Original Research Article

Morphological characterization of cytoplasmic male sterile lines with their respective maintainers in Cauliflower (*Brassica oleracea* var. *botrytis* L.)

Abstract

Forty lines of cauliflower (Twenty CMS and their respective maintainers) were evaluated and analyzed for twenty-two morphological traits. The experimental results showed that maximum stalk length was observed in CMS line UHF-CAU-16A (15.86cm) and minimum stalk length was observed in line UHF-CAU-4A (4.22cm). While among the maintainer lines maximum stalk length was observed in UHF-CAU-16B (17.46cm) and minimum stalk length was observed in lines UHF-CAU-5B and UHF-CAU-10B (10.00cm). Days to curd initiation was found to be maximum (130 days) in CMS lines (UHF-CAU-9A, UHF-CAU-10A, UHF-CAU-17A and UHF-CAU-20A) and minimum in lines UHF-CAU-1A, UHF-CAU-2A, UHF-CAU-4A, UHF-CAU-7A, UHF-CAU-12A, UHF-CAU-15A and UHF-CAU-18A (100 days). Whereas in the maintainer line the days to curd initiation was significantly higher (131.04 days) in line UHF-CAU-20B and minimum (99.80 days) in line UHF-CAU- 4B. CMS line UHF-CAU-13A (13.50 cm) recorded maximum curd polar diameter and maintainer line, UHF-CAU-13B (14.86 cm) recorded significantly higher curd polar diameter. Curd equatorial diameter was found to be maximum (19.80 cm) in CMS line UHF-CAU-16A. Whereas, among the maintainer lines, the curd equatorial diameter was significantly higher (21.40cm) in line UHF-CAU-13B. Further analysis of the lines by paired t-test showed significant differences between the CMS lines and their respective maintainer pair in terms of different morphological traits, providing evidence to the negative effects caused by the male sterile cytoplasm in the cytoplasmic male sterile lines of cauliflower.

Keywords Cauliflower, cytoplasmic male sterility, morphological traits, *Ogura*

Introduction

Brassica oleracea (CC, 2n = 18) constitutes a diverse group of commercially and nutritionally significant morphotypes known as cole vegetables (cabbage, cauliflower, broccoli, kale, kohlrabi, brussels sprout) (Maggioni et al 2018). Cauliflower (*B. oleracea* var.

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botrytis L.), one of the morphotypes of *B. oleracea*, is an important vegetable crop that originated in the Mediterranean region. The Latin words *caulis*, which means stalk, and *floris*, which means flower, are the origins of the English word cauliflower (Sharma et al2005). The Brassica vegetables are referred to as "super-foods" due to their importance as a source of antioxidants, vitamins, minerals, and secondary metabolites. Among the many glucosinolates found in cauliflower, the most important ones are sinigrin (9.3 micromol g^{-1}dw), 4-hydroxy glucobrassicin (1.6 µmol g^{-1}dw) and glucobrassicin (1.3 micromol g^{-1}dw) (Khusadet al1999). The 100 g fresh curd has 2.15 g of protein, 31.3 µg of lutein, 45.95 µg of folate, 47.14 µg of ascorbic acid, and key dietary minerals such as calcium (25.16 mg), potassium (329 mg), phosphorus (47.33 mg), iron (0.96 mg), and selenium (0.47 mg) (Longvahet al 2017).

Because of their uniform maturity, high yield, superior curd quality in terms of colour and compactness, and resistance to diseases, insect pests, and unfavorable weather, the F_1 hybrids have a lot of potential in cauliflower (Kucera et al 2006; Dey et al 2014). However, morphological characterization of these lines is urgently needed for evaluating the usefulness of these lines. CMS lines with good morphological traits in respective maturity groups would be instrumental in developing F_1 hybrids in cauliflower which could also be useful for selecting particular floral traits. Breeders can reduce the duplication of accessions in germplasm collection by employing morphological variability characterization to find accessions with desirable traits like leaf length, anthocyanin colouration, maturity based on curd initiation, etc. Evaluation of cytoplasmic male sterile lines derived from 'Ogura' could serve as parental lines for the development of hybrid cauliflower seeds. Moreover, it is also necessary to select the diverse lines in breeding programme. The potential of discovering superior lines increases with the amount of variation in the available germplasm (Srishti and Yogita 2023). By using CMS lines with a high degree of resemblance, heterotic hybrids may be less likely to occur. The variation among lines which was observed is useful in identification of superior lines for inclusion in breeding programmes or direct use as a cultivar. Furthermore, association of any of these morphological characters with desirable traits or yield components can serve as a phenotypic marker in the selection process. Further, this will help in studying the combining ability in general and general combining ability (GCA) in particular will reveal the potential of the lines in hybrid breeding. Lines with high GCA for distinct characters are crucial for further developing hybrids with precise required traits. Hence, this investigation was carried out in order to identify promising CMS lines for immediate application in hybrid development by morphological characterization.

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Materials and Methods

The present investigation was carried out in the experimental farm of the Department of Vegetable Science, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, H.P. during *Rabi*2021–22 and 2022–23. The experiment field is situated at 35.5 ^{0}North of latitude and 77.8 ^{0}E East of longitude with an altitude of 1,250 m above mean sea level falling in the mid-hill zone of Himachal Pradesh. The climate of the Experimental Research Farm is classified as sub-humid, sub-temperate with cool winters. During the experimental trial, average values of maximum and minimum temperature were recorded to be 16.1 to 33.2˚C and 2.3 to 18.9˚C. While the relative humidity ranged from 37 to 79 per cent. The total rainfall which occurred during the experimental trial varied from 1mm to 218.3 mm respectively. The soil texture of the Research Farm is sandy loam to clay loam comprising of sand (46.09 %), silt (32.12 %) and clay (25.01 %). The pH of the soil ranged from 6.85-7.05.

Twenty CMS lines and their respective twenty maintainers were sown in raised nursery beds under poly - tunnels and transplanted during the month of October, 2021 & 2022 in Randomized Complete Block Design (RCBD) with 3 replications (Table 1). Plant spacing of 60 cm × 45 cm was kept in a plot having size of 2.40 m × 2.25 m accommodating 20 plants per plot. The twenty CMS lines were used as the female parent while their respective twenty maintainers were used as male parent and were allowed to cross under open conditions. The CMS lines and their respective maintainers were evaluated and analysed for different morphological traits *viz.*, seedling anthocyanin colouration of hypocotyl, stalk length, leaf attitude, leaf length, leaf width, leaf shape, leaf lobe, leaf colour, leaf waxiness, leaf puckering, days to 50% curd initiation, curd covering by inner leaves, curd polar diameter, curd equatorial diameter, curd shape in longitudinal section, curd doming, curd colour, curd knobbing, curd texture, curd compactness, curd anthocyanin colouration at maturity and curd maturity on the basis of DUS guidelines. The mean values of data were subjected to analysis of variance and ANOVA was calculated as described by Gomez and Gomez1984 for Randomization Complete Block Design and it was used to compare the mean performance of genotypes within themselves. Paired-t test was used to test the significance of difference between the mean values of each cytoplasmic male sterile line with its respective maintainer as well as in-between both the groups. Analysis of variance was carried out as per the method given by Panse and Sukhatme 1985.

Results and Discussion

Morphological characterization

Morphological characterization of germplasm is the easiest and cheapest method of classification, estimating diversity and registering cultivar (Dossou-Aminon et al 2015). In the present study forty cauliflower lines (twenty CMS and their twenty respective maintainers) were morphologically characterized for twenty-two traits based on DUS guidelines. DUS testing is one of the most essential criteria to test lines for distinctness, uniformity and stability; it is one of the important requirements for granting Plant Breeders Rights (PBR) and is conducted according to the national guidelines prepared on the basis of UPOV guidelines. Morphological characters are useful to establish distinctiveness, uniformity and stability of a variety, based on which the variety is given protection according to "Protection of Plant Variety and Farmers' Right Act"2001. The characterized varieties are further used in varietal improvement programmes depending upon their desired characteristics (Singh et al 2013).

Qualitative leaf traits in cauliflower

Seedling anthocyanin colouration was observed in most of the CMS lines while, UHF-CAU-11A and UHF-CAU-12A didn't showed any anthocyanin colouration, along with maintainers UHF-CAU-11B and UHF-CAU-12B, same results were also reported by Singh et al.2013.Semi-erect leaf attitude was observed in twelve CMS lines, while UHF-CAU-8A, UHF-CAU-9A, UHF-CAU-10A, UHF-CAU-12A, UHF-CAU-15A, UHF-CAU-16A, UHF-CAU-17A and UHF-CAU-20A showed erect leaf attitude (Table 2). Among the twenty maintainers semi-erect leaf attitude was observed in eight genotypes while UHF-CAU-3B, UHF-CAU-5B, UHF-CAU-8B, UHF-CAU-9B, UHF-CAU-10B, UHF-CAU-12B, UHF-CAU-14B, UHF-CAU-15B, UHF-CAU-17B, UHF-CAU-18B and UHF-CAU-20B showed erect leaf attitude character. Horizontal leaf attitude was seen in a single line UHF-CAU-19B which belonged to the maintainers. For trait leaf attitude substantial difference was noticed among the CMS lines and their respective maintainer's. Hence further backcrossing was required for the above-mentioned CMS lines and their maintainers, while the remaining were found to be uniform and perfectly stable with each other. According to table 2, ten CMS lines showed the presence of leaf lobe, while in maintainers it was found to be present in twelve genotypes. Majority of the CMS lines and their respective maintainers showed uniformity for the trait leaf lobe and were found to be perfectly stable except the genotypes UHF-CAU-9A & UHF-CAU-9B and UHF-CAU-15A &UHF-CAU-15B which required more backcrossing before reaching stability. Leaf colour was observed visually, most CMS lines showed dark

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green colour while, the lines *viz*., UHF-CAU-6A, UHF-CAU-10A, UHF-CAU-11A, UHF-CAU-13A, UHF-CAU-19A and UHF-CAU-20A exhibited light green leaf colour. Only three lines namely UHF-CAU-4A, UHF-CAU-5A and UHF-CAU-8A showed bluish green leaf colour. In maintainers light green leaf colour was observed in lines namely UHF-CAU-6B, UHF-CAU-10B, UHF-CAU-11B, UHF-CAU-13B, UHF-CAU-19B and UHF-CAU-20B. Only two lines UHF-CAU-5B and UHF-CAU-8B expressed bluish green leaves among the maintainers. Same results were noticed by Singh et al2013. Medium leaf waxiness was observed in twelve CMS lines, whereas the lines namely UHF-CAU-4A, UHF-CAU-7A, UHF-CAU-12A, UHF-CAU-14A and UHF-CAU-18A showed strong leaf waxiness, and only three genotypes exhibited light leaf waxiness. Majority of the lines under maintainers showed medium leaf waxiness. Strong leaf waxiness was spotted UHF-CAU-4B, UHF-CAU-7B, UHF-CAU-12B, UHF-CAU-14B and UHF-CAU-18B. Only three lines among the maintainer lines showed light leaf waxiness and all the twenty CMS lines showed complete uniformity with their respective maintainers. Eight CMS lines expressed medium leaf puckering while UHF-CAU-3A, UHF-CAU-9A, UHF-CAU-10A, UHF-CAU-13A, UHF-CAU-16A, UHF-CAU-18A and UHF-CAU-20A didn't show any leaf puckering trait in them. While among the maintainer lines medium leaf puckering was observed in UHF-CAU-1B, UHF-CAU-2B, UHF-CAU-4B, UHF-CAU-6B, UHF-CAU-7B, UHF-CAU-12B and UHF-CAU-18B, but seven maintainer lines didn't express the trait.

Quantitative leaf traits in cauliflower

Outer stalk length ranged from 7.54 cm to 15.86cm in CMS lines and 10.00cm to 17.46cm in the maintainer lines.Among the CMS lines maximum stalk length was observed in UHF-CAU-16Aand minimum stalk length was observed in line UHF-CAU-4A.While among the maintainer lines maximum stalk length was observed in UHF-CAU-16B and minimum stalk length was observed in lines UHF-CAU-5B and UHF-CAU-10B (10.00cm). A further comparison of every CMS line with its respective maintainer through Paired t-test revealed that among the twenty pair stalk length varied significantly in fifteen lines and was found statistically similar in five pair. The present results were in conformity to the findings of Singh and Dogra 2013; Santhosha et al 2014 and Sharma et al2017. For character leaf length significant difference was observed which ranged from 28.40 cm to 41.40 cm in CMS lines and 29.90 cm to 45.40 cm in the maintainer lines. Minimum leaf length was observed in UHF-CAU-7A and UHF-CAU-8A and maximum leaf length was recorded in UHF-CAU-18A. While among the maintainer lines maximum leaf length was observed in UHF-CAU-

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19B and minimum leaf length was observed in UHF-CAU-6B. A comparison of every CMS line with its respective maintainer through Paired t-test revealed that among the twenty pair leaf length varied significantly only in one pair *viz.*,UHF-CAU-17A &UHF-CAU-17B. Leaf length ranged from 14.40 cm (UHF-CAU-16A) to 26.20 cm (UHF-CAU-4A) in CMS lines and 17.06 cm (UHF-CAU-11B) to 27.56 cm (UHF-CAU-20B) in the maintainer lines. Further comparison of every CMS line with its respective maintainer through Paired t-test revealed that among the twenty pair leaf width varied significantly in four pair *viz.*, UHF-CAU-13A &UHF-CAU-13B, UHF-CAU-17A &UHF-CAU-17B, UHF-CAU-19A &UHF-CAU-19B and UHF-CAU-20A &UHF-CAU-20B. Same observations have also been reported by earlier workers Kalia et al2014 and Dey et al 2017 (Table 2).

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Qualitative curd traits in cauliflower

Inner leaves covering the curd is found to be a desirable character as it protects the curds from direct sun exposure helping in retaining the perfect white colour of the curd. Among CMS lines maximum lines were found to be partly covered by inner leaves. Moreover lines *viz.*, UHF-CAU-3A, UHF-CAU-5A, UHF-CAU-18A and UHF-CAU-20A were fully covered by inner leaves providing highest degree of protection from direct sunlight. Only the curds of two lines namely UHF-CAU-4A and UHF-CAU-19A were found to be not covered by inner leaves. While among the maintainer eleven lines showed curds, which were partly covered by inner leaves. Lines namely UHF-CAU-3B, UHF-CAU-10B, UHF-CAU-15B, UHF-CAU-17B, UHF-CAU-18B, UHF-CAU-20B expressed curds which were fully covered by inner leaves and only lines *viz.*, UHF-CAU-4B, UHF-CAU-12B and UHF-CAU-19B were not covered by inner leaves. Singh et al. (2013) reported the same findings. Majority of the CMS lines were found in uniformity with their respective maintainers except lines UHF-CAU-5A & UHF-CAU-5B, UHF-CAU-10A & UHF-CAU-10B, UHF-CAU-12A & UHF-CAU-12B and UHF-CAU-17A & UHF-CAU-17B and therefore required more backcrossing for reaching the level of stability. Circular curd shape was expressed in majority of the CMS lines. Moreover lines *viz.*, UHF-CAU-1A, UHF-CAU-2A, UHF-CAU-3A, UHF-CAU-10A, UHF-CAU-11A and UHF-CAU-12A exhibited broad elliptic curd shape and only two genotypes expressed narrow elliptic curd shape which was UHF-CAU-9A and UHF-CAU-17A. While among the maintainers eleven lines showed circular curd shape and broad elliptic curd shape was observed in eleven lines. Only four lines expressed narrow elliptic curd shape (Table 3). The results were found to be in accordance with Singh et al 2013 and Santhosha et al 2014. Strong curd doming was observed in eight CMS lines. Moreover, the lines namely

UHF-CAU-1A, UHF-CAU-9A, UHF-CAU-11A, UHF-CAU-12A, UHF-CAU-13A, UHF-CAU-14A and UHF-CAU-18A showed medium curd doming in them and only five lines *viz.*, UHF-CAU-3A, UHF-CAU-5A, UHF-CAU-8A, UHF-CAU-10A and UHF-CAU-15A expressed week curd doming character. While it was noticed that among the maintainer lines strong curd doming was observed in eight genotypes. Other lines namely UHF-CAU-1B, UHF-CAU-9B, UHF-CAU-11B, UHF-CAU-12B, UHF-CAU-13B, UHF-CAU-14B and UHF-CAU-18B expressed medium curd doming in them and the remaining five lines exhibited weak curd doming in them. The same findings were given by Singh et al 2013. Majority CMS lines expressed creamy white curd colour except four lines namely UHF-CAU-9A, UHF-CAU-10A, UHF-CAU-18A and UHF-CAU-20A which showed white colour curds in them. While among the maintainer lines white curd colour was exhibited by UHF-CAU-9B, UHF-CAU-10B, UHF-CAU-18B and UHF-CAU-20B. All the remaining lines expressed cream white curd colour in them. The same results have also been reported by Chittora et al 2016 and Chatterjee et al 2018. All the twenty CMS lines showed complete uniformity with their respective twenty maintainers and were found to be perfectly stable for the character curd doming. Therefore, no further back-crossing was required for this trait. It was observed that for trait curd knobbing maximum CMS lines expressed coarse curd knobbing in them. Medium curd knobbing was expressed in only two lines *i.e.* UHF-CAU-12A and UHF-CAU-13A. Moreover, in the remaining lines fine curd knobbing was observed. While among the twenty maintainer lines twelve lines exhibited coarse curd knobbing character. Fine curd knobbing was disported by five lines. Only three lines namely UHF-CAU-11B, UHF-CAU-12B and UHF-CAU-13B expressed fine curd knobbing in them (Table 3). Curd texture was observed visually at the time of curd harvesting and the lines were found to be of fine, medium and coarse texture. Among the CMS lines majority of lines expressed coarse curd texture in them. Seven lines showed fine curd texture. While among the twenty maintainer lines disported coarse curd texture and the remaining lines expressed fine curd texture in them. Upon further analysis it was found that most of the CMS lines along with their respective maintainers showed uniformity with each other except the lines UHF-CAU-2A & UHF-CAU-2B, UHF-CAU-6A & UHF-CAU-6B, UHF-CAU-14A & UHF-CAU-14B and UHF-CAU-18A & UHF-CAU-18B which require further backcrossing for reaching the stage of perfect uniformity. Compact curds were found in nine lines. While medium curd compactness was observed in lines namely UHF-CAU-3A, UHF-CAU-6A, UHF-CAU-7A, UHF-CAU-11A, UHF-CAU-12A, UHF-CAU-15A and UHF-CAU-16A. Only four lines exhibited loose curd in them. Among the maintainer lines compact curds were

reported in nine lines. Lines namely UHF-CAU-3B, UHF-CAU-6B, UHF-CAU-9B, UHF-CAU-11B, UHF-CAU-12B, UHF-CAU-15B, UHF-CAU-16B and UHF-CAU-20B showed medium curd compactness and only three lines expressed loose curds in them. The results were found to be in accordance with Kumar et al2011, and Sharma et al2018. The character anthocyanin colouration of curd at maturity was categorized into two categories namely, absent and present. Among all the twenty CMS lines only two lines namely UHF-CAU-10A and UHF-CAU-15A expressed anthocyanin colouration in them at maturity while the remaining lines showed absence of anthocyanin colouration in them. Moreover, among the maintainer lines UHF-CAU-10B and UHF-CAU-15B expressed anthocyanin colouration in them while it remained absent in the remaining lines. All the twenty CMS lines showed complete uniformity with their respective twenty maintainers and were found to be perfectly stable for this trait (Table 3).

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Quantitative curd traits in cauliflower

For character outer stalk length variability ranged from 7.54 cm to 15.86cm in CMS lines and 10.00cm to 17.46cm in the maintainer lines. Among the CMS lines maximum stalk length was observed in UHF-CAU-16A which was found to be at par with lines UHF-CAU-8A and UHF-CAU-19A (15.20cm) and minimum stalk length was observed in line UHF-CAU-4A. While among the maintainer lines maximum stalk length was observed in UHF-CAU-16B which was statistically at par with UHF-CAU-8B (17.40cm) and minimum stalk length was observed in lines UHF-CAU-5B and UHF-CAU-10B. A further perusal of data revealed that for the character stalk length the means of CMS lines and their maintainers varied significantly with each other. Mean stalk length of CMS lines was found to be 11.80cm which was significantly low (*P<0.05) than the mean stalk length of maintainers i.e. 13.97cm. A comparison of every CMS line with its respective maintainer through Paired t-test revealed that among the twenty pair stalk length varied significantly in fifteen lines and was found statistically similar in five pair (Table 3). Same findings have also been reported by Santhosha et al 2014 and Sharma et al 2017. Variability for character curd initiation ranged from 100 days to 130 days in CMS lines and 99.80 days to 131.04 days in the maintainer lines. Among CMS lines, days to curd initiation was found to be maximum in lines UHF-CAU-9A, UHF-CAU-10A, UHF-CAU-17A and UHF-CAU-20A which was at par with other 02 lines UHF-CAU-3A (129 days) and UHF-CAU-5A (129 days) and it was minimum in lines UHF-CAU-1A, UHF-CAU-2A, UHF-CAU-4A, UHF-CAU-7A, UHF-CAU-12A, UHF-CAU-15A and UHF-CAU-18A. Whereas in the maintainer line the days to

curd initiation was significantly higher in line UHF-CAU-20B. Among the maintainer lines, days to curd initiation was minimum in line UHF-CAU- 4B which was found to be at par with six maintainer lines. A further perusal of data revealed that for the trait days to curd initiation the means of CMS lines and their maintainers did not varied significantly with each other. A significant amount of variability was observed for character polar diameter which ranged from 8.00 to 13.50 cm in CMS lines and 9.20 cm to 14.86 cm in the maintainer lines. Among the CMS lines, curd polar diameter was found to be maximum (13.50 cm) in line UHF-CAU-13A which was at par with line UHF-CAU-12A (13.20 cm) and it was minimum in lines UHF-CAU-10A and UHF-CAU-17A (8.00 cm) which was also at par with lines UHF-CAU-14A (8.56 cm) andUHF-CAU-18A (8.40 cm). Among the maintainer lines, the curd polar diameter was significantly higher (14.86 cm) in line UHF-CAU-13B which was at par with line UHF-CAU-12B (14.32 cm) and it was minimum (9.20 cm) in lines UHF-CAU-4B and UHF-CAU-18B which were at par with another four maintainer lines *viz*.,UHF-CAU-3B (9.40 cm), UHF-CAU-10B (9.32 cm), UHF-CAU-14B (9.30 cm) and UHF-CAU-17B (9.80 cm). A further perusal of data revealed that for the character curd polar diameter the means of CMS lines and their maintainers varied significantly with each other. Mean curd polar diameter of CMS lines was found to be 10.26 cm which was significantly low *P<0.05 than the mean curd polar diameter of maintainers *i.e*. 11.26 cm (Table 3). Variability was observed for the character curd equatorial diameter ranging from 13.40 cm to 19.80 cm in CMS lines and 14 cm to 21.40 cm in the maintainer lines. Among CMS lines, curd equatorial diameter was found to be maximum in line UHF-CAU-16A which was at par with line UHF-CAU-6A (19.40 cm) and it was minimum in line UHF-CAU-16A which was at par with other four lines. Among the maintainer lines, the curd equatorial diameter was significantly higher (21.40cm) in line UHF-CAU-13B. Among the maintainer lines, curd equatorial diameter was minimum (14 cm) in line UHF-CAU-20B which was at par with two maintainer lines *viz.*,UHF-CAU-17B (14.60 cm) and UHF-CAU-19B (14.60 cm). A further perusal of data revealed that for the character curd equatorial diameter the means of CMS lines and their maintainers varied significantly with each other. Mean curd equatorial diameter of CMS lines was found to be 16.02 cm which was significantly low (*P<0.05) than the mean curd equatorial diameter of maintainers *i.e*. 17.35 cm. Comparison of each CMS line with its counterpart maintainer line through Paired t-test revealed that among 20 pair, curd equatorial diameter varied significantly in seven line pair. Similar findings have also been reported by workers Singh and Dogra 2013; Yadav et al2013; Kalia et al2014, and Rakshita et al2021. The present results are also in conformity to these findings.

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Conclusion

It was concluded that significant differences were found between the CMS lines and their respective maintainer pair in terms of different morphological traits, providing evidence to the negative effects caused by the male sterile cytoplasm in the cytoplasmic male sterile lines of cauliflower. The CMS line UHF-CAU-18A (41.40 cm) recorded maximum leaf length, while among the maintainer lines maximum leaf length was observed in UHF-CAU-19B (45.40 cm). CMS line UHF-CAU-4A (26.20 cm) recorded maximum leaf width, while among the maintainer lines UHF-CAU-20B (27.56 cm) recorded maximum leaf width. Days to curd initiation was found to be maximum (130 days) in CMS lines (UHF-CAU-9A, UHF-CAU-10A, UHF- CAU-17A and UHF-CAU-20A) and minimum in lines UHF-CAU-1A, UHF-CAU-2A, UHF-CAU-4A, UHF-CAU-7A, UHF-CAU-12A, UHF-CAU-15A and UHF-CAU-18A (100 days). Whereas in the maintainer line the days to curd initiation was significantly higher (131.04 days) in line UHF-CAU-20B and minimum (99.80 days) in line UHF-CAU-4B. CMS line UHF-CAU-13A (13.50 cm) recorded maximum curd polar diameter and maintainer line, UHF-CAU-13B (14.86 cm) recorded significantly higher curd polar diameter. The CMS line UHF-CAU-16A (19.80 cm) observed maximum curd equatorial diameter. Whereas, among the maintainer lines, the curd equatorial diameter was significantly higher (21.40cm) in line UHF-CAU-13B. After using paired t-test, significant differences were found between the CMS lines and their respective maintainer pair in terms of different morphological traits, providing evidence to the detrimental effects caused by the *ogura* male sterile cytoplasm in the cytoplasmic male sterile lines of cauliflower.

References

Chatterjee S, Mukherjee D, Choudhuri P and Kanwar HS. 2018. Path Analysis and Quality Characters Studies in Some Mid Late and Late Cauliflower (*Brassica oleracea* var. *botrytis* L.) Genotypes. *Current Journal of Applied Sciences and Technology***31(1):**1-7.

Chittora A, Singh DA, and Kaushal A. 2016. Genetic Variability, Heritability and Genetic Advance in Early Maturing Cauliflower. *Annals of Plant and Soil Research***18:**251-56.

Dey SS, Bhatia R, BhardwajI, Mishra V, and Kumar R. 2017. Molecular-agronomic characterization and genetic study reveals usefulness of refined Ogura cytoplasm-based CMS lines in hybrid breeding of cauliflower *(Brassica oleracea* var. *botrytis* L.). *Scientia Horticulturae***224:**27-36.

DeySS, BhatiaR, ParkashC, KaliaP andBarwal RN. 2014. Evaluation of cauliflower (*Brassica oleracea* var. *botrytis*) CMS (Ogura) lines for agronomic and floral traits. *Indian Journal of Horticulture***71(3):**424–427.

Dossou-Aminon I, Yeyinou LL, Adjatin A, Eben-Ezer BK, Dansi A, Rakshit S, Cisse N, Patil JV, Agbangla C, Ambaliou S, Akpovi A and Akpagana K. 2015. Genetic divergence in northern Benin sorghum (*Sorghum bicolor* L. *Moench*) landraces as revealed by agro-morphological traits and selection of candidate genotypes. Scientific World Journal DOI 10.1155/916476.

GomezKA and Gomez AA. 1984. Statistical Procedures for Agricultural Research. 2nd ed. John Wiley and Sons Inc, New York. 680p.

Kalia P, Bhatia R, Prakash C, Dey SS andBarwal RN. 2014. Evaluation of cauliflower (*Brassica oleracea* var. *botrytis* L.) CMS (Ogura) lines for agronomic and floral traits. *Indian Journal of Horticulture***71:**424-27.

Kucera V, Chytilova V, Vyvadilova M and Klima M. 2006. Hybrid breeding of cauliflower using self-incompatibility and cytoplasmic male sterility. *Horticultural Science***33(4):**148–152.

Kumar M, Sharma SR, Kalia P and Saha P. 2011. Genetic variability and character association for yield and quality traits in early maturing Indian cauliflowers. *Indian Journal of Horticulture***68(2):**206-11.

Kushad MM, Brown AF, Kurilich AC, Juvik JA, Klein BP, Wallig MA and Jeffery EH. 1999. Variation of Glucosinolates in Vegetable Crops of *Brassica oleracea*. *Journal of Agriculture and Food Chemistry***47(4):**1541–1548.

Longvah T, Ananthan R, Bhaskarachary K and Venkaiah K. 2017. Indian Food Composition Tables. National Institute of Nutrition (Indian Council of Medical Research, Hyderabad, India.

Maggioni L, Von BR, Poulsen G, Lipman E. 2018. Domestication, diversity and use of *Brassica oleracea* L., based on ancient Greek and Latin texts. *Genetic Resources and Crop Evolution***65:**137–159.

Panse V and Sukhatme PV. 1985. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research Publication, 87-89pp.

PPV and FRA. 2001. Protection of Plant Varieties and Farmers' Rights Act (No. 53 of 2001). Dept of Agriculture and Cooperation, Ministry of Agriculture, Govt of India, Krishi Bhavan, New Delhi.

Rakshita KN, SinghS, Verma VK, Sharma BB, Saini N andIquebal MA. 2021. Agro-morphological and molecular diversity in different maturity groups of Indian cauliflower (*Brassica oleracea* var. *botrytis* L.). *Plos One***16:**0260246.

Santhosha HM, Varalakshmi B andShivashankara KS. 2014. Characterization of early cauliflower germplasm under tropical conditions. The Bioscan**9(2):**869-74.

Sharma SR, SinghPK, Chable V and Tripathi SK. 2005. A Review of Hybrid Cauliflower Development. *Journal of New Seeds***6:**151-93.

Sharma S, Singh Y, Sharma S and Sekhon BS. 2018. Studies on Mean Performance for Yield and its Contributing Traits in Cauliflower (*Brassica oleracea* L. var. *botrytis* L.) Under Mid Hill Conditions of North-Western Himalayas. *International Journal of Current Microbiology and Applied Sciences***7(02):**3288-296.

Sharma V, Sood S, Sood VK and Singh Y. 2017. Morphological characterization of Bell Pepper (*Capsicum annum* L. var. *grossum*Sendt). Genotypes. Hjar.org/index.php/hjar/article/view/128436.

SinghB, Chaubey T, Aastik J, Upadhyay DK and Pandey SD. 2013. Morphological Characterization of Cauliflower Varieties/Cultivars using DUS Characters. *SAARC Journal of Agriculture***11(2):**183-91.

Singh SP and Dogra RK. 2013. Studies on character association in some genotypes of cauliflower under mid hill conditions of western Himalayas. *Asian Journal of Horticulture***8:**29-31.

Srishti and Yogita. 2023. Screening of pole type French bean (*Phaseolus vulgaris* L) genotypes for high yield potential under mid-hill conditions of Himachal Pradesh. *International Journal of Farm Sciences* **13(4):**54-60.

Yadav M, PrasadVM andAhirwar CS. 2013. Varietal Evaluation of Cauliflower (*Brassica oleracea* var. *botrytis* L.) In Allahabad Agro – climatic Condition. *Trends in Biosciences***6(1):**99-100.

Table 1: List of the cauliflower genotypes used in the present investigation

S. No.	CMS Lines	Maintainers	Source
1	UHF-CAU-1A	UHF-CAU-1B	Dr YSP UHF Nauni, Solan (HP)
2	UHF-CAU-2A	UHF-CAU-2B	Dr YSP UHF Nauni, Solan (HP)
3	UHF-CAU-3A	UHF-CAU-3B	Dr YSP UHF Nauni, Solan (HP)
4	UHF-CAU-4A	UHF-CAU-4B	Dr YSP UHF Nauni, Solan (HP)
5	UHF-CAU-5A	UHF-CAU-5B	Dr YSP UHF Nauni, Solan (HP)

6	UHF-CAU-6A	UHF-CAU-6B	Dr YSP UHF Nauni, Solan (HP)
7	UHF-CAU-7A	UHF-CAU-7B	Dr YSP UHF Nauni, Solan (HP)
8	UHF-CAU-8A	UHF-CAU-8B	Dr YSP UHF Nauni, Solan (HP)
9	UHF-CAU-9A	UHF-CAU-9B	Dr YSP UHF Nauni, Solan (HP)
10	UHF-CAU-10A	UHF-CAU-10B	Dr YSP UHF Nauni, Solan (HP)
11	UHF-CAU-11A	UHF-CAU-11B	Dr YSP UHF Nauni, Solan (HP)
12	UHF-CAU-12A	UHF-CAU-12B	Dr YSP UHF Nauni, Solan (HP)
13	UHF-CAU-13A	UHF-CAU-13B	Dr YSP UHF Nauni, Solan (HP)
14	UHF-CAU-14A	UHF-CAU-14B	Dr YSP UHF Nauni, Solan (HP)
15	UHF-CAU-15A	UHF-CAU-15B	Dr YSP UHF Nauni, Solan (HP)
16	UHF-CAU-16A	UHF-CAU-16B	Dr YSP UHF Nauni, Solan (HP)
17	UHF-CAU-17A	UHF-CAU-17B	Dr YSP UHF Nauni, Solan (HP)
18	UHF-CAU-18A	UHF-CAU-18B	Dr YSP UHF Nauni, Solan (HP)
19	UHF-CAU-19A	UHF-CAU-19B	Dr YSP UHF Nauni, Solan (HP)
20	UHF-CAU-20A	UHF-CAU-20B	Dr YSP UHF Nauni, Solan (HP)

Table 2: Performance of CMS lines and their respective maintainers for different qualitative and quantitative leafy traits in cauliflower

Traits/CMS lines & their maintainers	Seedling anthocyanin colouration of hypocotyl	Outer stem length	Leaf attitude	Leaf shape	Leaf lobe	Leaf colour	Leaf waxiness	Leaf puckering	Stalk Length	Leaf Length	Leaf Width
UHF-CAU-1A	Present	Long	Semi-erect	Elliptic	Present	Dark Green	Medium	Medium	10.10*	35.60	17.90
UHF-CAU-1B	Present	Long	Semi-erect	Elliptic	Present	Dark Green	Medium	Medium	15.68	34.60	21.20
UHF-CAU-2A	Present	Long	Semi-erect	Elliptic	Present	Dark Green	Medium	Medium	14.16*	39.40	22.90
UHF-CAU-2B	Present	Long	Semi-erect	Elliptic	Present	Dark Green	Medium	Medium	16.16	35.20	21.90
UHF-CAU-3A	Present	Long	Semi-erect	Elliptic	Absent	Dark Green	Medium	Absent	11.90*	36.40	20.56
UHF-CAU-3B	Present	Long	Erect	Elliptic	Absent	Dark Green	Medium	Absent	14.10	41.60	20.40
UHF-CAU-4A	Present	Long	Semi-erect	Broad - Elliptic	Present	Bluish Green	Strong	Medium	7.54*	40.00	26.20
UHF-CAU-4B	Present	Long	Semi-erect	Broad - Elliptic	Present	Dark Green	Strong	Medium	12.00	42.80	21.60
UHF-CAU-5A	Present	Long	Semi-erect	Elliptic	Present	Bluish Green	Light	Weak	9.96	41.20	24.00
UHF-CAU-5B	Present	Long	Erect	Elliptic	Present	Bluish Green	Light	Weak	10.00	36.40	26.00
UHF-CAU-6A	Present	Long	Semi-erect	Elliptic	Present	Light Green	Medium	Medium	13.36*	30.40	20.70
UHF-CAU-6B	Present	Long	Semi-erect	Elliptic	Present	Light Green	Medium	Medium	16.10	29.90	22.60
UHF-CAU-7A	Present	Long	Semi-erect	Narrow - Elliptic	Present	Dark Green	Strong	Weak	14.60	28.40	17.30
UHF-CAU-7B	Present	Long	Semi-erect	Narrow - Elliptic	Present	Dark Green	Strong	Medium	15.14	33.40	19.30
UHF-CAU-8A	Present	Long	Erect	Broad-Elliptic	Present	Bluish Green	Medium	Medium	15.20*	28.40	20.00
UHF-CAU-8B	Present	Long	Erect	Elliptic	Present	Bluish Green	Medium	Medium	17.40	30.80	24.00
UHF-CAU-9A	Present	Long	Erect	Elliptic	Absent	Dark Green	Medium	Absent	11.10	36.00	19.20
UHF-CAU-9B	Present	Long	Erect	Elliptic	Present	Dark Green	Medium	Weak	11.00	37.20	22.50
UHF-CAU-10A	Present	Long	Erect	Broad - Elliptic	Absent	Light Green	Medium	Absent	8.80*	33.20	18.50
UHF-CAU-10B	Present	Long	Erect	Broad - Elliptic	Absent	Light Green	Medium	Absent	10.00	33.60	21.50

UHF-CAU-11A	Absent	Long	Semi - erect	Narrow - Elliptic	Absent	Light Green	Medium	Absent	8.76*	31.50	15.56
UHF-CAU-11B	Absent	Long	Semi - erect	Narrow - Elliptic	Absent	Light Green	Medium	Absent	10. 46	33.80	17.06
UHF-CAU-12A	Absent	Long	Erect	Narrow - Elliptic	Present	Dark Green	Strong	Medium	13.06	36.00	18.80
UHF-CAU-12B	Absent	Long	Erect	Narrow - Elliptic	Present	Dark Green	Strong	Medium	13.36	37.60	21.00
UHF-CAU-13A	Present	Long	Semi - erect	Narrow - Elliptic	Absent	Light Green	Light	Absent	9.80*	30.10	14.60*
UHF-CAU-13B	Present	Long	Semi - erect	Broad - Elliptic	Absent	Light Green	Light	Absent	12.00	39.50	22.20
UHF-CAU-14A	Present	Long	Semi-erect	Narrow - Elliptic	Absent	Dark Green	Strong	Weak	11.04*	36.80	15.06
UHF-CAU-14B	Present	Long	Erect	Narrow - Elliptic	Absent	Dark Green	Strong	Weak	12.60	40.10	19.20
UHF-CAU-15A	Present	Long	Erect	Broad - Elliptic	Absent	Dark Green	Medium	Medium	12.40*	39.20	23.30
UHF-CAU-15B	Present	Long	Erect	Broad - Elliptic	Present	Dark Green	Medium	Weak	14.08	37.70	23.42
UHF-CAU-16A	Present	Long	Erect	Narrow - Elliptic	Absent	Dark Green	Medium	Absent	15.86*	35.00	14.40
UHF-CAU-16B	Present	Long	Semi - erect	Narrow - Elliptic	Absent	Dark Green	Medium	Absent	17.46	37.80	19.16
UHF-CAU-17A	Present	Long	Erect	Elliptic	Present	Dark Green	Medium	Weak	15.04	31.20*	16.70*
UHF-CASU-17B	Present	Long	Erect	Elliptic	Present	Dark Green	Medium	Weak	15.10	43.00	21.80
UHF-CAU-18A	Present	Long	Semi-erect	Elliptic	Absent	Dark Green	Strong	Absent	9.76*	41.40	21.26
UHF-CAU-18B	Present	Long	Erect	Elliptic	Absent	Dark Green	Strong	Absent	16.04	38.80	25.20
UHF-CAU-19A	Present	Long	Semi-erect	Elliptic	Absent	Light Green	Medium	Weak	15.20*	40.60	20.66*
UHF-CAU-19B	Present	Long	Horizontal	Elliptic	Absent	Light Green	Medium	Weak	16.38	45.40	24.30
UHF-CAU-20A	Present	Long	Erect	Broad - Elliptic	Present	Light Green	Light	Absent	8.34*	41.00	23.70*
UHF-CAU-20B	Present	Long	Erect	Broad - Elliptic	Present	Light Green	Light	Absent	14.26	43.00	27.56

*Significant difference at 5% level of significance between CMS line and its maintainer

Table 3: Performance of CMS lines and their respective maintainers for different qualitative and quantitative curd traits in cauliflower

Traits/CMS lines & their maintainers	Curd covered by inner leaves	Curd shape in longitudinal section	Curd doming	Curd colour	Curd knobbing	Curd texture	Curd compactness	Curd anthocyanin colour at maturity	Curd initiation (Days to 50% of the plants with curd initiation from sowing of seed)	Curd polar diameter	Curd equatorial diameter
F-CAU-1A	Partly covered	Broad elliptic	Medium	Creamy white	Coarse	Coarse	Compact	Absent	100.00	10.80	16.26
UHF-CAU-1B	Partly covered	Broad elliptic	Medium	Creamy white	Coarse	Coarse	Compact	Absent	100.00	11.06	17.20
UHF-CAU-2A	Partly covered	Broad elliptic	Strong	Creamy white	Coarse	Fine	Compact	Absent	100.00	8.80*	14.86
UHF-CAU-2B	Partly covered	Broad elliptic	Strong	Creamy white	Coarse	Coarse	Compact	Absent	100.00	9.96	16.00
UHF-CAU-3A	Covered	Broad elliptic	Weak	Creamy white	Coarse	Coarse	Medium	Absent	129.00*	8.60	17.80*
UHF-CAU-3B	Covered	Broad elliptic	Weak	Creamy white	Coarse	Coarse	Medium	Absent	126.04	9.40	18.80
UHF-CAU-4A	Not covered	Circular	Strong	Creamy white	Fine	Fine	Compact	Absent	100.00	9.04	14.40*
UHF-CAU-4B	Not covered	Circular	Strong	Creamy white	Fine	Fine	Compact	Absent	99.80	9.20	17.60
UHF-CAU-5A	Covered	Circular	Weak	Creamy white	Coarse	Coarse	Loose	Absent	129.00	10.84*	16.60
UHF-CAU-5B	Partly covered	Circular	Weak	Creamy white	Coarse	Coarse	Loose	Absent	129.00	12.80	17.60
UHF-CAU-6A	Partly covered	Circular	Strong	Creamy white	Coarse	Coarse	Medium	Absent	124.00*	11.86*	19.40
UHF-CAU-6B	Partly covered	Circular	Strong	Creamy white	Fine	Fine	Medium	Absent	126.04	12.68	20.00
UHF-CAU-7A	Partly covered	Circular	Strong	Creamy white	Fine	Fine	Medium	Absent	100.00	10.16*	15.60*
UHF-CAU-7B	Partly covered	Circular	Strong	Creamy white	Fine	Fine	Compact	Absent	100.00	10.60	16.60
UHF-CAU-8A	Partly covered	Circular	Weak	Creamy white	Coarse	Fine	Loose	Absent	126.00*	11.40*	17.18
UHF-CAU-8B	Partly covered	Circular	Weak	Creamy white	Coarse	Fine	Loose	Absent	129.96	12.80	17.80
UHF-CAU-9A	Partly covered	Narrow elliptic	Medium	White	Coarse	Coarse	Loose	Absent	130.00	12.06*	14.90
UHF-CAU-9B	Partly covered	Narrow elliptic	Medium	White	Coarse	Coarse	Medium	Absent	130.00	13.60	15.00

UHF-CAU-10A	Partly covered	Broad elliptic	Weak	White	Coarse	Fine	Compact	Present	130.00	8.00*	14.00*
UHF-CAU-10B	Covered	Broad elliptic	Weak	White	Coarse	Fine	Compact	Present	130.00	9.32	16.14
UHF-CAU-11A	Partly covered	Broad elliptic	Medium	Creamy white	Fine	Fine	Medium	Absent	126.00*	12.72	17.60*
UHF-CAU-11B	Partly covered	Broad elliptic	Medium	Creamy white	Medium	Fine	Medium	Absent	124.00	13.00	18.80
UHF-CAU-12A	Partly covered	Broad elliptic	Medium	Creamy white	Medium	Coarse	Medium	Absent	100.00	13.20	18.80
UHF-CAU-12B	Not covered	Narrow elliptic	Medium	Creamy white	Medium	Coarse	Medium	Absent	100.00	14.32	19.80
UHF-CAU-13A	Partly covered	Circular	Medium	Creamy white	Medium	Fine	Compact	Absent	124.00	13.50*	19.80
UHF-CAU-13B	Partly covered	Circular	Medium	Creamy white	Medium	Fine	Compact	Absent	126.00	14.86	21.40
UHF-CAU-14A	Partly covered	Circular	Medium	Creamy white	Coarse	Coarse	Compact	Absent	126.00	8.56	15.20
UHF-CAU-14B	Partly covered	Circular	Medium	Creamy white	Coarse	Fine	Compact	Absent	124.00	9.30	15.60
UHF-CAU-15A	Partly covered	Circular	Weak	Creamy white	Fine	Coarse	Medium	Present	100.00	9.98*	17.80*
UHF-CAU-15B	Partly covered	Circular	Weak	Creamy white	Coarse	Coarse	Medium	Present	100.00	10.80	19.40
UHF-CAU-16A	Partly covered	Circular	Strong	Creamy white	Coarse	Coarse	Medium	Absent	126.00*	9.60	13.40*
UHF-CAU-16B	Partly covered	Circular	Strong	Creamy white	Coarse	Coarse	Medium	Absent	122.96	10.90	19.40
UHF-CAU-17A	Partly covered	Narrow elliptic	Strong	Creamy white	Fine	Coarse	Loose	Absent	130.00*	8.00*	14.00
UHF-CAU-17B	Covered	Narrow elliptic	Strong	Creamy white	Fine	Coarse	Loose	Absent	124.04	9.80	14.60
UHF-CAU-18A	Covered	Circular	Medium	White	Fine	Coarse	Compact	Absent	100.00	8.40*	15.60
UHF-CAU-18B	Covered	Circular	Medium	White	Fine	Fine	Compact	Absent	100.00	9.20	16.60
UHF-CAU-19A	Not covered	Circular	Strong	Creamy white	Coarse	Coarse	Compact	Absent	125.00*	9.80*	13.50
UHF-CAU-19B	Not covered	Circular	Strong	Creamy white	Coarse	Coarse	Compact	Absent	126.00	10.52	14.60
UHF-CAU-20A	Covered	Circular	Strong	White	Coarse	Coarse	Compact	Absent	130.00*	9.96*	13.60

UHF-CAU-20B	Covered	Narrow elliptic	Strong	White	Coarse	Coarse	Medium	Absent	131.04	11.00	14.00

*Significant difference at 5% level of significance between CMS line and its maintainer