off season crops. In protected environment, the natural environment is modified for optimum plant growth which ultimately provides quality vegetables. Protected cultivation of vegetables not only overcome the stresses but also open the gates for off-season and year-round supply of quality vegetables with remunerative prices to the growers. Location specific growing system is essential for quality product along with to meet the market demand throughout the year.

The present research is planned with the objectives of studying the effect of weather parameters on growth and development of tomato and cauliflower grown under protected environment and open field. Moreover, studies have been taken on comparison of the weather parameters on yield of tomato and cauliflower grown under protected environment and open field.

Methodology

The field experiment was conducted during Rabi 2023-24 at research farm of Center of Excellence on Protected Cultivation and Precision Farming, IGKV, Raipur which located at 21°14 N, 81°41 E. Details of protected environment used for the experiment is as follows. The structure was made of galvanized iron pipe covered with 200-micron UV-stabilized polyethylene film for the roof and side walls. The side walls were also equipped with insect proof 40-mesh netting to allow for natural ventilation while preventing the entry of pests. The polyhouse was oriented in the North-South direction to maximize sunlight exposure. Daily temperature, relative humidity, and light intensity were recorded under the protected environment and in an open field at 07:00 hours and 14:00 hours. The multimeter (LM-8000) recorded the measurement of minimum and maximum temperature and the whirling psychrometer recorded the measurement of relative humidity. The light intensity was recorded with the help of light meter (LX-1102). The preparation of field was done by cultivator followed by two cross-harrowing to pulverize the soil. To enrich the soil, well rotten FYM was applied after harrowing and well-mixed with the soil by planking. The field was levelled with planker. Ridge was made and lateral pipe of drip system is applied above the ridge and plastic mulch lay down before one week of transplanting.

Details of cultural practices were followed as standard

Plant nursery was grown by the seeds of indeterminate hybrid tomato (Yuvraj-1003) and cauliflower (White crystal) were sown in plastic pro trays by using soilless media with coco peat, inside the primary nursery of the centre on 5th October, 2023 to get healthy and disease-free seedlings of tomato and cauliflower. The seedlings were ready for transplanting nearly after one month of sowing and were subsequently transplanted inside the naturally ventilated polyhouse and open field area. One month old healthy seedlings of tomato (*Solanum lycopersicum*) and cauliflower (*Brassica oleracea* var. *botrytis)* was transplanted under naturally ventilated polyhouse and open field area. Other operations like Fertilizer application, Pruning and training and Plant protection measures were followed as standard. Observations were recorded on a single-plant basis from five randomly selected, healthy, and competitive plants in each plot for both tomato and cauliflower crops. Data collection was carried out separately for each crop and for all treatments, ensuring unbiased and reliable measurements across both under the protected environment and open field.

Results and Discussion

The result obtained from the study are briefly presented and discussed in this chapter under the following heads Weather parameters, growth and development of tomato and cauliflower. Second aspect studied was yield of tomato and cauliflower grown under protected environment and open field. The growth and development of tomato and cauliflower are significantly influenced by various weather parameters including temperature, relative humidity, light intensity, under protected environment and open field conditions. These parameters are fluctuates as per natural process, which may also negatively affect the growth and development of plants. Protected environment, with naturally ventilated polyhouse, helps to cope up with these fluctuations, providing a more stable and favorable microclimate for plant growth & development ultimately produces higher quantity and better quality.

1. Weather conditions under open field and protected environment

Minimum and maximum temperature (°C): Among the climatic factors affecting crop production, temperature is considered very important. It affects growth and development of crops in terms of seed germination, flowering, pollination, fruit set and quality of produce. The daily air temperature data was recorded at 07:00 hours and 14:00 hours under the protected environment and open field conditions during entire growing season of crops. These values were averaged on a weekly basis for both conditions and are presented in Figures 1 and 2.

The temporal variation in air temperature inside the protected environment was lower compared to that in the open field, indicating a more stable microclimate under protected environment conditions. The minimum temperature inside the protected environment was 2.1 °C higher than that in the open field from the 44th SMW (29th Oct - 04th Nov) to 9thSMW (26th Feb - 04th Mar). The maximum temperature outside the protected environment was 2.8 °C higher during 10thSMW (5th Mar-11th Mar) to 22ndSMW (28th May-3rdJune). The temperature differences between the protected environment and open field was approximately 0.6 °C at 07:00 hours, but increased progressively with the advancement of time and amounted to a difference of about 0.9 °C at 14:00 hours irrespective of the growth stages of the crops. During crop growth period, the average weekly maximum temperature under protected environment and open field ranges varied from 24.6 to 41.1 °C and 23.2 to 44.6 °C, respectively. The average weekly temperature inside the protected environment at 07:00 hours and 14:00 hours ranged from 15.6 to 29.5 °C and 24.6 to 41.4 °C, respectively, which was lower than open field conditions, where the temperature varied from 11.3 to 32.5 °C and 23.2 to 44.6 °C, respectively. Vegetative and reproductive processes in tomatoes are strongly affected by temperature alone or in conjunction with other environmental factors (Abdalla & Verkerk, 1968). Nimje and Shyam (1993) [22] also obtained similar results. Protected environment permits restricted entrance of lower amount of incident solar radiation of short-wave radiation due to the greater inference of the roof of protected environment against the incoming solar beam but it traps the outgoing long-wave radiation.

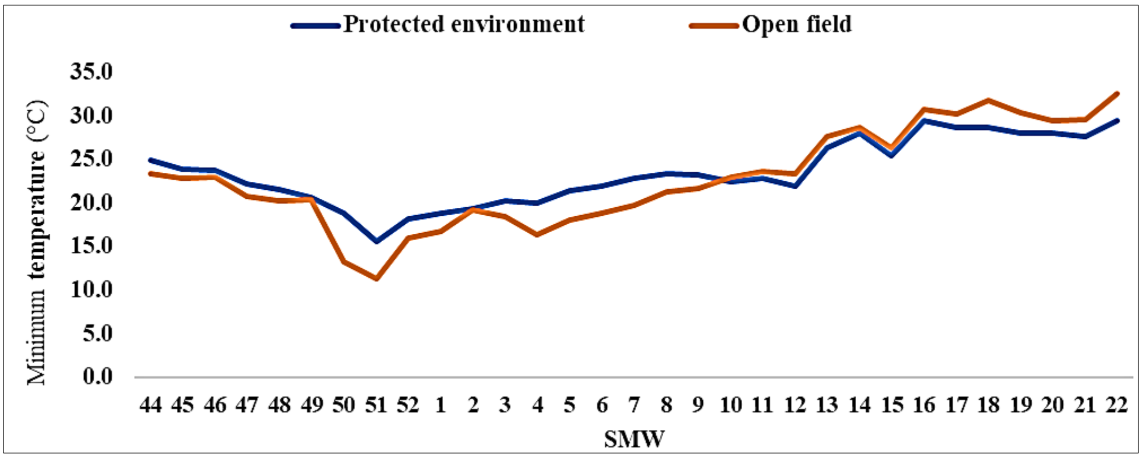

Fig 1: Average weekly minimum temperature (07:00 hours) under protected environment and open field.

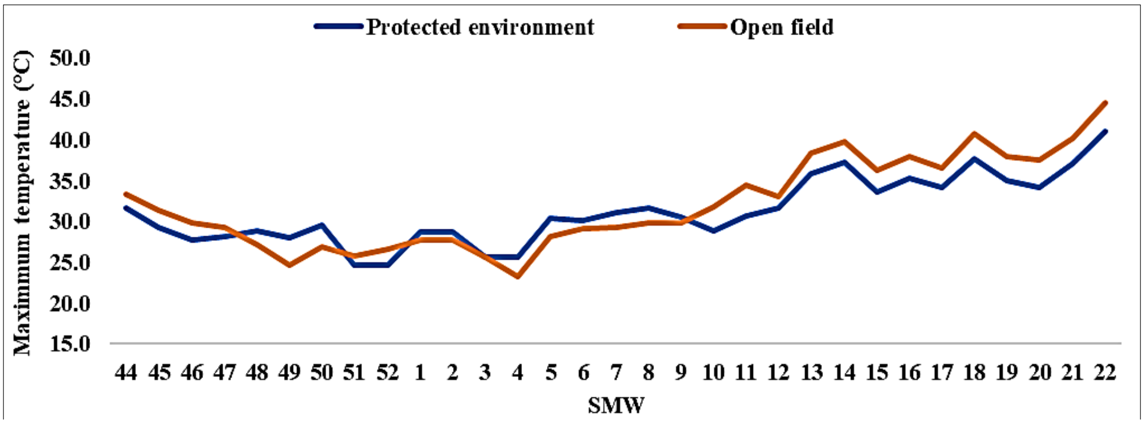

Fig 2: Average weekly maximum temperature (14:00 hours) under protected environment and open field.

Relative humidity (%)**:** Transport of nutrients from soil to plant organ is governed by water uptake translocation and transpiration, which is essential for proper growth and development of plants. Humidity affects leaf area development and stomatal conductance thereby interfering with the photosynthesis and dry matter production (Jolliet, 1994) [15]. Daily relative humidity recorded at 07:00 hours and 14:00 hours showed more or less reverse trend with respect to temperature under both the environmental conditions i.e., lower RH was found at 14:00 hours and higher RH was found at 07:00 hours, both within the protected environment and open field. Average weekly relative humidity under protected environment conditions at RH I and RH II ranged from 58-92% and 38-72%, respectively, while in the open field, RH I and RH II ranged from 48-93% and 24-62%, respectively, presented in Figures 3 and 4.

Relative humidity at 07:00 hours showed less difference between the protected environment and the open field, whereas at 14:00 hours, relative humidity in the protected environment was higher compared to the open field. The optimum relative humidity of air for most vegetable and fruit crops is 60-85%. During the cropping period, relative humidity under protected environment and open field conditions ranged between 51-80% and 37-74%, respectively, and remained within the optimum range throughout the crop growth period. However, excessively high humidity can lead to yield loss, particularly in tomato crop (Holder and Cockskull, 1990) [12].

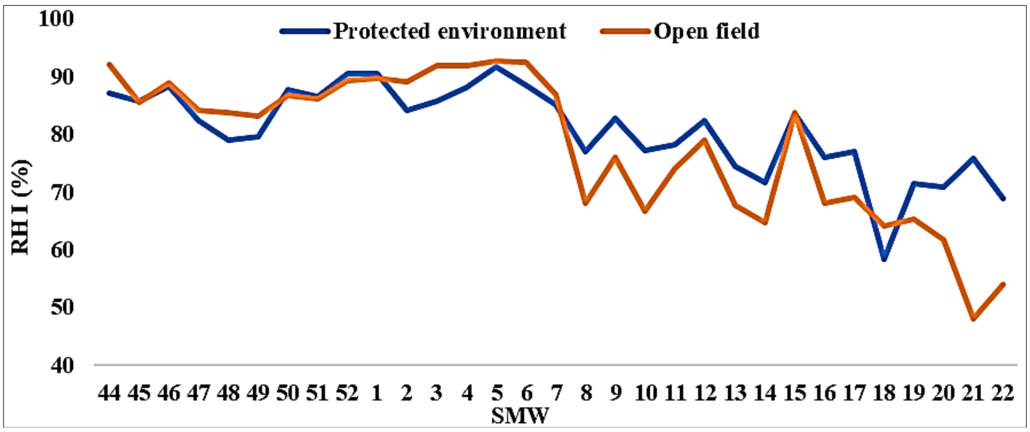

Fig 3: Average weekly relative humidity I (RHmor) under protected environment and open field.

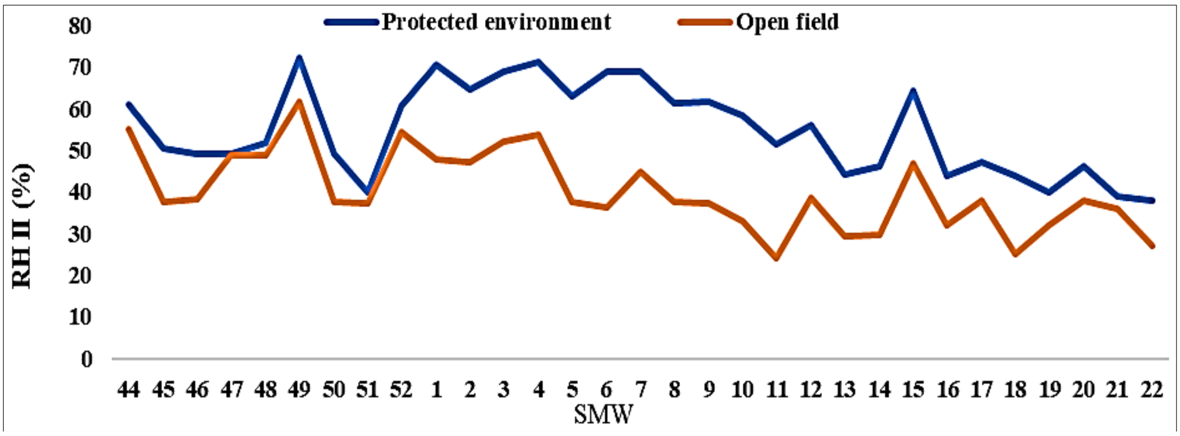

Fig 4: Average weekly relative humidity II (RHeve) under protected environment and open field.

Light intensity (klx): Light intensity affects the growth & development of the crop plants, colour of the leaves, fruit set, and fruit colour etc. Inside the protected environment was reduced by approximately 44% compared to the open field. The lower incident solar radiation under the protected environment compared to the open field was primarily due to the interference of the structure's roof with the incoming solar beam. The daily light intensity recorded at 07:00 and 14:00 hours during the crop growing period, along with the weekly averages, is presented in Figure 5 and Figure 6, respectively.

On an average, the weekly measured solar radiation at 07:00 hours ranged from 0.5 to 28.7 klx in the protected environment and from 1.1 to 56.2 klx under and open field condition. Similarly, at 14:00 hours, light intensity ranged from 1.2 to 48.6 klx in the protected environment and from 5.4 to 64.5 klx under open field conditions. This indicates that plants grown inside the protected environment received less light intensity compared to those grown open field. Kaname and Itagi (1973) [16] also reported similar findings for tomato cultivation under protected environments. They attributed the reduction in total solar radiation inside the protected environment to the type of roof material used. The reduction of solar energy received by the plants also leads to decreased evapotranspiration. Ganesan (2002) [11] reported that light intensity inside the protected environment was lower than that in the open field.

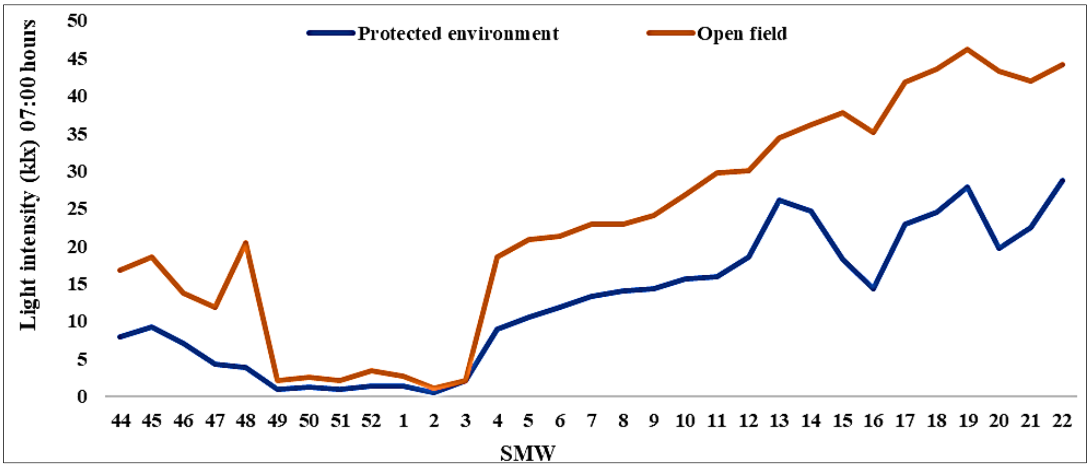

Fig 5: Average weekly light intensity (klx) at 07:00 hours under protected environment and open field.

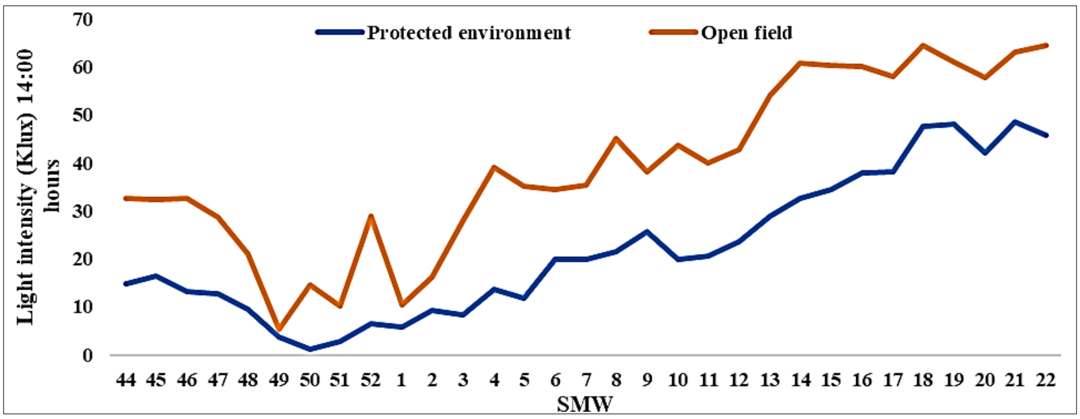

Fig 6: Average weekly light intensity (klx) at 14:00 hours under protected environment and open field.

2. Growth and Developmental traits

2.1 Tomato crop

Correlation studies between tomato fruit traits and meteorological parameters: Correlation studies have been carried out between fruit traits and meteorological parameters both under protected environments (Table-1) and open field conditions (Table-2). It is RHmor factor which is found to significantly affect number of leaves plant^{-1} and number of fruits $^{-1}$. RHeve is found to significantly affect number of leaves plant^{-1} under open field conditions.

Table 1: Correlation of weather parameters and tomato plant growth under protected environment.

Characters	MAXT (°C)	MINT (°C)	RH I (%)	RH II (%)	Light intensity (klx) 07:00 hours	Light intensity (klx) 14:00 hours
Plant height plant $^{-1}$ (cm)	0.619*	0.493	-0.528	-0.074	0.647*	0.903**
Number of leaves plant $^{-1}$	0.875**	0.806**	-0.810**	-0.508	0.665**	0.924**
Number of fruit cluster plant $^{-1}$	0.561	0.546	-0.454	-0.039	0.727*	0.445
Number of fruits per plant $^{-1}$	0.910*	0.941**	-0.807**	-0.921**	0.284	0.917**

**= 1% level of Significance, *= 5% level of Significance

Table 2: Correlation of weather parameters and tomato plant growth under open field.

Characters	MAXT (°C)	MINT (°C)	RH I (%)	RH II (%)	Light intensity (klx) 07:00 hours	Light intensity (klx) 14:00 hours
Plant height plant $^{-1}$(cm)	0.358	0.242	-0.454	-0.570	0.781**	0.619
Number of leaves plant $^{-1}$	0.505	0.388	-0.564	-0.651*	0.713*	0.666*
Number of fruit cluster plant $^{-1}$	-0.624	-0.611	0.578	0.750	-0.747	-0.630
Number of fruits per plant $^{-1}$	0.728	0.633	-0.586	-0.804	0.765	0.472

**= 1% level of Significance, *= 5% level of Significance

2.1.1 Plant height plant^{-1} (cm): Table 3 and Fig. 7 represent the height of tomato plants varied between the protected environment and open field conditions across all the growth stages. At 15 DAT, the tomato plants grown under the protected environment were taller, averaging 21.4 cm height, as compared to 17.7 cm height in the open field. This trend became more pronounced over time, with the protected environment plants reaching 197.2 cm height by 60 DAT, in contrast to 87.5 cm in the open field. At 120 DAT, tomato plants grown in the protected environment attained an average height of 311 cm, which was approximately 79.1% greater than the 173.6 cm recorded under open field. This increase in plant height reflects the beneficial impact of vertical growth in the protected environment which provides controlled environment favour the plant growth. Table 1 represents the correlation between weather parameters and plant height under a protected environment. A strong positive correlation was observed between plant growth and maximum temperature ($r = 0.619$, $p<0.05$), moderate positive correlation with light intensity (klx) at 07:00 hours ($r = 0.647$, $p<0.05$) and at 14:00 hours ($r = 0.903$, $p<0.01$). Table 2 shows a correlation between weather parameters and plant height under open field conditions. it shows negative correlation with RH I ($r = -0.632$, $p<0.05$) and a significantly positive correlation with light intensity (klx) at 07:00 hours ($r = 0.781$, $p<0.01$). Plant height is an important growth parameter in indeterminate type tomato variety Yuvraj-1003. The total yield of tomato is influenced by plant vigor because it has indeterminate growth habit, where the plant height plays a vital role. Ganesan in 2001 also revealed that Pusa ruby attained maximum plant height (211cm) under protected environment conditions.

Table 3: Plant height plant^{-1} (cm) of tomato at different stages under protected environment and open field.

DAT	Protected environment	Open field
15	21.4	17.7
30	89.2	44.7
60	197.2	87.5
90	270.0	137.4
120	311.0	173.6

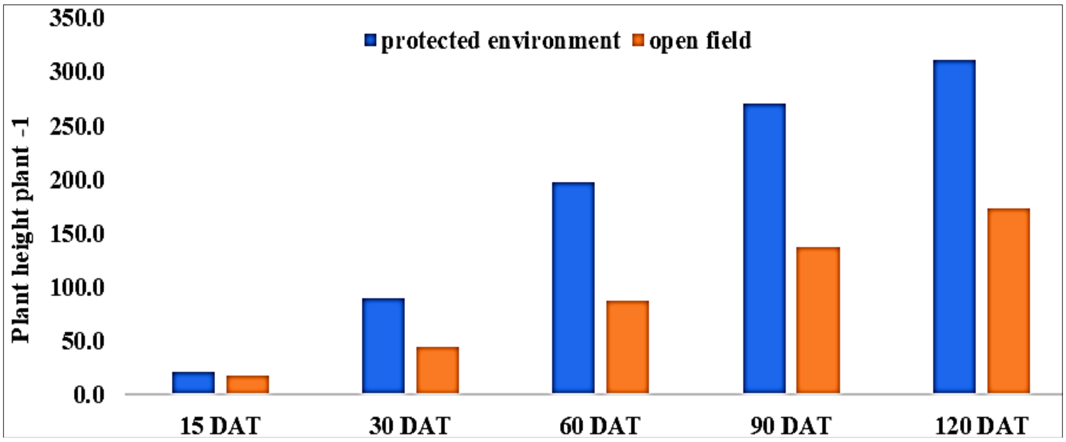

Fig 7: Plant height (cm) at different stages of tomato grown under protected environment and open field.

2.1.2 Number of leaves plant $^{-1}$

Number of leaves plant^{-1} recorded during the present investigation presented in Table 4 and depicted in Fig. 8. The production of leaves^{-1} was consistently higher under the protected environment. At 15 DAT, tomato plants in the protected environment had an average of 10 leaves, slightly higher than the 6 leaves recorded in the open field conditions. At 60 DAT, the leaf count increased progressively, in tomato plants grown under protected environment having 45 leaves as compared to 29 leaves recorded in the open field. At 120 DAT, the plants grown in protected environment developed an average of 108 leaves, which was more than double of the 56 leaves recorded in the open field. These results suggested that the protected environment provided congenial environment for proper vegetative growth, resulted higher number of leaves production.

Table 1 represents the correlation between weather parameters and the number of leaves plant^{-1}. Under a protected environment positive correlation with minimum and maximum temperature r = 0.806 and 0.875, $p < 0.01$, and RH I exhibited a negative correlation r= -810, $p < 0.01$. Observed the light intensity (klx) at 07:00 hours and at 14:00 hours both reported a positive correlation r = 0.665, $p < 0.05$ and r = 0.924, $p < 0.01$ respected. Table 2 indicates in open field conditions correlation studies indicates that weather parameter and number of leaves plant^{-1} shows negative correlation with RH II (r = -0.651*, $p < 0.05$). Light intensity at 07:00 hours as well as at 14:00 hours with number of leaves plant^{-1} were positive correlation and r value were (0.713, $p < 0.05$ and r = 0.666, $p < 0.05$), respectively.

Table 4: Number of leaves plant^{-1} of tomato at different stages in protected environment and open field.

DAT	Protected environment	Open field
15	10	6
30	20	14
60	29	29
90	71	44
120	108	56

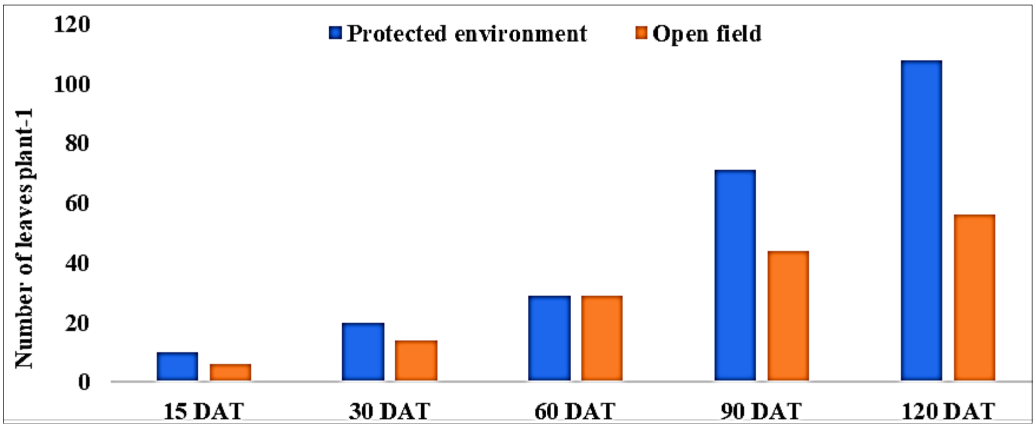

Fig 8: Number of leaves plant $^{-1}$ different stages of tomato under protected environment and open field.

2.1.3 Days to first flowering: Days to first flowering in tomato which are shown in Table 5 differed noticeable between the protected environment and open field conditions. Plants grown under protected environment conditions initiated flowering earlier, with an average of 35 days after transplanting (DAT), as compared to 38 days after transplanting (DAT) in the open field condition. Early flowering indicates early fruit setting, which consequently contributes to earlier and higher yields. Similar observations were reported by Ganesan (2002) [11], who found that crops grown under protected environments flowers earlier than those in open field due to moderated temperature and reduced environmental stress. Kaname and Itagi (1973) [16] noted early flowering in tomato plants under protected environment, which contributed to early fruit set and higher yields.

Table 5: Days to first flowering of tomato under protected environment and open field.

Days to first flowering	
Protected environment	**Open field**
35	38

2.1.4 Number of fruit cluster plant $^{-1}$: Data presented in Table 6 and depicted in Fig 9 state that there is a clear-cut differences of result obtained from protected environment and open field regarding number of fruit cluster plant^{-1} which varied across developmental stages. At 60 days after transplanting (DAT), plants grown under protected environment conditions developed an average of 6 fruit cluster, whereas those in the open field produced only 4.1 fruits cluster. At 90 DAT, the number of fruit cluster produces 8 under protected environment whereas it increased up to 5 in the open field conditions. At 120 DAT, the crops grown in protected environment maintained a higher average number of fruit cluster (7.4) as compared to 4.2 in the open field. These results indicate that the controlled environment of the protected environment, particularly the moderated temperature and relative humidity, had a positive influence on flowering and fruit cluster development.

Table 1 represents the correlation between weather parameters and number of fruit cluster plant^{-1} under protected environment conditions, and shows a strong positive correlation with light intensity (klx) at 07:00 hours (r = 0.727, $p<0.05$). Whereas in open field conditions there is no significant relationship observed between weather parameters and the number of fruit cluster plant^{-1} presented in Table 2. The increase in the number of fruitclusterplant^{-1} might be attributed due to the favorable environmental conditions prevailing in the protected environment, which promoted the formation of more flower clusters plant^{-1}, leading to a higher fruit set percentage. Similar results were also obtained by Papadopoulos and Ormrod (1991), Sharma *et al.* (2011) [29] and Aguirre and Cabrera (2012) in cherry tomato.

Table 6: Number of fruit cluster plant^{-1} under protected environment and open field in tomato crop.

DAT	Protected environment	Open field
60	6.0	4.1
90	8.0	5.0
120	8.4	3.6

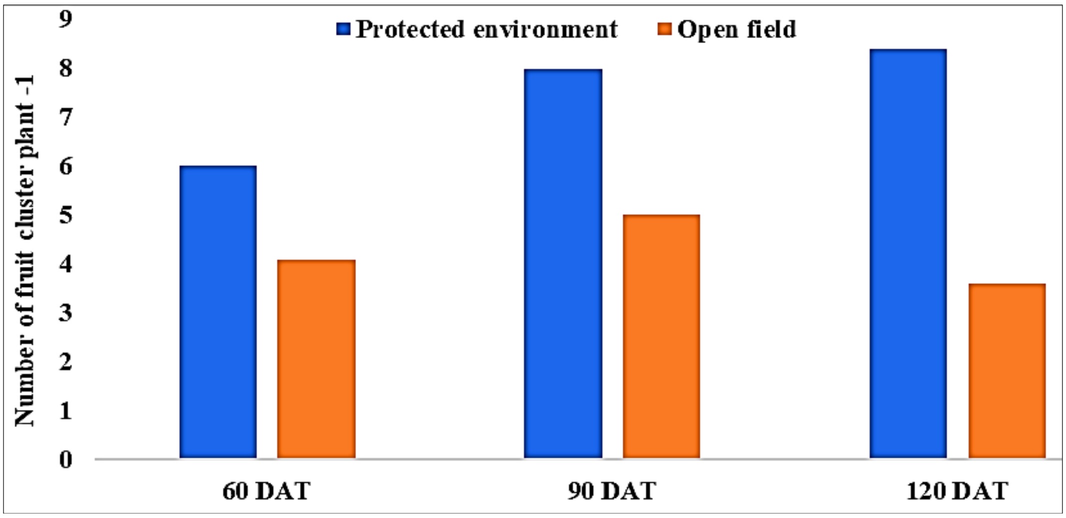

Fig 9: Number of fruit cluster plant^{-1} at different stages of tomato grown under protected environment and open field.

2.1.5 Number of fruits plant^{-1}: Table 7 shows that the number of fruits plant^{-1} was higher in protected environmental conditions at all the stages of observations. At 90 days after transplanting (DAT), plants grown in protected environment produced an average of 27 fruits plant^{-1} as compared to 18 fruits observed under open field. At 150 DAT, the number of fruits reached up to 44 plant^{-1}in the protected environment, which was 51.7% higher than the 29 fruits plant^{-1} recorded in the open field. The overall average number of fruits plant^{-1} under protected environment conditions was 39, as compared to 26 fruits plant^{-1}in the open field.

Data presented in Table 1 shows the correlation between weather parameters and the number of fruits plant^{-1} under a protected environment. A significantly strong positive correlation was observed with minimum and maximum temperatures with number of fruits plant^{-1} with r value of 0.941, p = 0.01 and 0.910, p = 0.05, respectively. A strong negative correlation was found with RH I and RH II that was r = -0.807 and -0.921, $p < 0.01$, respectively. And light intensity (klx) at 14:00 hours, exhibited a very strong positive correlation r value was 0.917, p = 0.01. Table 2 shows the correlation analysis between the numbers of fruit plant^{-1} and weather parameters in open field such as maximum and minimum temperature, relative humidity and light intensity revealed no statistically significant relationship ($p > 0.01$). The increased fruit production under protected environment conditions might be attributed to the regulated microclimate, which minimizes abiotic stresses such as extreme temperatures, fluctuations in relative humidity and high light intensity thereby promoting optimal physiological processes and improved reproductive growth and development.

Table 7: Number of fruits plant^{-1} in protected environment and open field for tomato crop.

DAT	Protected environment	Open field
90	27	18
120	29	26
150	38	25

2.1.6 Fruit length (cm): Table 8 represents the mean fruit length of tomato exhibited a difference between the protected environment conditions (8.1 cm) and open field (7.7 cm). The marginally greater fruit length under the protected environment suggested that the protected environment may have contributed to improved fruit elongation due to favorable microclimatic conditions. Similar studies carried out by Parvej *et al.* (2010) [26] who reported significantly higher fruit length and diameter in tomato grown under protected environmental conditions compared to open field. This might be due to stable microclimate inside the protected structure, which reduces stress on plants and promotes better fruit development.

2.1.7 Fruit breadth (cm): Data presented in Table 8 state that there is a clear-cut differences of result obtained from protected environment and in the open field the maximum mean fruit breadth was recorded under protected environment conditions i.e. 8.2 cm, as compared to 7.3 cm recorded in the open field. This minor increases in fruit breadth under protected cultivation may be attributed to the favorable microclimate conditions that enhance fruit development. Highest fruit breath of Yuvraj-1003 varieties recorded might due to their genetic character and the response of these varieties to acclimatize to the protected environment conditions. Similar results of significant variation in fruit diameter of tomato were also obtained by Oum (1995) [24].

Table 8: Mean fruit length (cm) and breadth (cm) of tomato under protected environment and open field

Fruit length (cm)		Fruit breadth (cm)	
Protected environment	Open field	Protected environment	Open field
8.1	7.5	8.2	7.3

2.2 Cauliflower crop

Correlation Studies made for cauliflower crop under protected environment and open field has been shown in Table-9 and Table-10, respectively.

Table 9: Correlation between weather parameters and cauliflower plant growth under protected environment.

Characters	MAXT (°C)	MINT (°C)	RH 1 (%)	RH 2 (%)	KLUX 7AM	KLUX 2PM
Plant height plant^{-1} (cm)	-0.471	-0.749	0.629	0.470	-0.167	-0.324
Number of leaves plant^{-1}	-0.416	-0.622	0.641	0.619	-0.063	0.164

**= 1% level of Significance, *= 5% level of Significance

Table 10: Correlation coefficient cauliflower plant growth with weather parameters in open field condition.

Characters	MAXT (°C)	MINT (°C)	RH 1 (%)	RH 2 (%)	KLUX 7AM	KLUX 2PM
Plant height plant^{-1} (cm)	-0.721	-0.533	0.834*	0.160	-0.095	0.107
Number of leaves plant^{-1}	-0.670	-0.600	0.849*	0.013	-0.067	0.139

**= 1% level of Significance, *= 5% level of Significance

2.2.1 Plant height plant^{-1} (cm): The outcome of plant height measured in cauliflower presented in Table 11 and depicted in Fig 10, the cauliflower plant height varied due to the growing environment. At 15 days after transplanting (DAT), plants grown under protected environment attained a height of 12 cm, which was markedly higher than the 7 cm recorded under open field conditions. This trend continued at subsequent growth stages. At 30 DAT, plant height of cauliflower was 27 cm under protected environment as compared to 13 cm in the open field conditions. By 45 DAT, the plant height reached 53 cm in the protected environment, while in the open field, it was only 17 cm. Correlation of weather parameter and plant height of cauliflower grown under the protected environment are presented in Table 9. Results indicates that then was no significant correlation was observed between weather parameters and plant height of cauliflower grown under protected environment where in open field conditions, the RH I exhibited a significant positive correlation with plant height ($r = 0.833$, $p < 0.05$) presented in Table 10. These results indicate that the favorable microclimate prevailed within the protected environment, such as higher temperature and reduce environmental stress, contributed to enhanced vegetative growth in cauliflower.

Table 11: Plant height (cm) at different stages of cauliflower grown under protected environment and open field.

DAT	Protected environment	Open field
15 DAT	12	7
30 DAT	27	13
45 DAT	53	17
60 DAT	58	21

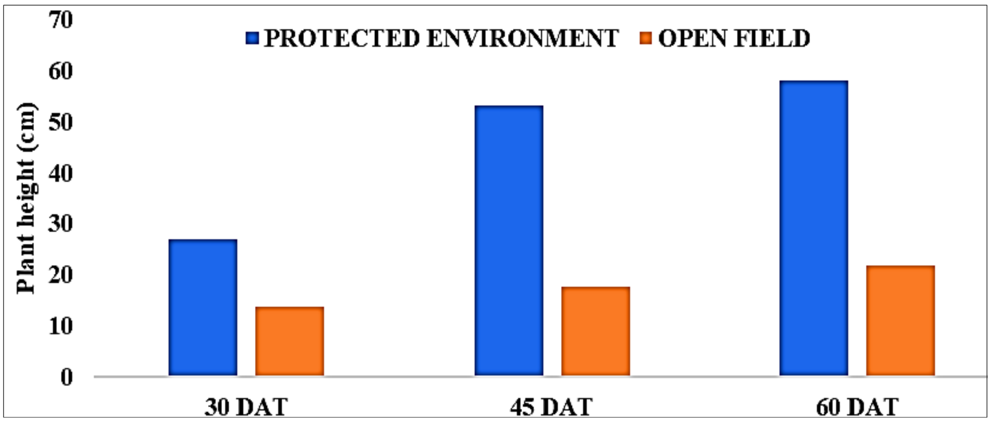

Fig 10: Plant height (cm) at different stages of cauliflower under protected environment and open field.

2.2.2 Number of leaves plant^{-1}: The effect of weather parameter on number of leaves of cauliflower grown under protected environment and open field are presented in Table 12 and depicted in Figure 11. The results reveals that at 15-day after transplanting (DAT), The number of leaves plant^{-1} recorded under protected environment was 7, whereas in the open field, it was only 4 leaves. This trend of enhanced number of leaves continued throughout the crop period. At 30 DAT, plants grown under the protected environment exhibited a higher number of leaves 12 as compared to 6 leaves plant^{-1} in the open field. At 45 DAT, the number of leaves reached 19 under protected environment, while only

11 leaves were recorded in the open field. The overall mean number of leaves plant^{-1} was 19 under the protected environment and where as it was 10 in the open field.

Table 9 shows that there is no statistically significant difference observed between the numbers of leaves per plant and weather parameters under a protected environment ($p>0.01$). Whereas in open field a strong positive correlation and number of leaves plant^{-1}was noticed in RH I ($r = 0.849$, $p < 0.05$) presented in table 10.

These findings are in line with those of Sharma (2016) [30], who also recorded a higher number of leaves in cauliflower under protected environment conditions compared to open field. Parvej *et al.* (2010) [26] also reported greater vegetative growth and yield under protected conditions, attributing due to the increased temperature and decreased relative humidity within the protected environment, which collectively encourage favorable condition for leaf development. Higher temperature were found to delay curd initiation; however, they were also associated with an increased number of leaves plant^{-1}. The results are in confirmation with the findings of Wiebe (1975) [38], Nowbuth and Pearson (1998) [23], Ara *et al.* (2009) [6] and Fujime and Hirose (1980) [9] who also reported that there was increase in number of leaves with increased temperature.

Table 12: Cauliflower number of leaves plant $^{-1}$ under protected environment and open field condition

DAT	Protected environment	Open field
15	7	4
30	12	6
45	19	11

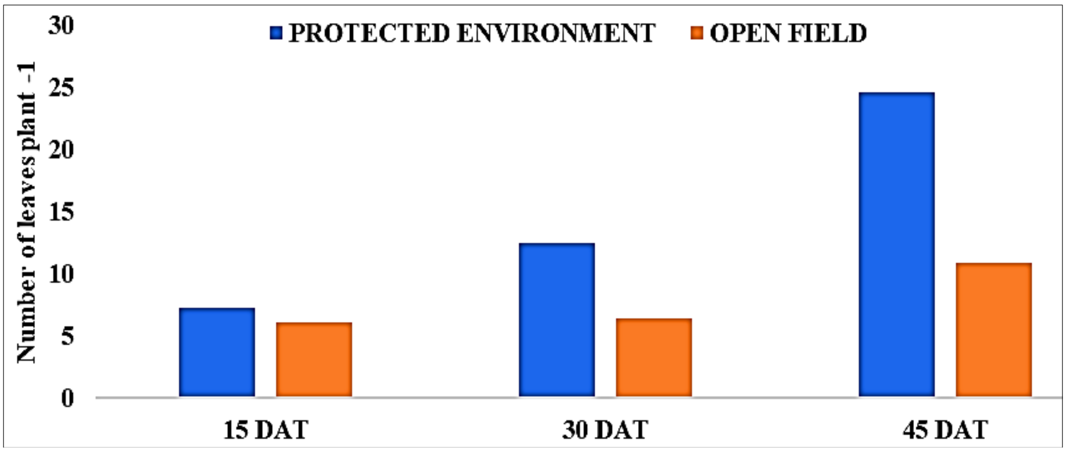

Fig 11: Number of leaves plant $^{-1}$ at different stages of cauliflower under protected environment and open field.

3. Yield of tomato and cauliflower grown under protected environment and open field.

3.1 Tomato crop

3.1.1 Average fruit weight (g)

The weight of fruits as influenced by different growing conditions are presented in Table 13. The average weight of tomato fruit under protected environment was higher (67.12 g/fruit) as compared to open field condition (56.78 g/fruit).

Table 13: Average tomato fruit weight (gm) under protected environment and open field condition.

Protected environment	Open field
67.12	56.78

3.1.2 Tomato fruit yield (t ha^{-1}): The total yield of tomato obtained under protected environment and open field condition are presented in Table 14 and depicted in Fig. 12. The growing conditions influence the fruit yield hectare^{-1}. The plant grown under protected environment recorded higher yield ha^{-1} i.e. 44.80 t ha^{-1} which was approximately 1.74 times higher than the tomato yield obtained from the open field (25.70 t ha^{-1}). This might be due to favorable weather parameters maintained in protected structure. As per the results, tomato crops grown in the protected environment performed significantly better than those growing in open field nearly twice as well. This might be due to the ideal temperature, light intensity and relative humidity maintained in the protected structure, which promoted more vegetative growth and development which turn more flowers, fruits and maximum fruit weight. The uncontrolled climatic conditions in a natural environment without any structure might be the reason for the lower yield in open field as compared to a protected environment. Similar results were also obtained by Nagendra prasad (2001) [21]. Ganesan (2002) [11] observed that fruit yield was about two times higher from protected environment than in the open field due to warm and humid weather inside. Nimje and Shyam (1993) [22] and Chauhan (1972) [8] also reported similar results for Okra crop.

Table 14: Tomato fruit yield (t ha^{-1}) under protected environment and open field condition.

Protected environment	Open field
44.80	25.70

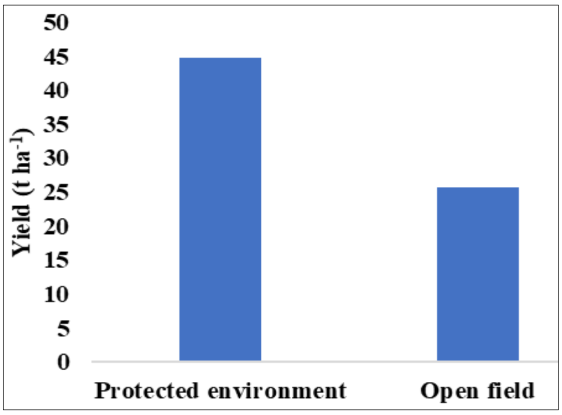

Fig 12: Tomato fruit yield (t ha^{-1}) under protected environment and open field condition.

3.2 Cauliflower crop

3.2.1 Curd diameter (cm): The curd diameter measured in cauliflower presented in Table 15. it was observed that there was wide variation in the curd diameter of cauliflower grown under both the conditions. The average curd diameter measured in the protected structure was 18.4 cm. which was higher then curd diameter recorded under open condition that was 15.2 cm. This enhancement in curd size under protected environment might be attributed due to the favorable microclimate conditions. In the open field conditions, being more exposed to fluctuating weather variables, likely imposed stress on plant growth and curd development.

Table 15: Curd diameter (cm) under protected environment and open field.

Protected environment	Open field
18.4	15.2

3.2.2 Average curd weight (kg curd^{-1}): The average curd weight (kg curd^{-1}) recorded under both the environment. presented in Table 16. It is clear from the data that the average curd weight of cauliflower under protected environment was higher than recorded in open field. Maximum average curd weight (0.720 kg) was observed under protected environment while minimum average curd weight (0.432 kg) was observed in open field. protected environment provides positive effect of microclimate on growth parameters resulted higher average curd weight under protected environment than open field conditions. Swagatika *et al*., (2006) [32] also reported that cauliflower exhibited superior performance under 50% shade level, likely due to the favorable microclimate characterized by moderated light intensity, optimal temperature, and enhanced relative humidity. Such conditions can stimulate photosynthetic efficiency and promote greater assimilate accumulation, thereby improving overall plant growth and leads to higher average curd weight in protected environment. Meena *et al.* (2017) [18], Gogoi *et al.* (2016) [19], Boroujerdnia and Ansari (2007) [7] and Joshi *et al.* (2018) [20] also reported significant effect of protected environment conditions on average curd weight as compared to open field conditions.

Table 16: Average curd weight (kg) of Cauliflower under protected environment and open field condition.

Protected environment	Open field
0.720	0.432

3.2.3 Curd yield (t ha $^{-1}$): The mean yield (t ha^{-1}) was calculated and presented in Table 4.17 and depicted in Fig. 13. It was observed that maximum yield of 35.56 t ha^{-1} was recorded under protected environment which was noticeable higher than the curd yield obtained from open field that was 21.31 t ha^{-1}. The early and higher yield of vegetables crops inside the protected environment was mainly because of favourable weather parameters prevailed during crop growth period such as optimum temperature observed during winter month. protected environment may provide a new scope for commercial production of high value vegetables. It has been used for vegetable production with far better yield (Kanthaswamy *et al*., 2000, Ganesan, 2002 [17, 11], Srivastava *et al*., 2002, Aberkain *et al*., 2006) [31, 2]. These results are in conformity with the findings of Phookan and Saika (2003) [27], who also observed that crop grown under protected environment resulted better growth especially in the early stage resulted early harvest and more yield.

Table 17: Cauliflower curd yield (t ha^{-1}) under protected environment and open field condition.

Protected environment	Open field
35.56	21.32

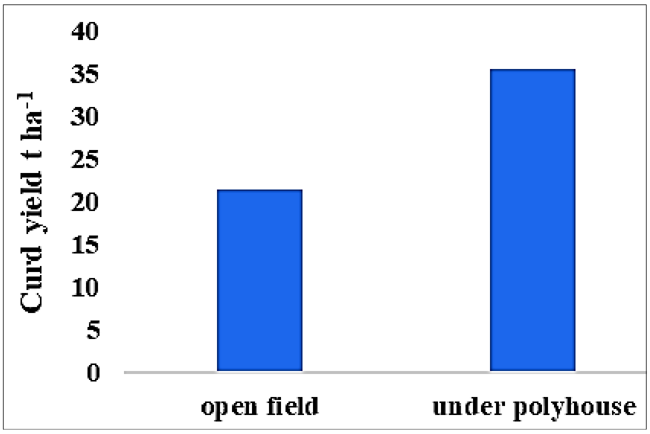

Fig 13: Cauliflower curd yield (t ha^{-1}) under protected environment and open field condition.

Yasoda *et al.* (2018) [40] studied influence of environmental variables such as temperature, relative humidity and light intensity on cauliflower and observed that different shade levels showed great influence on yield as well as plant growth. There were significant variations in plant height, number of leaves, curd weight which leads to most important parameter i.e. yield of cauliflower.

Favourable effect of protected environment conditions enhanced the growth and yield attributes which ultimately resulted in highest curd yield. Our findings are corroborated with the resulted of Srivastava *et al.* (2002) [31], Pradeep *et al.* (2002) [28] in cauliflower, Saleem *et al.* (2014) in cabbage, Agrawal *et al.* (2003) in cauliflower, knol-khol and cabbage and Thapa *et al.* (2013) [34] in Broccoli, they reported that yield of all these vegetable crops were found encouraging because of availability and utilization of high rate of carbon dioxide inside the protected cultivation.

Conclusions

The growth parameters such as plant height (249.3 cm), number of leaves plant^{-1} (103 leaves plant^{-1}), days to first flowering (35 days), number of fruit clusters plant^{-1} (8.16 cluster plant^{-1}), number of fruits plant^{-1} (39 fruits plant^{-1}) of tomato were higher under the protected environment as compared to the open field. In tomatoes, parameters like plant height, number of leaves plant^{-1}, and number of fruit plant^{-1} showed strong positive correlations with maximum and minimum temperatures and light intensity 07:00 hours and 14:00 hours under protected environmental conditions, while RH I and RH II exhibited a negative correlation. Similarly, cauliflower grown under a protected environment exhibited enhanced plant height (45 cm) and number of leaves plant^{-1} (19 leaves plant^{-1}), with early and consistent development of cauliflower crop. While RH I (r value 0.834*) and RH II (r value 0.849*) showed significant positive correlation with plant height and number of leaves plant^{-1} of cauliflower in open field conditions. Yield attributes such as average fruit weight (67.12 g fruit $^{-1}$) and yield (44.80 t ha^{-1}) of tomato were higher under protected environment than crop grown in open field. Tomato yield under a protected environment was 1.74 times greater than in open field conditions. In cauliflower curd diameter (18.4 cm), average curd weight (0.720 kg $curd^{-1}$) and yield of cauliflower curd (35.56 t ha^{-1}) was found to be higher under protected environments, while cauliflower curd yield was 1.67 times higher under a protected environment than crop grown in open field.

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