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A comparison of cabbage crop growth parameters and harvest maturity indices under different planting methods, with an emphasis on mechanical harvesting

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Abstract

Manual cabbage harvesting dominates Indian contests, which is laborious. Mechanical harvesting may resolve this. A plant physical properties database is needed before designig the mechanical harvesting system. In view of this, a study was conducted to examine the effect of planting methods (flat, ridge-furrow and ridge-furrow with plastic mulch) on physical growth and harvesting age of crop and thereby find out the most suitable planting method for mechanical harvesting. The effect of planting methods in terms of the physical growth parameters (plant height, plant diameter, length of leaf stem, length of stem, stem diameter, head diameter and head weight) and harvest maturity indices (compactness, specific gravity, total soluble solids, pH and pattern of wrapper leaves) were evaluated for two cabbage cultivars (Syngenta BC-79 and S-996). The planting methods had shown a significant effect on growth parameters such as plant height (270.56 mm), plant diameter (549.39 mm), stem length (58.61 mm), stem diameter (34.58 mm), head diameter (144.89 mm) and head weight (1.12 kg) at harvest. The maximum number of matured heads (83.66%) was recorded in ridge-furrow with mulch planting. The interaction effect of planting methods and cultivars was insignificant for all physical growth indicators. From the perspective of mechanical harvesting, the findings of this study provide a valuable planting method for cabbage growers.

Key words: Cabbage, planting method, cultivars, maturity indices

Introduction

Cabbage (*Brassica oleracea var. capitata*) is one of the important "cole crops" and belongs to the "*Cruciferae*" family. It is commonly consumed as a vegetable and cultivated all over the World. The worldwide annual production is around 70.8 million tonnes of fresh heads from 2.4 million hectares and India is the World's second-largest producer of cabbage with a cultivated area of approximately 0.40 million ha, total production of 9.2 million tonnes and average productivity of 23.2 t/ha (Anonymous, 2020). Despite the large amount of cabbage produced, harvesting is not mechanized and is done manually, which is very labor intensive. Mechanical harvesting is one solution to this problem.

The ridge-furrow with mulch planting approach has been practised with various vegetable crops. Results demonstrated that this method increased vegetative growth and shortened the maturity period. Pankaj *et al.* (2000) studied the influence of different planting methods on plant growth and curd maturity. They observed that ridge planting leads to healthier plant growth and earlier curd maturity than other methods. Memon *et al.* (2017) reviewed the effect of ridge furrow with mulching on yields and other attributes for different crops. They concluded that the mulching technique increased crop yields by about 20-180% compared to the conventional planting method, *i.e.*, flatbed planting. The mulching approach in the planting method for vegetable crops in cropping systems is accepted by more than 95% of farmers (Hasan, 2010). However, no systematic research has been conducted to assess the efficient planting method for getting higher yields, early and uniform maturity for cabbage production.

Numerous studies have reported the importance of plant properties related to specific crop production and processing machine design (Khura *et al.*, 2010; Pagare *et al.*, 2022). The physical plant characteristics such as plant spread, head diameter, head weight, stem length and stem diameter are crucial dimensions in the mechanical harvesting of cabbage crops (Sarkar and Rehman 2021).

The postharvest losses of perishable products are about 30 to 40 % every year (Anonymous, 2001). The major cause of these losses is harvesting at early maturity or overmatured stage. The quality of fruits and vegetables after harvesting cannot be improved, it can be only maintained (Gast, 1994). At proper maturity of heads, harvesting ensures optimum yield, is acceptable for long-term storage and makes potential to export markets. The maturity indicators vary with commodity, but for cabbage crop, head size and weight are the principal harvest maturity indices (Kays, 1999). However, a single index is insufficient to assess the degree of maturity in cabbage (Tanaka and Niikura, 2003). Therefore, some other main harvest maturity indicators, including firmness, specific gravity, compactness, pH and TSS, are used for cabbage crop (Champa *et al.,* 2007; Gil *et al.,* 2012).

Farmers generally judge maturity based on the pattern of wrapper leaves and the compactness of the head (Sarkar and Rehman 2021). Champa *et al. (*2007) found that the cabbage heads can be harvested when the head attains a weight 1.2 to 1.5 kg, diameter of 11 cm, specific gravity of 0.78 to 0.86, high TSS and low pH value. However, the maturity varied by several factors such as variety, environmental conditions, planting method, etc.

Conventionally, cabbage harvesting in India is done manually using a sickle. It requires 250-300 man-h/ha, about 50% of total labour and 77% of total operating cost for cabbage cultivation (Chagnon *et al.*, 2004). The manual harvesting carried out in bending posture imposes a lot of stress upon the back of the workers and results in drudgery, thereby causing musculoskeletal disorders (Gite *et al.* 2020. Harvesting is one of the most labour-intensive farm operations in the cultivation of cabbage and needs immediate attention for its mechanization.

Most of these studies were conducted in foreign countries. Very few works have been reported for Indian cabbage varieties and it is well known that there are a lot of differences in varietal and farming methods. There is no scientific evidence about the effect of planting methods on the maturity of the head of cabbage. So, there is a need to study the Indian variety to decide the proper harvesting period. Therefore, the present study aimed to investigate the effect of the planting method and scope of mechanical harvesting in cabbage cultivation. The uniform maturity of the heads is one of the most important criteria in determining the feasibility of single-pass harvesting of cabbage and predicting the best time to harvest.

Materials and methods

The experiment was conducted at the ICAR-Central Institute of Agricultural Engineering research farm, Bhopal (23º18'35'' N latitude and 77º24'10'' E longitude) in *Rabi* season during 2021-22. The soil type was vertisols (32% sand, 22% silt and 44% clay). The land area of 150 m^2 was taken for each type of planting method, with a total of 8 rows of 60 plants in each row. A day before transplanting seedlings, the recommended basal dose of fertilizer was applied. The cabbage seedlings of 25 to 30 days of age were transplanted manually at spacing of 60×45 cm. Widely cultivated hybrid cabbage varieties Syngenta BC-79 and S-996 were selected for the study. All the recommended practices were followed throughout the crop growth period for better plant growth. The experimental treatments included three planting methods, *i.e.*, flat, ridge-furrow and ridge-furrow with mulch system in open field conditions (Fig. 1).

The harvesting operation was performed after attaining the optimum maturity of heads (80 DAT) (Champa *et al.* 2007). The samples were tagged and labelled for each test and biometric observations on various growth attributes such as plant height, plant diameter, length of leaf stem, length of stem, stem diameter, head diameter and head weight were recorded at harvest using suitable equipment in each treatment and replication. (Fig. 2).

The percentage of total heads that were ready to harvest was

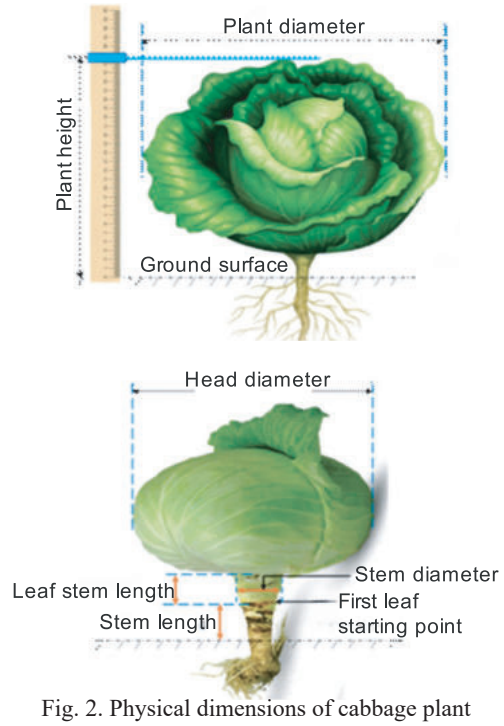

Fig. 2. Physical dimensions of cabbage plant

determined based on head weight, diameter, compactness, specific gravity, total soluble solids (TSS), pH and pattern of wrapper leaves (Champa *et al.* 2007; Gil *et al.* 2012).

The specific gravity was determined using the water displacement technique. The TSS value of the cabbage head was measured directly with a hand refractometer (ATAGO, Pal-1). Two to three drops of head leave juice were dropped on the refractometer detector using a clean cloth. The readings were recorded in °Brix. The extracted juice of head leaves (using a mixer) was placed into a beaker, and its pH was measured using a pH meter. The head compactness was estimated by compressing the head with light palm pressure. Also, it can be estimated based on the Z-value from Eq. (1), as suggested by Pearson (1931).

$$Z = \frac{C}{W^3} \quad (1)$$

Where,

Z = Index of compactness. C = Net weight of head (g). W = Average diameter of head (cm)

The higher index value of Z showed a more compacted head (Gil *et al.* 2012), the desired quality attributes, and their resistance or tolerance to withstand handling and processing.

Statistical analysis: A completely randomized block design with full factorial was adopted, and statistical SPSS software was used

Fig. 1. Planting methods (a) Flat (b) Ridge-furrow and (c) Ridge-furrow with mulch

to analyze variance. Additionally, the means of all treatments were compared using Tukey's(b) at a 5% significance level.

Results and discussion

Effect on physical growth parameters: The effects of various planting methods and cultivars on the physical growth parameters of cabbage plants at harvest (80 days after transplanting, DAT) were studied.

Statistical analyses revealed that planting methods had a significant influence ($P<0.01$) on all physical growth parameters. Similarly, cultivars had a significant impact on all growth parameters except plant diameter. However, for all physical growth indicators, the interaction effect between planting methods and cultivars was found to be non-significant ($P>0.05$).

When planted in ridge-furrow with mulch, the S-996 cultivar had the highest plant height (316.67 mm), plant diameter (643.33 mm), stem length (80.67 mm), stem diameter (41 mm), head diameter (165 mm), and head weight (1.68 kg) (see Table 1). The flat planting method, on the other hand, yielded the lowest values for head weight (0.5 kg), plant height (242.3 mm), and plant diameter (386.6 mm). Notably, the ridge-furrow with mulch planting method outperformed the others across most growth parameters, owing to improved vegetative growth and early maturity. Early maturation allows cabbage heads more time to accumulate dry matter (Champa et al., 2007).

The coefficient of variation analysis revealed that head weight had the most variability, followed by stem length, plant diameter, and stem diameter. These findings highlight the greater variability in vegetative growth attributes observed in cabbage plants grown using the ridge-furrow with mulch system versus the traditional flat planting method.

Furthermore, the use of mulching technology had a significant impact on both the growth and yield of the cabbage plants, correlating with previous research by Ghosh et al. (2006) and Ahmad et al. (2010). This highlights the significance of incorporating mulching practices to improve overall cabbage cultivation results.

Effect on harvest maturity indices: The determination of crop harvesting age relied on various maturity indicators, encompassing net head weight, diameter, compactness, specific gravity, total soluble solids (TSS), and pH. Table 2 provides an overview of the influence of planting methods and cultivars on different harvest maturity attributes. Statistical analysis indicated a significant effect of planting methods ($P<0.01$) on all harvest maturity indices, excluding specific gravity and pH. For cultivars, a significant impact was observed on net head weight and diameter, while compactness, TSS, specific gravity, pH, and the percentage of matured heads remained non-significant (Table 3). Notably, specific gravity exhibited a decreasing trend with an increase in head diameter, potentially attributed to the higher volume of heads for selected varieties.

The observed range of head compactness varied from 25.60 to 42.22 in mean values. Furthermore, TSS values were notably higher in ridge-furrow planting compared to other planting methods. The findings align with those of Isenberg et al. (1975), reinforcing the consistency of the results.

Tukey's(b) Post Hoc test was also performed for statistical means comparison among planting methods (Table 4). The plant height in ridge-furrow with mulch planting method was significantly higher than other planting methods. Flat and ridge-furrow planting methods had no significant difference in plant height. The plant diameter was significantly different for the flat planting method compared to the ridge-furrow and mulch. A similar trend was observed for the compactness of the head. The maximum

Table 1. Mean values of physical growth parameters for cabbage (Values in mm unless otherwise stated)

Planting method	Plant height	Plant diameter	Stem length	Stem diameter	Head diameter	Head weight (kg)
			Syngenta BC-79			
Flat	242.33 (14.98)	386.67 (90.16)	41.33 (1.16)	25.03 (2.08)	125.33 (4.93)	0.52 (0.04)
Ridge-furrow	257.67 (10.51)	580.33 (19.73)	53.33 (1.52)	34.40 (0.37)	142.33 (2.52)	1.12 (0.02)
Ridge-furrow with mulch	272.67 (4.73)	622.33 (2.08)	71.33 (6.51)	39.45 (0.42)	150.33 (7.64)	1.42 (0.04)
			S-996			
Flat	260.67 (15.63)	449.33 (18.0)	45.0 (1.73)	30.10 (3.40)	138.67 (9.02)	0.69 (0.12)
Ridge-furrow	273.33 (18.83)	614.33 (8.15)	60.0 (2.0)	37.47 (1.42)	147.67 (3.79)	1.28 (0.068)
Ridge-furrow with mulch	316.67 (33.71)	643.33 (26.63)	80.67 (1.53)	41.03 (1.71)	165.0 (8.54)	1.68 (0.15)

(Standard deviation value in parentheses)

Table 2. Mean values of harvest maturity indices for cabbage

Planting method	Net head weight (g)	Head diameter (cm)	Compactness (Z- value)	Specific gravity	TSS | (^{0}Brix)	pH
			Syngenta BC-79			
Flat	520 (36.05)	12.53 (0.45)	26.43 (1.34)	0.96 (0.07)	5.29 (0.85)	6.61 (1.04)
Ridge-furrow	1116.67 (20.82)	14.23 (0.25)	38.75 (1.35)	0.92 (0.07)	7.67 (0.51)	6.43 (0.72)
Ridge-furrow with mulch	1423.33 (40.42)	15.03 (0.77)	42.22 (5.39)	0.89 (0.06)	6.59 (1.13)	6.23 (0.45)
			S-996			
Flat	686.67 (120.56)	13.87 (0.91)	25.60 (0.98)	0.86 (0.09)	5.57 (1.18)	7.03 (0.61)
Ridge-furrow	1276.67 (68.07)	14.77 (0.38)	39.67 (1.97)	0.86 (0.003)	7.03 (0.42)	6.24 (0.34)
Ridge-furrow with mulch	1683.33 (145.72)	16.5 (0.86)	37.54 (2.60)	0.99 (0.07)	6.29 (0.54)	7.31 (0.26)

(Standard deviation value in parentheses)

Table 3. Two-way analysis of variance (ANOVA) for different parameters of cabbage (Values in mm unless otherwise stated)

Source of variation	Plant height	Plant diameter	Stem length	Stem diameter	Head diameter	Head weight, kg	Compactness (Z- value)	Specific gravity	TSS ^{0}Brix	pH	Matured head (%)
						F-value					
Planting method (P)	8.35**	49.62**	177.19**	71.01**	23.01**	189.43**	49.7**	0.85	8.09**	1.1	82.44**
Variety (V)	8.73*	4.32	20.97**	13.39**	12.94**	23.59**	1.43	0.22	0.32	2.19	1.91
P * V	1.05	0.43	1.3	1.32	0.89	0.64	1.67	3.88	0.46	1.54	0.72
Mean	270.56	549.39	58.61	34.58	144.89	1.12	35.03	0.91	6.41	6.64	71.05
CV (%)	10.52	19.07	24.82	17.14	9.36	37.79	20.26	8.10	17.00	10.07	16.25
R^2	0.70	0.90	0.97	0.93	0.84	0.97	0.90	0.45	0.59	0.41	0.93

* significant at 5% and **significant at 1% level of significance

Table 4. Mean values comparison for different parameters of cabbage (Values in mm unless otherwise stated)

Planting method	Plant height	Plant diameter	Stem length	Stem diameter	Head diameter	Head weight (kg)	Compactness (Z- value)	Specific gravity	TSS (^{o}Brix)	pH	Matured head (%)
Flat	251.50^a	418.00^a	43.17^a	27.57^a	132.00^a	0.61^a	26.02^a	0.91^a	5.43^a	6.82^a	57.43^a
Ridge-furrow	265.50^a	597.33^b	56.67^b	35.93^b	145.00^b	1.20^b	39.21^b	0.88^a	7.35^{ab}	6.34^a	72.06^b
Ridge-furrow with mulch	294.67^b	632.83^b	76.00^c	40.25^c	157.67^c	1.55^c	39.88^b	0.94^a	6.44^b	6.77^a	83.66^c

Means with different letters superscripts are significantly different at $p < 0.05$

stem length was obtained in ridge-furrow with mulch planting method, which was significantly different from the other two planting methods. Similar trends were observed for stem diameter, head diameter, head weight and matured head (%).

A comprehensive examination of matured heads revealed distinct characteristics: wrapper leaves were spread, and the head was exposed. Applying light palm pressure allowed for differentiation between soft heads indicating immaturity and solid or hard heads indicating maturity. Ridge-furrow with mulch planting demonstrated the maximum percentage of matured heads (83.66%), followed by ridge-furrow (72.06%) and flat planting (57.43%). This outcome is attributed to the enhanced vegetative growth and early maturity associated with ridge-furrow planting methods.

The study implies that the maturity of heads under ridge-furrow with mulch planting is sufficient for the application of mechanical harvesting in cabbage crops. This insight contributes to the optimization of harvesting practices for improved efficiency and crop management.

The study revealed that uniform physical growth and early uniform maturity were observed in ridge-furrow planting with mulch. The maturity parameters showed no significant differences in the ridge-furrow and ridge-furrow with mulch planting methods. For mechanical harvesting in cabbage production, the ridge-furrow with mulch planting method and hybrid cabbage varieties (F1) with uniform maturity seem highly acceptable.

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