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Effect of weather parameters on the growth and yield of Cauliflower

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Abstract

Weather parameters influence all stages of plant growth and thereby affect the crop productivity. Each crop has its own set of optimum and tolerable environmental conditions under which it can grow efficiently. Knowledge about the relationships between crop growth stages and weather parameters is very important to maximize the production and productivity by adjusting the crop management practices. For a plant to be successful in a given region, the sequences of its growth phases must fit in the climate to ensure good growth and adequate production. Agro-climatological knowledge of individual crops and individual locations is thus very essential. Vegetable crops, the important component of horticulture, assume great significance in providing food and nutritional security. Even though India ranks second in the world production of vegetables (NHB, 2011), the availability of vegetables still continues to be much low below the dietary requirements. There is ample scope to increase the productivity by the development of location and situation specific technologies. But the challenges before us are to produce more from shrinking land and declined water in the scenario of climate change. Cauliflower (*Brassica oleracea* var. botrytis) belonging to the family brassicaceae is one among the most popular vegetable crops cultivated in India. Cauliflower is very sensitive to growing conditions and for the transformation from vegetative to curd initiation phase and for the development of curd, it needs distinct climatic conditions. So, we have to find out the relationships between the magnitude of yield fluctuations and environmental influences of the crop growing season.

Key words: **Cauliflower, Climate change, Crop growth, Yield**

Introduction

Cauliflower (Brassica oleracea var. botrytis) is a cool season crop grown for its immature inflorescence called curd which is a rich source of dietary nutrients and antioxidants. Cauliflower is very sensitive to growing conditions and requires more attention than cabbage, broccoli and other close relatives and hence it is regarded as the aristocrat of the cruciferae family. It can be grown in a wide range of climates, but for the transformation from vegetative to curd initiation phase and for the development of curd, it needs distinct climatic conditions. Therefore the influence of weather on growth and development of cauliflower is reviewed here.

Effect of temperature

Gill and Singh (1973) reported that maximum and minimum temperatures of 15.4-18.9°C and 4.6-6.8°C, respectively during October, November and December induced good vegetative growth in cauliflower in Kullu Valley. They also reported that temperature fluctuations in the month of February affected the seed yield adversely. Fujime and Hirose (1980) investigated the effects of diurnal variation of temperature on curd formation of cauliflower by growing under low temperature during one part of the day and high temperature during the remaining part of the day and concluded that the stimulus of low temperature given in a certain period of the day will get reduced but not nullified by subsequent high temperature. They also reported that even though the plants are grown at diurnal variation of temperature and have not formed curds, the low temperature effect will accumulate in the plants and they soon form curds when the chilling requirement is satisfied. Some cauliflower cultivars initiate curd formation at about the same rate whether they are grown under cool or very warm weather conditions. Other cultivars require more than twice as long a time to form curds under high - temperature conditions than under cool or moderate temperatures. The delay or retardation of curd formation is the result of lack of sufficient growing time during which the temperature is below a critical value. This critical temperature appears to vary with different cultivars

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(Liptay, 1981). Wurr *et al.* (1988) based on experiments conducted at Wellesbourne, reported that cauliflower plants showed maximum rate of vernalization between 5°C and 17°C and at temperatures lower and higher than this range, reduced vernalization rates were observed which resulted in large variation in the mean number of leaves formed at the time of curd initiation which ranged between 22 and 36.7 leaves. Plant to plant variation within a cauliflower crop in respect of curd initiation date is due to both differences in date on which the juvenile phase ends and differences in temperature experienced subsequently by the individual plants. The duration of the harvest period is determined primarily by the date of juvenility, temperature after the end of the juvenility and temperature during curd growth, possibly all interacting with a genetic component. The final number of leaves also depends on temperature after the juvenile phase (Booij, 1990a). Booij (1990b) reported that curd fresh weight at maturity was reduced by low temperatures before transplanting, especially in the case of plants with a higher number of visible leaves at the time of transplanting. In an experiment conducted at Netherlands, Booij and Struik (1990) observed that after the juvenile phase, the apical dome diameter of cauliflower plants kept under weak curd-inducing conditions (22°C) increased very slowly compared to those kept under strong curd inducing conditions (14°C). Chatterjee and Som (1990) reported that average maximum temperature of 26.3°C, minimum temperature of 20.1°C and relative humidity of 88.3-88.6% were effective in stimulating plant growth and curd formation in cauliflower in Pedong, Kalimpong. The temperature during vegetative growth has a strong influence on the time of curd initiation and, together with variation in the duration of curd growth from initiation to maturity, affects the time taken from transplanting to maturity (Wurr and Fellows, 1990). In the experiment conducted by Wurr and Fellows, 2000)in controlled environment cabinets, it was found that there was a linear relationship between early curd growth and temperature between 8°C to 18°C. Pearson *et al.* (1994) reported that the rate of curd initiation in cauliflower increased up to a mean temperature of 14°C, but declined thereafter. The thermal time required to elapse for curd initiation to occur was 296°C da ys accumulated above a base temperature of 2.8°C. They found a curvilinear relationship between the logarithm of curd diameter and thermal time for the variety Revito. Wheeler *et al.* (1995) reported that the period from transplanting to curd initiation and the subsequent growth of the curd is strongly influenced by temperature. Curd weight exhibited a negative linear function with respect to mean temperature. Due to this negative relation and the low temperature requirement for curd initiation, they opined that the crop duration for late transplanted crops will be longer in a warm climate. Warmer temperatures reduced total biomass at the last harvest, due partly to later initiation of curds and reduced curd growth rates. The dry weight reduction was 6 per cent for every 1°C rise in temperature. Wurr and Fellows (1998) reported that in early sown cauliflower crop, rise in temperature greatly reduced the length of juvenile and curd growth phases but had little effect on vernalization and consequently reduced the overall duration of growth. But for later sown crop, temperature rise reduced the lengths of juvenile and curd growth phases but increased the duration of vernalization because temperatures were beyond its optimum. They also reported that under Wellesbourne conditions, the rate of vernalization is more at 9-9.5°C and is zero below 9°C or above 21°C for the cultivar White Fox. As temperature rises above 9.5°C, the rate of vernalization declines. According to Csizinszky (1996), under warm-humid climatic conditions, seedling growth and planting of green cauliflower should be timed when minimum temperatures fall to less than 21°C. Wurr (2001) reported that in Wellesbourne of UK, increased temperatures (up to 4°C above the ambient temperature) delayed curd initiation in the cauliflower cultivar March by up to 49 days and increased the final number of leaves by 36. Nowbuth (1997) reported that warmer temperatures favoured leaf production in cauliflower up to a maximum after which a decrease was noticed. Leaf production peaked at 22.5°C for the temperate variety Revito and at 25°C for the local Mauritian variety and after that leaf production declined. Curd initiation in Revito occurred at a temperature range of 11-19.5°C compared to the local tropical variety which initiated curd at a higher range of 11-22.5°C. No curd formation was observed at and beyond 22.5°C in Revito and 25°C in the local variety.

Warm temperatures also showed an inhibitory effect on the rate of apex diameter expansion. Olesen and Grevsen (1997) found that the relative leaf area expansion was found to be a linear function of daily mean leaf surface temperature, but at temperatures above 21°C, lower rates are exhibited. Wien and Wurr (1997) reported that high frequency of curd disorders are possible in cauliflower, if they are grown beyond the range of temperature conditions for which they are originally developed. Leaf production and expansion rate increases with temperature up to the end of juvenility, but if the temperature exceeds the range needed for vernalization, curd formation could be delayed or interrupted by further leaf formation and at temperatures lower than the optimum, leaf area development could be curtailed, leading to buttoning or the production of ricey curds. According to Nowbuth and Pearson (1998), warmer temperatures cause decreased production of leaves. The final number of leaves was less when the temperature was 25-30°C. Wurr and Fellows (1998) conducted an experiment in winter cauliflower to study the leaf production and curd initiation in response to temperature. In this experiment, they used perforated polythene and non-woven fleece to cover the crops in order to raise the temperature by 1.6°C and 1.1°C respectively, compared to that of open planted crops. They reported that the time to curd initiation extended up to 93 days in the cauliflower selection 'December/January' and up to 57 days in the selection 'March'. They also reported that winter cauliflower vernalize most effectively between 10 and 16°C with an optimum rate of vernalization at about 14°C. According to Hazra and Som (1999), when the early high temperature tolerant cultivars are grown late in the low temperature conditions, quick transformation to curding without proper vegetative development takes place resulting in the production of small button like curds and in more low temperature condition, direct formation of typical green buds takes place. They also reported that the optimum soil temperature range for germination of cauliflower seed is 10-30°C. The minimum, maximum and optimum temperatures for germination are 4.4°C, 37.8°C and 25°C respectively. Olesen and Grevsen (2000) used a base temperature of 1.9°C for describing the ageing of leaf area and leaf mass, whereas root mass is handled with a base temperature of 0°C to describe the ageing of roots. According to Uzun and Peksen (2000), base temperature for thermal time calculations for both from planting to curd initiation and from curd initiation to harvest in cauliflower is 2.8°C in Turkey. Depending on the cultivars, plants required 600 to 1600°C days to initiate curd. Curd weight decreased with increased thermal time up to 1200°C days and increased after this point up to 1600°C days. They revealed based on their study that lower the thermal time required by the plants for vegetative growth, the earlier they mature. They also concluded that temperatures during vegetative growth of the cauliflower plants should be higher than those of curd growth for obtaining higher yield. Wurr and Fellows (2000) reported that under UK conditions, the optimum temperature for curd induction of all maturity groups of cauliflower varied between 9°C and 14°C. They also reported thatthe early summer crops took shorter period from planting to curd initiation whereas the winter cauliflower took the longest period. According to Chatterjee and Kabir (2002), young cauliflower seedlings of early cultivars cease growth at temperatures slightly above 0°C in temperate regions. The optimum temperature for the growth of young plant is around 23°C at first which later drops to 17-20°C. The tropical cultivars show growth even at 32°C. However, at high temperatures than that required for curding, the plant remains vegetative and continues to form new foliage. Even when the plants become generative, more leaves are usually formed at higher temperatures than at lower temperatures. In the study conducted by Pradeep kumar *et al.* (2002) at Wayanad district of Kerala, it was observed that the early planted crops (5th October) yielded highest curd weight with shorter crop duration which was attributed by the low maximum and minimum temperatures experienced by the crop. Guo *et al.* (2004) reported that in Netherlands, the most effective temperature for the induction of inflorescence in the cold-requiring cultivar cv. '60 day' was 10°C and at 25°C, flowering did not occur. He also reported that temperature along with its duration affected flowering and inflorescence development. Ajithkumar (2005) based on the experiment conducted at Anand, Gujarat, reported that the maximum, minimum and mean temperatures were negatively and significantly correlated with number of days during the curd induction phase and curd maturity phase. Warland *et al.* (2006) reported that in southern Ontario, hot weather during the month of August reduced the quality of cauliflower curds. About 10% reduction in yield was occurred when the temperature reached 30°C or more during the growing season. Ajithkumar and Savani (2007) reported that in Anand, Gujarat, for the completion of crop growth of cauliflower cultivar Snowball 16, the average values of accumulated growing degree days, heliothermal units and photothermal units were found to be 2173.5°C days, 20555°C day hours and 23308.4°C day hours respectively. According to Gopalakrishnan (2007), yield of cauliflower varies with varieties and temperature. At temperatures above 25°C, curds will be small, loose or yellow. At this temperature, maximum yield in early varieties is only 10 t ha-1. Yield in same cultivar will increase to 12-15 t ha-1 at 20-25°C. Rahman *et al.* (2007a) conducted an experiment in UK to study the relationship between temperature and growth and development of cauliflower after curd initiation and observed that the cauliflower curds increased in size and shape with increase in mean growing temperatures after curd initiation up to an optimum and declined thereafter. The optimum temperature for curd growth was 21-22°C which was higher than that required for growth of vegetative components (19°C) except for stem length. They reported that the growth and development of cauliflower after curd initiation could be resolved into linear or curvilinear function of effective temperatures calculated with optimum temperature of 19-23°C. They also suggested that future warmer climates will be beneficial for winter cauliflower production rather than summer production. Singh (2007) opined that early maturing cauliflower varieties thrive best where temperature varies between 20°C to 25°C in September to October and 5°C to 10°C in December to January. The optimum monthly temperature for curd formation is 15-22°C, with an average maximum temperature of 25°C and average minimum of 8°C. High temperature during curd maturation promotes defective curds and deteriorates quality of curds. According to Kohli *et al.* (2008), cauliflower plants changeover to curding phase from 5°C to nearly 28-30°C, depending on the variety. Cauliflower can tolerate temperature as low as 4°C and as high as 38°C, however, it cannot withstand so low or high temperature as cabbage does. Hot and dry weather is not at all suited for its cultivation. If temperature remains higher than that required for curding in specific varieties, the plant will remain vegetative without forming any curd and continue to form new foliage. Temperature should not fluctuate too much during the curd initiation and development phase otherwise, the curd quality will deteriorate. Singh (2008) reported that cauliflower grew best in cool to warm conditions (15-25°C) with high humidity. Though some varieties can grow at temperatures above 30°C, most varieties are very sensitive to higher temperature. Delayed curd initiation in cauliflower occurred due to increased temperature. According to Koike *et al.* (2009), most of the cauliflower growing areas in California have a day-time temperature of 17-29°C and the night-time temperature varies between 3°C and 12°C. At temperatures of 27°C and above, cauliflower tends to have small jacket leaves, small curds and solar yellowing. Cauliflower varieties are very responsive to temperature, so they require specific temperature for their curd initiation and development.

Varieties are classified into different maturity groups based on temperature requirements as extra early (20-27°C), early (20-25°C), medium (16-20°C), mid-late (12-16°C) and late (10-16°C) groups (Singh and Nath, 2011). Suseela and Rangaswami (2011) reported that under greenhouse conditions, higher temperature showed an inhibitory effect on plant spread, but it increased plant height. They also found that the plant spread and plant height in the open field was significantly lower than the crop planted in the greenhouse. Cauliflower gave better yield when maximum and average temperatures during vegetative and curd initiation stages inside the greenhouse were less than 30.5°C and 28.5°C respectively during winter season and less than 33°C and 30°C during summer season. When maximum and average temperatures exceeded 33.5°C and 30.5°C respectively, crop showed abnormal vegetative growth and resulted in low yield. Suseela (2012) reported that during summer season vegetative growth of cauliflower was less compared to the winter season crop.

Effect of solar radiation

Wheeler *et al.* (1995) reported that Radiation conversion coefficient in cauliflower is found to be higher at elevated CO_2 levels and it increased by 42% at 531µmol mol-1 CO_2 concentration but decreased slightly with increase in temperature. Olesen and Grevsen (1997) reported that radiation conversion coefficient appeared to be largely unaffected by temperatures above 14°C, but it declined with increase in irradiance. They also reported that in high irradiance treatments, reductions in leaf area expansion rate and dry matter production rate were observed in cauliflower and broccoli.

In an experiment conducted at Lombok, Indonesia to determine whether tropical cauliflower cv. Milky was able to produce curds in the high, non-inducing temperatures of the lowland tropics, Jaya *et al.* (2002) observed that the high temperature and irradiance during the curd growth phase resulted in poor quality curds. Rahman *et al.* (2007a), based on their experiment done at UK reported that leaf area, stem length, fresh and dry weights of leaf and stem at four weeks after curd initiation were significantly higher in high incident radiation conditions during summer than in the low incident radiation conditions during winter. Curd growth parameters like curd length, diameter, fresh and dry weights were also significantly higher in the high incident radiation conditions compared to low incident radiation conditions. But the curd dry matter accumulation was more efficient under low radiation levels compared to high radiation levels. Rahman *et al.* (2007b) found out a clear positive linear relationship between the accumulated incident radiation integral and logarithm of plant dry weight. Similar relationship was also observed in curd dry matter accumulation.

Radiation conversion coefficients for both plant and curd of cauliflower were observed to be higher under lower incident radiation levels than higher radiation levels. Thus they indicated that the rate of increase per unit incident radiation integral is greater under lower radiation conditions. Masarirambi *et al.* (2011) reported that direct exposure to sunlight resulted in the development of yellow pigments on curds. Curds left uncovered will discolour due to activation of peroxidise enzyme by sunlight and curd will loosen in the sun's heat.

Effect of humidity

Sharma and Parashar (1982) reported that cooler and wet weather helped plant growth and development in respect of yield parameters resulting in increased production compared to higher temperature with absolutely no rainfall resulting in lower yield of cauliflower. Chatterjee and Kabir (2002) reported that high relative humidity induced riciness in some cultivars of cauliflower. Nathoo (2003) conducted a study to understand the comparative performance of four summer cauliflower varieties with local cultivar at Mauritius under humid and super-humid conditions and it was found that the marketable yield at humid zone was significantly higher than super-humid zone for all the varieties. The two varieties White Contessa and Splendor when planted during winter recorded the lowest yield in super-humid region because of the prevailing low temperature in this region which initiated premature flowering in these varieties. Cauliflower performed better at the humid region in terms of curd circumference and compactness. Ajithkumar (2005) based on the experiment conducted at Anand, Gujarat, reported that the number of days taken for the completion of juvenile phase showed significant negative correlation with forenoon relative humidity.

Effect of light

In a pre-transplanting light treatment experiment, Khan and Holliday (1968) observed that increasing natural daylight from 8 to 12 hours suppressed the leaf number as well as the dry matter yield of the curd per plant. Wheeler *et al.* (1995) observed the canopy light extinction coefficient of cauliflower as 0.4 which may be associated with a slightly erect leaf inclination. According to Olesen and Grevsen (1997), canopy light extinction coefficient is 0.55 for cauliflower and 0.45 for broccoli. The lower extinction coefficient in broccoli compared to cauliflower was because of the presence of more erect leaves and there was no significant influence of irradiance was detected. Phuwiwat (2000) carried out a study in Thailand to determine the growth and yield of net house grown cauliflower under three shade levels and reported that cauliflower plants exhibited adaptation to the reduced light by increasing plant height, leaf area per plant and the leaf chlorophyll content. Alt *et al.* (2001) reported that shaded cauliflower plants had higher stem to leaf ratios than non-shaded plants. According to Ismail and Ann (2004), shading of plants significantly reduced vegetative growth and curd size of cauliflower, but colour of shaded curd was whiter than that of non-shaded curd. Rahman *et al.* (2007a) reported that growth and development of cauliflower after curd initiation declined with increasing shade levels. Leaf area and leaf dry weight were reduced progressively with increasing shade levels both during autumn and summer plantings and these reductions were found to be consistent throughout the growing period after curd initiation. Curd growth also followed the same pattern. Decrease in stem dry weight was found to be twice under higher incident radiation integral during summer than that under low radiation integral during autumn. According to Singh (2007), cauliflower is very exacting in photoperiod requirements and the early varieties require short day conditions. Capuno *et al.* (2009) reported that plants grown under rain-shelter were taller than open-field planted crop. Protected plants were subjected to a relatively reduced light which resulted in an increase in the plant height in search of light.

Effect of Planting Date on the Growth and Yield of Cauliflower

According to Howe and Waters (1982), maturity in cauliflower varies with the time of the year. In west-central Florida, fall plantings take the longest to mature followed by winter and spring which take progressively shorter periods to mature. In an experiment conducted with 8 planting dates between 1st May and 15th July by Booij (1987), it was observed that there was a correlation between the number of days from transplanting to harvesting and the date of curd initiation. He reported that late curd initiation resulted in late harvest. When six cultivars of cauliflower were transplanted on 11th June, 2nd May, 24th May and 24th June in Aarslev, Denmark, Grevsen (1990) observed that the period between transplanting and curd initiation showed more variation than that from curd initiation to harvest. Patil *et al.* (1995) revealed that under Poona conditions, appropriate time for cauliflower sowing and transplanting in terms of higher yield are first week of August and first week of September respectively. According to Gill and Sharma (1996), sowing times depend on the varieties and the agroclimatic conditions prevailing in a particular region. In North-Indian plains, early cauliflowers are sown from May end to mid-July, mid types from July to August end and snowball types from September to October. In the hills, sowing of snowball types is done by August end or September beginning and mid-types are sown from April to July. At high altitudes (more than 2000m above MSL), snowball is sown in April. In Kullu valley and Saproon valley, the most optimum time of transplanting cauliflower is the first fortnight of October. In a study done at Jorhat, Assam, it was observed that sowing of cauliflower on 15th July gave the maximum curd weight (78.48 q ha-1) which significantly declined with each delay in sowing time (30th July and 14th August). The early sown crops resulted in longer duration and produced taller plants with more number of leaves, higher plant spread, more leaf size index and lowest percentage of abnormal curds than late sown crops (Gautam *et al.*, 1998).At North Lakhimpur of Assam, an experiment was carried out with nine cultivars planted on three dates at 10 days interval *viz.,* 3 early (1st, 11th and 21st September), 3 mid-season (11th, 21st and 31st October) and 3 late (15th and 25th November and 5th December) and observed that planting time exhibited a significant effect on days to curd formation, curd size, curd weight and yield. With gradual delay in planting in early and mid-season cultivars, rise in yield was registered and for late cultivars, mid planting date was found to be superior. The highest yields in early, mid and late cultivars were obtained from the 21st September, 31st October and 25th November plantings respectively (Dutta, 1999). In a study done at Pedong, Kalimpong, Chatterjee and Som (1990) observed that sowing of cauliflower seeds in August-January was suitable for cauliflower curd production, but the maximum gross and net weights as well as size of the curd were more in the crop transplanted in the month of September. Sphehia and Korla (2000) reported that in Hisar, cauliflower planted on 5th October gave the highest yield of cauliflower whereas 5th November planting resulted in the production of unmarketable curds. Uzun and Peksen (2000) reported that in Samsun of Turkey, thermal time elapsing from planting to curd initiation and leaf number per plant declined with delay in planting time. In the first planting on 1st July, vegetative growth was enhanced by the effect of low mean temperatures compared to other planting times, namely 15th July and 1st August. Curd weight was also highest in the 1st July planting because of the higher vegetative growth of the plants. It was also found that increasing temperatures during the second and third planting times caused the plants to have shorter vegetative growth periods. At RARS, Ambalavayal, Kerala, located at an altitude of 974m above MSL which experiences a mild subtropical climate during October to February, a study was undertaken to investigate the performance of different cauliflower cultivars through sequential planting starting from October. Early (5th October) planting induced production of more number of leaves and short stalks. The gross and net weight and total yield were recorded to be highest in the early planting, whereas, late planting resulted in lower yield. The days to maturity was 66 for the variety PES-1 when planted on 5th October and the duration increased to 68 and 77.5 days, when planting date delayed to 25th October and 16th November respectively. The same trend was also found in all the varieties tested. The study revealed that even 20 days interval in planting is critical for this temperature sensitive crop and early planting is ideal for realizing potential yields in the high range regions of Kerala (Pradeepkumar *et al*., 2002). Srivastava *et al.* (2002) conducted an experiment in Uttaranchal during rainy season and obtained the highest yield (194.6 q ha-1) from the 10th August planted crop. They also reported that delay in planting date from 26th July to 25th August resulted in increase in plant height and decrease in number of leaves. When semi-early cultivars of cauliflower were tested under Southeast Spain conditions, Fernandez *et al.* (2003) observed that November planting of cv. Tenere took the longest time for curd initiation (77 days), while the shortest was in the February plantings of cv. Fargo and Kimball (33 days). The duration of the cultivation cycle exceeded 100 days in first and second crops because of the lower than usual winter temperatures during the cultivation period, with a mean value of 11°C. In subsequent plantings, the cycle gradually shortened as the weather improved and the last planting in March took only 70 days, but it yielded the lowest curd weight. According to Nathoo (2003), there are three distinct cropping seasons for cauliflower production in Mauritius. These are the early season (January-April), the mid season (May-August) and the late season (September-December). The most popular variety cv. Local which is open-pollinated grows well in a temperature range of 15- 25°C, but no production is possible during the summer months (October- March). Thapa and Pati (2003) conducted a study in Mohanpur, West Bengal and found that transplanting on 5th September resulted in more number of leaves and plant height, curd weight per plant, curd size and curd yield compared to planting on 20th august, 20th September and 5th October. Ajithkumar (2005) conducted a study on cauliflower with three dates of planting at Anand, Gujarat and observed that the 1st November planted crop resulted in more curd yield and biomass compared to the crops planted on 15th November and 1st December. Bing Liang *et al.*(2005) conducted a study in Beijing, China to investigate the plant growth under five different dates of sowing *viz.,* 25th May, 5th, 20th and 30th June and 15th July and revealed that the leaf length and width of the biggest leaf and plant height increased significantly during curd initiation with each delay in sowing date, but the number of leaves decreased. Cebula *et al.* (2005) reported that in Krakow, Poland, the planting time for the late and early cultivars of cauliflower were second half of June and first half of July respectively. Jana and Mukhopadhyay (2006) conducted an experiment at Cooch Behar, West Bengal with three dates of sowings and reported that sowing on 15th August gave the highest curd yield which later decreased with each delay in sowing time. According to Sharma *et al.* (2006a), transplanting of cauliflower seedlings should not be delayed beyond first week of June in dry temperate zone of western Himalaya. They reported that transplanting of Pusa Snowball K1 on June 2nd gave significantly higher yield and out-yielded the other combinations of transplanting dates and varieties in the dry temperate zone of western Himalaya. Early transplanting (18th May) resulted in low yield due to the prevailing low temperatures which restrict the growth during the early stages. In the case of late transplanted crop, gradual increase in temperature was observed which proportionately reduced the vegetative growth. Swarup (2006) reported that in southern (Karnataka, Tamil Nadu and Andhra Pradesh) and western India (Maharashtra and Gujarat), early and mid-season maturing cultivars can be sown during December- February and late season snowball types in September-October. However, the appropriate time of sowing may vary according to location, climate, cultivar and local practices. Ajithkumar and Savani (2007) based on their two year investigations conducted in Anand, Gujarat, on the cultivar Snowball 16 reported that the number of days taken by the crop for completion of each phenophase varied with the date of planting. The number of days taken for harvest was higher in the crop planted in 1st November in both years of study (104 and 112 days respectively) and consistently decreased with subsequent plantings. The days taken to harvest were much lower in case of 30th November in both the years of study (89 and 87.9 days respectively). The crop planted on November 1st recorded the highest yield than the delayed plantings. According to Din *et al.* (2007), June is the suitable month for the sowing of cauliflower in Juglote, Gilgit of Pakistan and the most appropriate sowing date is 16th June in terms of curd weight and fresh plant weight compared to other sowing dates *viz.,* 1st June, 1st July, 16th July and 31st July. According to Joseph and Markose (2007), cauliflower is grown both in hills and plains from 11°N to 35°N during July to March in northern plains and from March to November in hills in India. In an experiment conducted at PAU, Ludhiana, Kaur *et al.* (2007) observed significantly higher curd yield (196.9 q ha-1) in the earlier planting on 15th November and lowest yield in the delayed planting on 5th November (108.1 q ha-1). In the study conducted at Karnal, Haryana, Selvakumar *et al.* (2007) observed that the curd diameter and the number of days required to reach different phenophases in cauliflower got reduced as the date of sowing delayed from 20th July to 20th August. Ara *et al.* (2009) reported that all the vegetative growth parameters like plant height, number of leaves, whole plant weight, and marketable curd weight and per hectare yield were influenced significantly by the date of planting. They inferred from the study done at Bangladesh that irrespective of the lines, cauliflower should be planted in the month of August for better performance. Plant height and number of leaves per plant were maximum at earlier planting on 1st May and then decreased gradually with subsequent delay in planting, but marketable curd weight and whole plant weight were found to be highest in the late planting on 1st August. According to Fritz *et al.* (2009), in Minnesota, early maturing varieties of cole crops are more sensitive to low temperature damage than those maturing later. So, the initial planting date seldom goes earlier than mid-April. Fall season plantings should be made in early July, since the end of the season in Minnesota is approximately early November. The various cauliflower growing tracts and seasons in California were described by Koike *et al.* (2009). According to them, cauliflower is transplanted and harvested virtually year-round in them central and south coast of California. In the San Joaquin Valley, planting begins in mid-July and in the southern deserts, planting begins in August and continues until early December.

Conclusion

The height of the plants at different weeks after transplanting was observed to be highly variable among the different planting times with respect to prevailing weather conditions. However, at the time of harvest, no significant difference for plant height was noticed with respect to the planting time. The maximum, minimum and mean temperatures showed positive correlation with plant height until curd initiation and after that increase in temperature exhibited negative effect on plant height. Increase in bright sunshine hours, solar radiation and wind speed exhibited positive effect on plant height. Increase in forenoon and afternoon vapour pressure deficits in response to decrease in the corresponding humidity also favoured the enhancement of plant height. Riceyness was observed when the minimum temperature before and after the initiation of curd was higher and it was in agreement with the opinion of Kohli et al. (2008) that warm cloudy nights were favourable for the riceyness disorder. Buttoning disorder of cauliflower is marked by the development of small curds when the plants are small and it was observed in the delayed plantings and was in agreement with the opinion of Hazra and Som (1999) that planting of early variety late in the season can result in this disorder. Dutta et al. (2011) reported that rate of disease increment was positively correlated with forenoon and afternoon relative humidity and rainfall and negatively correlated with maximum, minimum and mean air temperature. They also revealed that average temperature of 27-30°C and average relative humidity greater than 85% and presence of rainfall were associated with this disease. Hazra and Som (1999) reported that black rot disease is prevalent in regions where rainfall or dew is plenty. Singh (2007) also reported that the incidence of black rot is favoured by frequent rains. The heavy rainfall in the initial weeks after transplanting caused the incidence of Alternaria leaf spot. The magnitude of incidence of leaf spot disease depends upon the duration of wetness. For better yield the minimum temperature should be low in the curd development phase than the curd initiation phase and it was observed that earlier curd initiation resulted in highest curd weight. Afternoon relative humidity showed positive influence and vapour pressure deficit showed negative influence on curd weight. Bright sunshine hours and solar radiation during the early vegetative and curd development stages exhibited negative influence on curd weight and the wind speed during the curd maturation period showed significant negative influence on curd weight.

References

Ajithkumar, B., 2005. Response of cauliflower (Brassica oleracea var. botrytis) to weather with varying irrigation schedules and testing of vegetable model for middle Gujarat Agro-climatic Zone. PhD (Ag) thesis, Anand Agricultural University, Anand, 163p.

Ajithkumar, B. and Savani, M, B., 2007. Phasic development model for cauliflower (Brassica oleracea var. botrytis) using thermal indices. ***J. Agromet***. 9(2): 231-235.

Alt, C., Kage, H., and Stutzel, H., 2001. Nitrogen status and light environment influence dry matter partitioning in cauliflower. ***J. Am. Soc. Hort. Sci***.126(6): 750-756.

Ara, N., Kaisar, M. O., Khalequzzman, K. M., Kohinoor, H., and Ahamed, K. U., 2009. Effect of different dates of planting and lines on the growth, yield and yield contributing characteristics of cauliflower. ***J. Soil Nat***. 3(1): 16-19.

Bing Liang, W., Min, X., and JiaShu, C., 2005. Effect of seeding date and cultivars on plant growth and abnormal curd in early cauliflower. ***Chin. Veg***. 5: 13-15.

Booij, R., 1987. Influence of temperature on length of the growing period of cauliflower. ***Acta Hort.*** 198: 243-248.

Booij, R., 1990a. Cauliflower curd initiation and maturity: Variability within a crop. ***J. Hort. Sci.*** 65(2): 167-175.

Booij, R., 1990b. Influence of transplant size and raising temperature on cauliflower curd weight. ***Gartenbauwissenschaft.*** 55(3): 103109.

Booij, R. and Struik, P. C., 1990. Effects of temperature on leaf and curd initiation in relation to juvenility of cauliflower. ***Sci. Hort.*** 44: 201-214.

Capuno, O. B., Gonzaga, Z. C., Loreto, M. B., Briones, E. D., Tulin, A. T., Gerona, R. G., Mangmang, J. S., and Rogers, G. S. 2009. Performance of Cauliflower (Brassica oleracea var. botrytis L.) and Broccoli (Brassica oleracea var. italica L.) Grown Under Rain-shelter and in the Open Field in Cabintan, Ormac city, Leyte, Philippines. Working Paper No. 10, ***Australian Centre for International Agricultural Research, Philippines***, pp.9.

Cebula, S., Kalisz, A., and Kunicki, E., 2005. The course of growth and yielding of white and green cauliflower cultivated in two terms for autumn production. ***Folia Hort***. 17(1): 23-35.

Chatterjee, R. and Som, M. G., 1990. Effect of sowing date on curd production and seed yield of cauliflower. ***Veg. Sci.***17(1): 66-69.

Chatterjee, S. S. and Kabir, J. 2002., Cole crops. In: Bose, T. K., Kabir, J., Maity, T. K., Parthasarathy, V. A., and Som, M. G. (eds.), Vegetable Crops: Vol. 1. Naya Prokash, Kolkata, pp. 345-492.P. 1984. Factors causing small curds in cauliflower crops. ***J. Agri. Sci***.102: 405-413.

Csizinszky, A. A. 1996. Optimum planting time, plant spacing and nitrogen and potassium rates to maximize yield of green cauliflower. ***Hort Science.*** 31(6): 930-933.

Din, M., Qasim, M., Jan, N. E. and Faridullah., 2007. Response of different sowing dates on the growth and yield of cauliflower. ***Sarhad J. Agric.*** 23(2): 289-291.

Dutta, J. P. 1999. Effect of dates of planting on the performance of different groups of cauliflower under the condition of north bank plains zone of Assam. ***J. Agric. Sci. Soc. N. E. India*** 12(1): 38-42.

Dutta, S., Thapa, G., Barman, A. R., Hembram, S., and Khatua, D. C. 2011. Prediction of black rot disease progression of cabbage based on weather parameters. *Rajshahi univ.* ***J. Environ. Sci.*** 1: 30-33.

Fernandez, J. A., Franco, J. A., Banon, S., and Ochoa, J., 2003. Timing of cauliflower production in Southeast Spain. ***Acta Hort.*** 607: 103-108.

Fritz, V. A., Rosen, C. J., Grabowski, M. A., Hutchison, W. D., Becker, R. L., Tong, C. B. S., Wright, J. A., and Nennich, T. T., 2009. Growing Broccoli, Cabbage and Cauliflower in Minnesota [on line]. University of Minnesota Extension Bulletin.Available:http://www.extension.umn.edu/distribution/ horticulture/ M1247.html [28 Feb. 2012].

Fujime, Y. and Hirose, T., 1980. Studies on thermal conditions of curd formation and development in cauliflower and broccoli. II. Effects of diurnal variation of temperature on curd formation. ***J. Jpn. Soc. Hort. Sci.*** 49(2): 217-227.

Khan, N. A. and Holliday, R., 1968. Effect of pre-transplanting light treatments on the leaf number and curd yield of summer cauliflower. *Pakist*. ***J. Agric. Sci.*** 5(2):174-176.

Kohli, U. K., Singh, R., and Rana, M. K., 2008. Cauliflower. In: Rana, M. K. (ed.), Olericulture in India. Kalyani Publishers, Ludhiana, pp. 226-254.

Koike, S. T., Cahn, M., Cantwell, M., Fennimore, S., Lestrange, M., Natwick, E., Smith, R. F., and Takele, E., 2009. Cauliflower Production in California. Vegetable Research and Information Center Vegetable Production Series, Division of Agriculture and Natural Resources, University of California, Oakland, pp 6.

Liptay, 1981. Cauliflower: Curd initiation and timing of production in a high-temperature growing season. ***Acta Hort.*** 122: 47-52.

Gautam, B. P., Shadeque, A., and Saikia, L., 1998. Effect of sowing dates and varieties on growth and yield of early cauliflower. ***Veg. Sci.*** 25(1): 1-4.

Gill, H. S. and Singh, J. P., 1973. Effect of environmental factors on seed production of late cauliflower in Kullu valley. ***Indian J. Agri. Sci.*** 43(3): 234-236.

Gill, H. S. and Sharma, S. R., 1996. Cole crops. In: Paroda, R. S. and Chadha, K. L. (eds.), 50 Years of Crop Science Research in India. Indian Council of Agricultural Research, New Delhi, pp. 635-645.

Gopalakrishnan, T. R., 2007. Vegetable crops. In: Peter, K. V. (ed.), Horticulture Science Series: Vol. 4. New India Publishing Agency, New Delhi, pp. 199-224.

Grevsen, K., 1990. Prediction of harvest in cauliflower based on meteorological observations. ***Acta Hort.*** 267: 313-322.

Guo, D. P., Shah, G. A., Zeng, G. W., and Zheng, S. J., 2004. The interaction of plant growth regulators and vernalization on the growth and flowering of cauliflower (Brassica oleracea var. botrytis). ***Plant Growth Regul.*** 43: 163-171.

Hazra, P. and Som, M. G., 1999. Technology for Vegetable Production and Improvement. Naya Prokash, Calcutta, pp 395.

Howe, T. K. and Waters, W. E., 1982. Evaluation of cauliflower in west-central Florida. ***Proc. Fla. State Hort. Soc.*** 95: 319-323.

Ismail, M. R. and Ann, L. J., 2004. Effect of root cooling and shading on growth and yield of tropical cauliflower (Brassica oleracea var. botrytis) in coconut coir dust culture. ***Acta Hort.*** 644: 269274.

Jana, J. C. and Mukhopadhyay, T. P., 2006. Effect of sowing dates and varieties on growth and curd yield of cauliflower in terai zone of West Bengal. ***Orissa J. Hort.*** 34(1): 45-48.

Jaya, I. K. D., Bell, C, J., and Sale, P. W. 2002. Leaf production, apex expansion and yield of cauliflower (Brassica oleracea var. botrytis) in the lowland tropics. ***Trop. Agric.*** 79(4): 231-236.

Joseph, S. and Markose, B. L., 2007. Tips on Winter Vegetable Cultivation. Kalyani Publishers, Ludhiana, pp.179.

Kaur, H., Khurana, D. S., and Singh, K., 2007. Growth and yield of cauliflower (Brassica oleracea var. botrytis) as influenced by various planting dates in different intercrops. ***Haryana J. Hort. Sci.*** 36: 324-325.

Kohli, U. K., Singh, R., and Rana, M. K., 2008. Cauliflower. In: Rana, M. K. (ed.), Olericulture in India. Kalyani Publishers, Ludhiana, pp. 226-254.

Koike, S. T., Cahn, M., Cantwell, M., Fennimore, S., Lestrange, M., Natwick, E., Smith, R. F., and Takele, E., 2009. Cauliflower Production in California. Vegetable Research and Information Center Vegetable Production Series, Division of Agriculture and Natural Resources, University of California, Oakland, pp 6.

Masarirambi, M. T., Oseni, T. O., Shongwe, V. D., and Mhazo, N., 2011. Physiological disorders of brassicas/cole crops found in Swaziland: A review. ***Afr. J. Plant Sci.*** 5(1): 8-14.

Nathoo, M., 2003. Comparative performance of four summer cauliflower varieties with the local cultivar. In: Lalouette, J. A., Bachraz, D. Y., and Bheenick, K. J. (eds.), Proceedings of the Sixth Annual Meeting of Agricultural Scientists; 8-9 May, 2003; Reduit. Food and Agricultural Research Council, Reduit, Mauritius, pp. 91-101.

Nowbuth, R. D. and Pearson, S., 1998. The effect of temperature and shade on curd initiation in temperate and tropical cauliflower. ***Acta Hort.*** 459: 79-88.

Olesen, J. E. and Grevsen, K., 1997. Effects of temperature and irradiance on vegetative growth of cauliflower (Brassica oleracea L. botrytis) and broccoli (Brassica oleracea L. italica). ***J. Expt. Bot.*** 48(313): 1591-1598.

Olesen, J. E. and Grevsen, K., 2000. A simulation model of climate effects on plant productivity and variability in cauliflower (Brassica oleracea L. botrytis). ***Sci. Hort.*** 83: 83-107.

Patil, J. D., Ranpise, S. A., and Jadhav, S. B., 1995. Effect of spacing and date of seed sowing on yield of different cultivars of cauliflower. ***Madras Agric. J.*** 82(11): 613-614.

Pearson, S., Hadley, P., and Wheldon, A. E., 1994. A model of the effects of temperature on the growth and development of cauliflower (Brassica oleracea L. botrytis). ***Sci. Hort.*** 59: 91-106.

Phuwiwat, W., 2000. Growth and yield of nethouse cauliflower production under three shade levels. ***J. Agric.*** 16(3): 291-300.

Pradeepkumar, T., Babu, D. S., and Aipe, K. C., 2002. Adaptability of cauliflower genotypes in the high ranges of Kerala. ***J. Trop. Agric.*** 40: 45-47.

Rahman, H. U., Hadley, P., and Pearson, S., 2007a. Relationship between temperature and cauliflower (Brassica oleracea L. var. botrytis) growth and development after curd initiation. ***Plant Growth Regul.*** 52: 61-72.

Rahman, H. U., Hadley, P., Pearson, S., and Dennett, M. D., 2007b. Effect of incident radiation integral on cauliflower growth and development after curd initiation. ***Plant Growth Regul.*** 51: 4152.

Reeves, J., Fellows, J. R., Phelps, K., and Wurr, D. C. E., 2001. Development and validation of a model describing the curd induction of winter cauliflower. ***J. Hort. Sci. Biotech.*** 76(6): 714-720. 122.

Selvakumar, P., Sinha, S. N., and Pandita, V. K., 2007. Hybrid seed production in cauliflower (Brassica oleracea var. botrytis subvar. cauliflora). ***Indian J. Agric. Sci.*** 77(10): 649-651.

Sharma, A., Pathania, N. K., Sharma, S., and Pathak, S., 2006a. Effect of transplanting time on growth and marketable curd yield of different cultivars of cauliflower (Brassica oleracea var. botrytis subvar. cauliflora) under dry temperate high hill conditions. ***Indian J. Agric. Sci.*** 76(6): 343-345.

Sharma, R. P. and Parashar, K. S., 1982. Response of cauliflower to soil moisture regimes, nitrogen and phosphorus levels. ***Veg. Sci.*** 9(2): 75-81.

Singh, D. K., 2007. Modern Vegetable varieties and Production Technology. International Book Disrtibuting Co, Lucknow, pp.393.

Singh, D. N. and Nath, V., 2011. Varieties and Hybrids of Vegetables. Satish Serial Publishing House, Delhi, pp.426.
Singh, D. K., 2007. Modern Vegetable varieties and Production Technology. International Book Disrtibuting Co, Lucknow, pp.393.
Singh, H. P. 2008. Development in horticultural crop production with climate change. ***Indian Hort.*** 53(5): 39-45.

Spehia, R. S. and Korla, B. N., 2000. Effect of different transplanting dates on yield and quality in cauliflower (Brassica oleracea var. botrytis Linn). ***Haryana J. Hort. Sci.*** 29: 111-113.

Srivastava, P., Srivastava, B. K., and Singh, M. P., 2002. Effect of date of planting and growing environment on the plant survival, growth and yield of early cauliflower in rainy season. ***Veg. Sci.*** 29(2): 157-160.

Suseela, P., 2012. Influence of growth parameters on the yield characteristics of cauliflower (Brassica oleracea var. botrytis). ***Mysore J. Agric. Sci.*** 46(1): 1-6.

Suseela, P. and Rangaswami, M. V., 2011. Influence of temperature inside the greenhouse on growth attributes and yield of cauliflower. ***Karnataka J. Agric. Sci.*** 24(5): 706-708.

Swarup, V., 2006. Vegetable Science and Technology in India. Kalyani Publishers, Ludhiana, pp.656.

Thapa, U. and Pati, M. K., 2003. Effect of planting date and variety on the growth and curd yield of early cauliflower. ***Envion. Ecol.*** 21(3): 664-666.

Uzun, S. and Peksen, A., 2000. Study on determination of planting time for some cauliflower cultivars (Brassica oleracea var. botrytis) under Samsun ecological conditions by using plant growth and developmental models based on thermal time. ***Pakist. J. Biol. Sci.*** 3(6): 915-919.

Warland, J., McKeown, A. W., and McDonald, M. R., 2006. Impact of high air temperatures on brassicaceae crops in southern Ontario. ***Can. J. Plant Sci.*** 86(4): 1209-1215.

Wheeler, T. R., Ellis, R. H., Hadley, P., and Morison J. I. L., 1995. Effects of CO2, temperature and their interaction on the growth, development and yield of cauliflower (Brassica oleracea L. botrytis). ***Sci. Hort.*** 60: 181-197.

Wien, H. C. and Wurr, D. C. E., 1997. Cauliflower, broccoli, cabbage and Brussels sprouts. In: Wien, H. C. (ed.), The physiology of Vegetable Crops. CAB International, Wallingford, pp. 511-552.

Wurr, D. C. E., Elphinstone, E. D., and Fellows, J. R., 1988. The effect of plant raising and cultural factors on the curd initiation and maturity characteristics of summer/autumn cauliflower crops. ***J. Agric. Sci.*** 111: 427-434.

Wurr, D. C. E. and Fellows, J. R., 1990. The influence of field environmental conditions on the growth and development of four cauliflower cultivars. ***J. Hort. Sci.*** 65(5): 565-572.

Wurr, D. C. E. and Fellows, J. R., 1998. Leaf production and curd initiation of winter cauliflower in response to temperature. ***J. Hort. Sci. Biotech.*** 73(5): 691-697.

Wurr, D. C. E. and Fellows, J. R., 2000. Temperature influences on the plant development of different maturity types of cauliflower. ***Acta Hort.*** 539: 69-74.