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Screening for Heat and Rain Tolerant Cultivars of Cauliflower for Cultivation in Monsoon Season in the Subtropical Region of Bhutan

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ABSTRACT

There is a shortage of cauliflower in the domestic market during monsoon and early autumn seasons in Bhutan due to the absence of suitable cultivars for cultivation in subtropical region during these seasons. This study was conducted to assess the genotypic variability in yield of different cultivars of cauliflower under heat and rain (flood) stresses in the subtropical region. Four F1 hybrid varieties of cauliflower from the Takii Seeds, Japan (KSB-12.179, KSB-12.180, KSB-18.297 and KSB-20.320) and three F1 hybrid varieties from Syngenta Seeds, India (C-6099, CFL-1522 and Monsoon Queen) were evaluated in August 2022 in open field at ARDC Samtenling. The experiment was laid out in a RCDB design with three replications using Snow Mystique as the check variety. The objective of the study was to identify short duration, rain and heat tolerant varieties of cauliflower for cultivation in the monsoon season (July-August) in the subtropical region of Bhutan. In addition, all the cultivars were further assessed in September, and five cultivars that performed well in monsoon planting were evaluated in November 2022 as the second and third staggered planting trials to find out their performance in late monsoon and main seasons (September-November) respectively. The results from three staggered trials showed that Monsoon Queen matured in 53 days after transplanting (DAT), 56 DAT and 35 DAT in the first, second and third staggered planting trials with the mean head of 462 g, 376 g and 211 g respectively. In comparison, the check variety matured in 142 DAT, 114 DAT and 77 DAT in the first, second and third staggered planting trials with the mean head of 658 g, 403 g and 767 g, respectively. Monsoon Queen was the earliest maturing variety with good head weight and curd quality among the eight cauliflower varieties when transplanted in August 2022. However, both the head yield and curd quality of this cultivar declined in later plantings, indicating that this variety is not suitable for main season (autumn) planting. With the identification of Monsoon Queen as the heat and rain tolerant cultivar in this study, cauliflower can now be grown even in the monsoon season in the subtropical region of Bhutan.

Keywords: *Cauliflower; Heat tolerant; Rain tolerant; Variety; Short duration, Yield*

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1 Introduction

Cauliflower (*Brassica oleracea* var. *botrytis* L.) is one of the most important vegetable crops in Bhutan. Cauliflower, broccoli and cabbage are cole crops which are usually grown during the cool winter season. They prefer temperature of about 7 to 13^{o}C for optimal growth and development (AVRDC, 1990). In Bhutan, the area under cauliflower was 1,228 acres with the total production of 2,447.8 metric tons in 2021 (RSD, 2020). Curd is the edible part which is consumed as vegetables, eaten fresh as salad and also used in preparing pickles, fried snacks, burger and sandwich (Ashraf et al., 2017; Warland, McKeown, & McDonald, 2006). Cauliflower is rich source of vitamins and minerals like phosphorus, potash, calcium, sodium and iron which can protect from cancers, heart diseases and also help to maintain the cholesterol level and immune system of the body if consume regularly (Keck & Finley, 2004).

Cauliflowers varieties currently cultivated in Bhutan are mostly hybrids suitable for cultivation in autumn for harvest in winter, except for two hybrids namely Pragati 40 and White Express 50 which are recommended for spring season. In Bhutan, currently there are no suitable cauliflower varieties recommended for cultivation from July to September. Cauliflower is highly sensitive to climatic factors that influence the formation and growth of the curds. Based on temperature requirement, they are classified into early, mid and late season groups. Early varieties of cauliflower require higher temperature (20-25°C) for curd formation, while late varieties require lower temperature of 10-16°C (Chatterjee & Mahanta, 2013). The temperature above 25°C adversely affects the formation of curd that results in poor qualities or defective curds in the late varieties (Aleem et al., 2021; Swiader, Ware, & McCollum, 1992). Cool-season varieties of cauliflower cannot thrive under prolonged periods of warm weather, so there is no cauliflower production during the summer months in subtropical region of Bhutan. Thus, there is a good market opportunity for summer-grown cauliflower in this region of Bhutan if varieties tolerant to heat-induced disorders are identified. In cauliflower, the commonly observed high temperature induced disorders include bract development (development of small green leaves in the head), uneven head development, ricyness, bolting and brown/purple beads. However, the initiation of curds in cauliflower also depends on the genetic characteristics of the varieties (Saini, 1996).

Plant breeders have recently developed several new cauliflower varieties with improved heat tolerance over the more traditional varieties. According to Wang et al. (2011), the three main groups of cauliflower are:

a). European/temperate cauliflowers

i. Traditional cool-season varieties of cauliflower that perform well only in cold winter (temperature above 20°C adversely affects curd formation).
ii. Medium to late maturing varieties with curd head weight greater than 1.5 kg.
iii. Require lower temperature of 10-16°C for curd formation.
iv. If the temperature remains high, the plant will continue remain in vegetative phase without forming any curd.

b). Asian/Indian/tropical cauliflowers

i. Grow well in warm weather (heat tolerant).
ii. Early maturing cauliflowers which can harvested within 50-65 days.
iii. Require higher temperature (20-25°C) for curd formation.
iv. Usually small sized curd head (> 1 kg).

c). Semi-tropical cauliflowers

i. Intermediate between European and Asian cauliflowers in growth habit.
ii. Head weight ranges between 1.0 to 1.5 kg.

With the ban on import of green chillies, snap beans and cauliflowers to Bhutan from June 2016 due to a high residual content of pesticides, there is an urgent need to have early, heat and rain tolerant cauliflower cultivars in the country to make domestically grown cauliflower available in the market in late monsoon and early autumn seasons. All the existing cauliflower cultivars are of medium-late maturing varieties which perform well only during cool winter season. High temperature and waterlogging are the major abiotic stresses that hinder cauliflower cultivation during monsoon in the subtropical region of Bhutan. On the other hand, the heat tolerant cultivars of cauliflower can form heads at mean temperatures higher than 25°C (Collado-González, Piñero, Otálora, López-Marín, & Del Amor, 2020). Thus, early varieties of cauliflower that perform well in heat and rain for autumn harvest are needed to fill the gap in the domestic market. Over the past decade, there have been considerable increases in cauliflower production in the tropics and subtropics because of the availability of new, tropically adapted cultivars, resulting in increased farmer incomes (Lin, Chen, Li, & Lo, 2015).

The objective of this study was to introduce and identify heat and rain tolerant varieties of cauliflower that mature within two months for cultivation in monsoon season in the subtropical region of Bhutan for autumn harvest.

2 Materials and Methods

2.1 Cauliflower varieties and nursery management

Four F1 hybrid varieties of cauliflower introduced from the Takii Seeds, Japan and three F1 hybrid varieties from Syngenta Seeds, India were evaluated for their heat and rain tolerances at Agriculture Research and Development Centre (ARDC) Samtenling in RCDB design with three replications using the non-heat tolerant variety of cauliflower, Snow Mystique, as the check in open fields in August 2022 in the first staggered planting trial (Table 1). In addition, those cauliflower varieties that performed well and harvested within two months after transplanting in monsoon cultivation were further evaluated in the main season by transplanting in September (second staggered planting) and in November 2022 (third staggered planting) to assess their performance under autumn and winter plantings. The primary objective of second and third staggered planting trials was to find out the performance of the heat and rain tolerant genotypes of cauliflower that perform well in monsoon season when planted in autumn and winter seasons (September–November).

Table 1. Cauliflower varieties screened in three staggered planting trials in 2022 at ARDC Samtenling

Variety	Crop type	Seed source	Staggered planting trial
Snow Mystique (*)	F1 hybrid	Takii Seeds, Japan	1, 2 & 3
KSB-12.179	F1 hybrid	Takii Seeds, Japan	1 & 2
KSB-12.180	F1 hybrid	Takii Seeds, Japan	1 & 2
KSB-18.297	F1 hybrid	Takii Seeds, Japan	1, 2 & 3
KSB-20.320	F1 hybrid	Takii Seeds, Japan	1 & 2
C-6099	F1 hybrid	Syngenta seeds, India	1, 2 & 3
CFL-1522	F1 hybrid	Syngenta seeds, India	1, 2 & 3
Monsoon Queen (C-6105)	F1 hybrid	Syngenta seeds, India	1, 2 & 3

(*) Non-heat and rain tolerant (main season) check variety

Seeds of all cauliflower cultivars were sown in the plastic nursery plug trays (having 16 holes per tray) filled with FYM, topsoil and sand in 2:1:1 proportion in a greenhouse. The nursery was raised on 5 July, 15 August and 31 October 2022 for first staggered planting, second

staggered planting and third staggered planting, respectively at Agriculture Research and Development Centre (ARDC) Samtenling, Sarpang. Seedlings with four to six true leaves were transplanted in the trial fields on 18 August, 21 September and 30 November 2022 as the first staggered planting, second staggered planting and third staggered planting, respectively.

2.2 Experiment site, experiment design and data recording

Screening trial was conducted at the research farm (N $26^0$54'40", E 90°25'33"; elevation 375 m) of ARDC Samtenling. Seedlings of each cultivar with four to six true leaves were transplanted in the trial at a spacing of 60 x 45 cm (plant x row) in all three staggered trials. The treatments were arranged in a randomised complete block design (RCBD) and each treatment were replicated three times. Each plot was a raised bed of 25 cm high, measuring 2.25 m long by 1.0 m wide. The plots were separated by 50-cm-wide drains to facilitate drainage of rain run-off water. There were two rows in each plot, accommodating a total of 10 plants in each plot and five plants in each row. All the experimental plots were mulched with silver-coloured plastic mulch film before the planting of seedlings. The field trial had border rows on four sides, each border consisting of two rows of plants of Snow Mystique cultivar. The data were not collected from these border row plants. The standard cultural and management practices for cauliflower were followed. Briefly, 12.5 tonne/ha of well decomposed farm yard manure (FYM) was incorporated to the field at the time of field preparation. Fertilizer 50 kg N, 80 kg P_2O5 and 75 K_2O per hectare were applied before final land preparation. In addition, 50 kg urea was applied in two equal split doses at 30 and 45 days after transplanting. Irrigation was given immediately after planting and later as and when required. Weeds from the field were removed from the field by hands at 20, 35 and 45 days after transplanting (DAT).

2.3 Data collection

The data were collected from all 10 plants in each plot for all the parameters included in this study. Plant height was recorded just before the harvest by measuring the distance from the ground to the top (tallest leaf) of each plant. Days to harvest (maturity) and curd colour were also recorded at the time of harvest. Plants were harvested as and when they matured and were harvested at full maturity stage when the heads became smooth, firm and compact. The data on head (curd) weight per plant and yield per plot were recorded in each plot during harvest.

Yield per plot was converted to tonne per acre (t/acre). Incidence of major pests and diseases were also observed and recorded in all three staggered planting trials.

2.4 Data analysis

The data were subjected to analysis of variance (ANOVA) using the PROC MIXED procedure of the Statistical Analysis System (SAS) (version 9.4; SAS Institute, Cary, NC, USA). Multiple comparisons among the means were conducted using Fisher's protected least significant differences (LSD) test when effects were statistically significant ($p < 0.05$).

3 Results and Discussion

3.1 Major pests and diseases

The main pests and diseases observed in the trials were cabbage webworm (*Hellula undalis*), bacterial soft rot (*Pectobacterium carotovorum,* previously called *Erwinia carotovora* var. *carotovora*), black leg (*Phoma lingam*) and black rot (*Xanthomonas campestris)* (Table 2).

Table 2. Pests and diseases observed in three staggered planting trials of cauliflower

Variety	Pests and diseases incidences (%) in 3 staggering trials			
	Bacterial soft rot	Blackleg	Black rot	Cabbage webworm
Monsoon Queen	10 (1)	10 (1)	0	0
CFL-1522	10 (1)	10 (1)	10 (1)	10 (1)
C-6099	10 (1)	10 (1)	10 (1)	0
KSB-12.179	10 (1)	10 (1)	10 (1)	10 (1)
KSB-18.297	20 (1)	10 (1)	10 (1)	10 (1)
KSB-12.180	20 (1)	10 (1)	10 (1)	10 (1)
KSB-20.320	20 (1)	20 (1)	10 (1)	10 (1) & 15 (2)*
Snow Mystique	20 (1)	20 (1)	10 (1)	15 (1) & 10 (2)*

*****Number in parenthesis ( ) indicates the staggered planting trial

3.2 Yield and yield components

The data on plant height, maturity date, head weight and head yield of all seven varieties of cauliflower evaluated at ARDC Samtenling in three staggered planting trials are presented in Table 3, Table 4 and Table 5.

Table 3. Crop maturity duration and yield of cauliflower varieties in the first staggered planting trial (planted on 18 August 2022)

Variety	Maturity		Head wt. (g)	Yield/ plot (kg)	Yield/ acre (kg)	Plant height (cm)
	Date	DAT				
Monsoon Queen	10 Oct 2022	53 e	462 ab	3.903	6,581	41.7 e
CFL-1522	14 Oct 2022	57 e	441 ab	3.881	6,544	46.4 cde
C-6099	24 Oct 2022	67 d	475 ab	3.027	5,104	43.4 de
KSB-12.179	7 Nov 2022	81 c	538 ab	4.304	7,258	50.7 cb
KSB-18.297	4 Nov 2022	78 c	283 b	2.520	4,249	49.6 cde
KSB-12.180	22 Dec 2022	126 b	501 ab	2.829	4,770	61.9 b
KSB-20.320	27 Dec 2022	131 b	476 ab	3.559	6,001	51.6 c
Snow Mystique	7 Jan 2023	142 a	658 a	3.289	5,546	70.6 a
CV (%)	---	5.2	11.6	12.2	---	8.1
P-value	---	<0.0001	0.0140	0.4214	---	<0.0001

Table 4. Crop maturity duration and yield of cauliflower varieties in the second staggered planting (planted on 21 September 2022)

Variety	Maturity		Head wt. (g)	Yield/plot (kg)	Yield/ acre (kg)	Plant height (cm)
	Date	DAT				
Monsoon Queen	6 Nov 2022	46 b	376.4 ab	3.542 ab	5,973	45.3 bc
CFL-1522	25 Nov 2022	65 b	324.7 b	2.976 ab	5,018	46.1 bc
C-6099	26 Nov 2022	66 b	349.7 ab	3.497 ab	5,897	44.4 c
KSB-12.179	4 Dec 2022	74 b	374.2 ab	2.971 ab	5,010	49.0 abc
KSB-18.297	7 Dec 2022	77 b	335.8 b	2.468 b	4,162	52.0 ab
KSB-12.180	29 Dec 2022	99 a	530.9 a	4.247 a	7,162	49.5 abc
KSB-20.320	30 Dec 2022	100 a	533.2 a	3.905 ab	6,585	53.6 a
Snow Mystique	13 Jan 2023	114 a	403.2 ab	3.067 ab	5,172	54.7 a
CV (%)	---	10.6	12.5	11.7	---	7.4
P-value	---	0.0002	0.0087	0.0304	---	0.0235

Table 5. Crop maturity duration and yield of cauliflower varieties in the third staggered planting (planted on 30 November 2022)

Variety	Maturity		Head wt. (g)	Yield/plot (kg)	Yield/ acre (kg)	Plant height (cm)
	Date	**DAT**				
Monsoon Queen	4 Jan 2023	35 c	210.9 b	1.533 c	2,585	32.3 c
CFL-1522	23 Jan 2023	54 b	361.7 b	1.952 c	3,292	53.7 b
C-6099	4 Jan 2023	35 c	240.2 b	2.145 c	3,617	35.3 c

KSB-18.297	8 Feb 2023	70 a	621.9 a	5.241 b	8,838	59.4 b
Snow Mystique	15 Feb 2023	77 a	767.3 a	7.395 a	12,470	68.8 a
CV (%)	---	7.1	12.3	11.5	---	7.5
P-value	---	<0.0001	<0.0001	<0.0001	---	<0.0001

In the first staggered planting (18 August 2022), Monsoon Queen and CFL-1522 matured in 53 and 57 DAT respectively (Table 3). This maturity date of these two cultivars was statistically significant from other cauliflower cultivars. The mean head weight of Monsoon Queen and CFL-1522 were 462 g and 441 g respectively, but not statistically different from the highest weight (658 g) recorded in check cultivar (Snow Mystique). No severe pests and diseases in these two cauliflower cultivars. Their calculated productions per acre were 6,581 kg and 6,544 kg respectively. The check variety (Snow Mystique) took the maximum days after planting (142 DAT) for head maturity having the mean head weight of 658 g in the first staggered planting corresponding to the productivity of 5,546 kg per acre. The months of August and September were very hot with rain events occurring sporadically and sometimes heavy (data not shown) leading to increased levels of pest and disease incidences in non-heat and rain tolerant genotypes (Table 2). This high pest and disease and incidences coupled with hot growing conditions resulted in a low number of plant survival producing low head yield per plot by those cultivars. Consequently, Snow Mystique with highest mean head weight (658 g) did not produce the highest yield per plot in the first staggered planting trial.

In second staggering planting, the maturity ranged from 46 DAT to 114 DAT among cultivars, the earliest and the latest maturing cauliflower cultivars being Monsoon Queen and Snow Mystique, respectively (Table 4). The mean head weight of Monsoon Queen (376 g) was statistically not significant from other cultivars. Although the maturity of CFL-1522 not statistically significant from that of Monsoon Queen, it had lower head weight (325 g) that was significantly different from the KSB-20.320 that produced the highest head weight (533 g) in the second staggered trial. The days taken by KSB-12.180, KSB-20.320 and Snow Mystique for maturity were significantly different from the rest cauliflower cultivars in the second staggered planting trial.

The earliest maturing cultivar in the third staggered planting was Monsoon Queen with maturity duration of 35 DAT. However, some fuzziness and buttoning of curd were observed in this genotype (Figure 2c) but more of these physiological disorders recorded in CFL-1522,

thereby lowering the marketable yield of cauliflower head. As in the first and second staggered plantings, Snow Mystique took the maximum number of days (77 DAT) for head maturity (Table 5, Figure 1a).

All the cultivars matured earlier in the second and third staggered plantings than in the first staggered planting except CFL-1552 that took eight days more for maturity in the second staggered plantings (Figure 1a). Similarly, the head weights of all the cultivars were lower in the second staggered planting except three cultivars (KSB-18.297, KSB-12.180 and KSB-20.320) in comparison to that of the first staggered planting. There was increase in head weight only in KSB-18.297 (622 g) and Snow Mystique (767) in the third staggered planting compared to that in the first staggered planting (Figure 1b). The mean heads of Monsoon Queen in the second and third staggered planting trials were only 81% (376 g) and 46% (211 g) respectively in comparison to its first staggered planting (462 g). Similarly, the mean head weight of CFL-1522 was only 74% (325 g) and 82% (362 g) in the second and third staggered planting trials respectively in comparison to its first staggered planting (441 g).

The growth and development of cauliflower is classified into three stages: vegetative phase, curd initiation phase and curd development phase (Bhattarai, Pardhan, Chalise, & Piya, 2014). Cauliflower varieties or lines also generally differ in the requirement of temperature for curd initiation (Ara, Kaisar, Khalequzzaman, Kohinoor, & Ahamed, 2009). Temperature plays an important role in cauliflower influencing all these phases. Wurr, Fellows and Phelps (1996) suggested that the optimal temperature for curd initiation is lower in cauliflower types that mature in the summer than in those that mature in winter. The present study identified that the temperatures between 20℃ and 22℃ are good for curd formation for Monsoon Queen, the newly introduced heat and rain tolerant genotype of cauliflower. Further, this study found that only heat tolerant genotypes (Monsoon Queen and CFL-1552) were able to develop curd at high temperature, while the heat susceptible genotypes (Snow Mystique and KSB-18.297) were not able to develop curd at high temperature. Earliness in curd maturity is critical to marketability and profitability because less time from planting to harvest corresponds to reduced cost of production (mainly cost associated with pest control and weeding) and increased market value. In this study, the cultivars suitable for monsoon cultivation, Monsoon Queen and CFL-1552, expressed physiological disorders like buttoning and fuzziness of curd when planted in the main (winter) season.

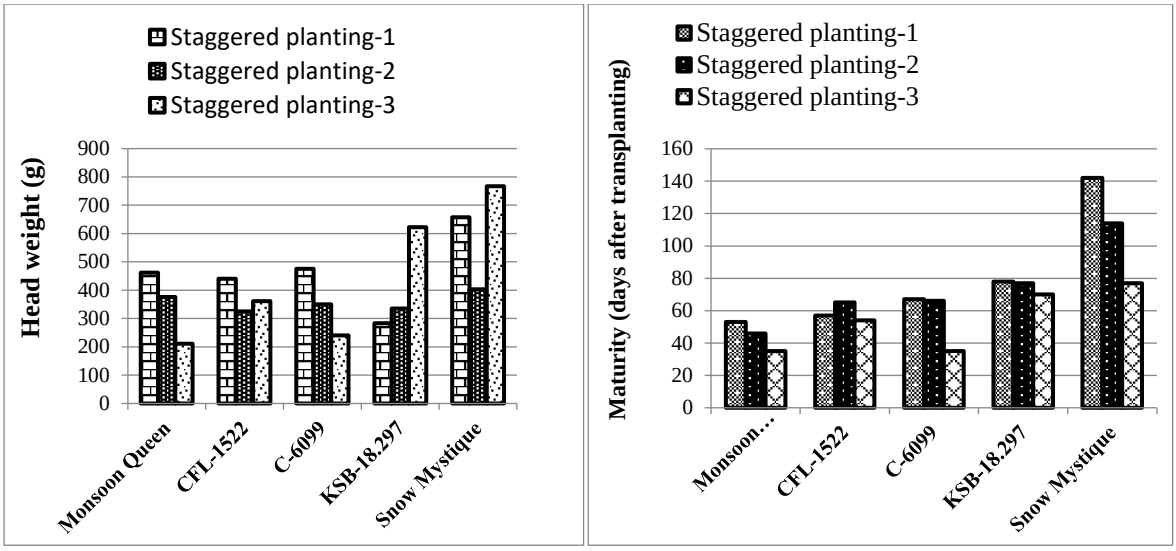

Figure 1. Curd head weight (left) and head maturity duration (right) of different cultivars of cauliflower in first, second and third staggered planting trials

With the development of tropical Indian hybrids cauliflowers, cultivation of cauliflower is possible throughout the year in India (Islam, Datta, & Chatterjee, 2016). The finding of this study is in line with that of Lin, Chen, Chen, Lee and Hsieh (2019) who reported that the cultivars of tropical cauliflower initiated curd development but with a different pattern from temperate cultivars when grown in cool season. Cebula Cebula, Kalisz and Kunicki (2005) suggested that the period before curd formation is shorter in early-maturity cultivars than in late-maturity cultivars in moderate climates. Another study reported that the number of leaves required to induce curd initiation was less than nine in tropical cauliflower at temperatures of 18 to 30℃ (Wurr, Fellows, & Fuller, 2004). For the conventional varieties of cauliflower, the optimum temperature for young seedlings is around 25℃ which at later growing stage drops to 20℃ for curd formation (Chatterjee & Mahanta, 2013; Kindo & Singh, 2018). However, if the temperature remains high (higher than required for curd formation), the plant will continue to remain in vegetative phase without forming any curd (Lin et al., 2019). In the present study, cauliflower cultivar Snow Mystique took 142 days for maturity after transplanting when planted on 18 August 2022 but it took only 77 days when transplanting was carried out on 30th November 2022.

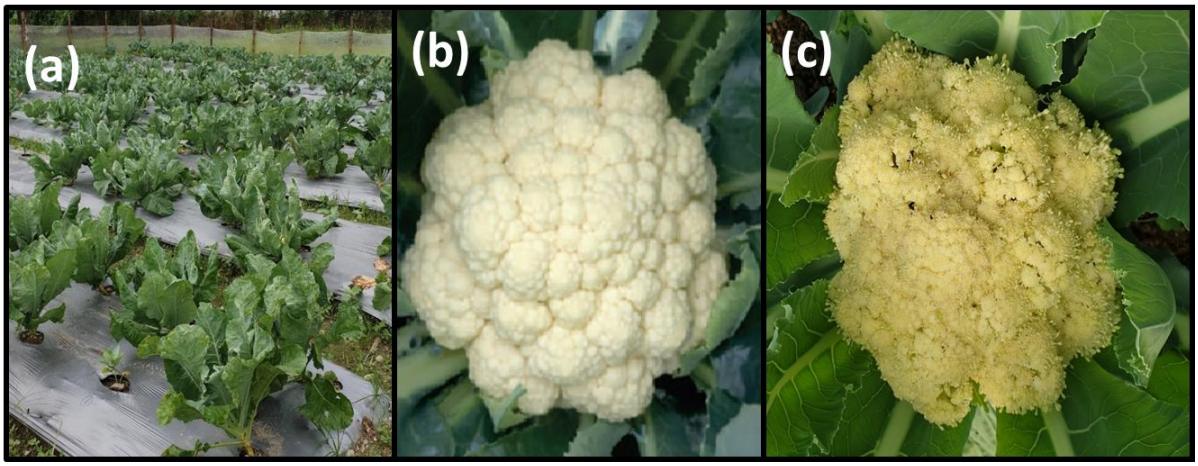

Figure 2. Plants (a) and curd head (b) of cauliflower cultivar Monsoon Queen in the first staggered trial and curd head (c) in the third staggered trial

In summary, the head weight and yield of heat tolerant genotypes of cauliflower, Monsoon Queen and CFL-1552 declined with each successive delay of transplanting date among the three transplanting dates (18th August, 21st September, and 30th November). Thus, the transplanting of Monsoon Queen variety between August and September is recommended for obtaining quality curd and maximum yield. Meanwhile, transplanting the cool season, cauliflower cultivar (Snow Mystique) in November matured early and produced the highest yield with lesser incidence of pests and diseases in this study. The findings of this study indicate that selection of varieties and optimum planting time are the key factors for high yield and quality curd production of cauliflower. The future study may focus on earlier transplanting dates (June-July) to see the curd quality and performance of Monsoon Queen for early monsoon cultivation in the subtropical region of Bhutan. In addition, economic analysis of cultivation of heat and rain tolerant genotypes of cauliflower during monsoon season is recommended.

4 Conclusion

The results from three staggered planting trials in different months confirmed that cauliflower cultivars Monsoon Queen and CFL-1552 were of shorter duration, tolerant to heat and rain stresses suitable for planting during monsoon season. These varieties produced good quality curd with marketable head weight and matured within 65 DAT when planted in August and September. However, the head weight of CFL-1552 was lower (325 g) than that of KSB-20.320 that produced the highest head weight (533 g) in the second staggered trial. On the other hand, the check cultivar, Snow Mystique which matured in 77 DAT in November

transplanting with the highest head weight among three staggered plantings was found indisputably suitable for autumn cultivation. Based on the results, Monsoon Queen was released in the 25th VRC of the Department of Agriculture, held in June 2023 in Thimphu. Release of this variety can extend cauliflower growing season in the subtropical region of Bhutan. With the identification of this early maturing, heat and rain tolerant cauliflower variety, maize-cauliflower-beans cropping system will likely emerge as the most economical cropping system in the dryland for southern foothill region of Bhutan as these three crops can be cultivated within a year in sequence. Further, this newly introduced cultivar of cauliflower could offer market opportunity in the region because of their good head size and excellent curd quality for monsoon cultivation.

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