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Innovative Selective Harvesting Technology for Cauliflower: A Design Approach using Plant Characteristics

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ABSTRACT

Traditional manual harvesting methods for cauliflower are labor-intensive, time-consuming, and costly, and non-selective harvesting often leads to significant yield losses due to immature curds being harvested. To address these challenges, there is growing interest in developing selective cauliflower harvesters that can accurately identify and harvest mature and healthy cauliflower heads while minimizing damage and waste. This research paper focuses on the determination of design parameters for an efficient and adaptive selective cauliflower harvester based on a comprehensive understanding of the physical and mechanical properties of cauliflower plants. Two cauliflower varieties, Pusa Meghna, and Pusa Sharad, were studied to measure various physical properties such as plant width, height, curd diameter, curd depth, stalk diameter, stalk length, and stalk moisture content. Additionally, cutting force was measured to design the cutting unit of the harvester. The results revealed that design parameters, including frame height, width, length, cutter length, and cutter height, should be tailored to the specific physical properties of cauliflower plants to optimize the selective harvesting process. This research contributes valuable insights to the advancement of agricultural robotics and engineering, laying the groundwork for the development of sophisticated selective cauliflower harvesters.

Keywords Selective cauliflower harvesting, Pusa Meghna, Pusa Sharad, Cutting force, Chassis.

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INTRODUCTION

Cauliflower (*Brassica oleracea* var *botrytis*) is a popular and nutritious winter vegetable, cultivated extensively in various regions around the world. In global cauliflower production, India holds the second position, following China. The country's cauliflower cultivation accounts for 34.6% of the total global production (Anonymous 2020b). With increasing awareness of health and nutrition, the demand for cauliflower has grown significantly in recent years (Savita *et al.* 2014). The cultivated area for cauliflower in India spans 0.48 million hectares, resulting in a total production of 9.53 million metric tonnes and a productivity rate of 19.6 metric tonnes per hectare in 2021-22. The period from 2012 to 2022 witnessed a notable growth of 20.9% in cauliflower production and a corresponding increase of 20.7% in the overall cauliflower cultivation area in India (Anonymous 2022c). Consequently, the agricultural industry is facing challenges in meeting this growing demand while ensuring efficient and cost-effective harvesting practices. Traditional manual harvesting methods for cauliflower are labor-intensive (100 man-h/ha), time-consuming, and very costly (up to 50% of the overall production cost) (Anonymous 2018c, Dixit and Rawat 2022). On the other hand, the cauliflower curds were not matured at the same time. Research stated that only 50% of the curds gained maturity (based upon curd size) on the first harvest often resulting in significant yield losses due to non-selective harvesting done by the recently developed mechanical harvester (Verma *et al.* 2017). In response to these challenges, there is a growing interest in developing selective cauliflower harvesters, which can accurately identify and harvest mature and healthy cauliflower heads while leaving the immature ones untouched. Selective harvesting not only maximizes yield and quality but also reduces post-harvest losses, labor costs, and the environmental impact associated with conventional harvesting techniques. To achieve this objective, it is crucial to determine the appropriate design parameters for the selective cauliflower harvester i.e., frame height, frame width, frame length, cutter length, cutter height. These parameters should be based on a comprehensive understanding of the physical and mechanical properties of cauliflower plants. The physical properties encompass characteristics such as curd size, curd depth, stalk diameter, stalk length, stalk moisture content, plant height, and plant width (Anonymous 2012, Dixit and Rawat 2022, F. S. Wright and W. E. Splinter 1966, Kanamitsu and Yamamoto 1994, Sarkar and Raheman 2023) while the mechanical properties involve factors such as stalk strength and resistance to bending (Zhao *et al.* 2022). This research paper aims to contribute to the advancement of agricultural robotics and engineering by providing valuable insights into the physical and mechanical characteristics of cauliflower plants. Through the analysis of these properties, the necessary design parameters for an efficient and adaptive selective cauliflower harvester can be determined.

MATERIALS AND METHODS

The design process of the selective cauliflower harvester was based on the comprehensive determination of both the physical and mechanical properties of cauliflower. For this study, two varieties of cauliflower, namely Pusa Meghna and Pusa Sharad, were chosen. Pusa Meghna belonged to the early maturity variety group, while Pusa Sharad fell under the mid-early maturity variety group.

Physical properties measurement

During the harvesting stage, a comprehensive evaluation of the various physical properties of both the cauliflower stalk and foliage was conducted. Some observations were directly recorded in the field, while others were measured in the laboratory after being removed from the bed. Several physical properties, including plant width (represented by plant diameter or maximum feeder leaf diameter), plant height, curd (head) diameter, curd (head) depth, stem (stalk) diameter, stem (stalk) length, and stem moisture content, were measured for both cauliflower varieties. This assessment was depicted in Fig. 1. To ensure a representative sample, a total of thirty cauliflower

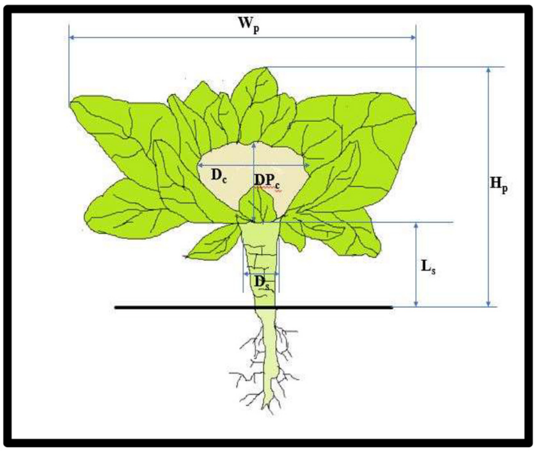


Fig. 1. Physical properties of cauliflower plant: W_p, Plant width; H_p, Plant height; D_c, Curd diameter, DP_c, Curd depth, D_s, Stem diameter L_s, Stalk length.

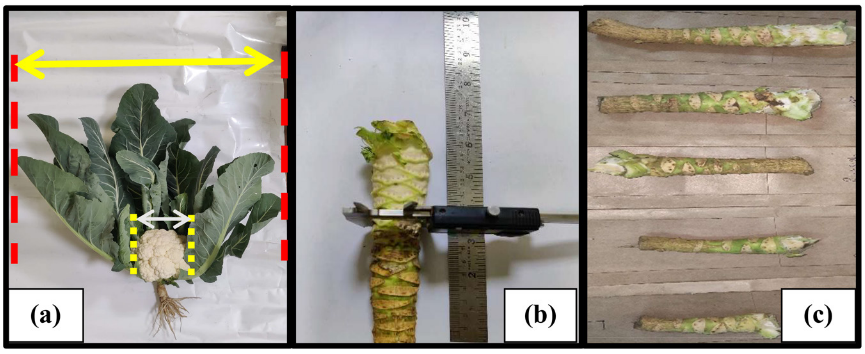


Fig. 2. Measurement of physical properties.

samples from each variety were randomly selected for the purpose of measuring these physical properties.

Plant width

In the context of cauliflower, the term "plant diameter" or "plant width" referred to the measurement of the entire plant's width, taken perpendicular to the row. This specific attribute was of great significance in designing the width of the harvester frame (Fig. 2a).

Plant height

In the context of cauliflower, the height of a cauliflower plant was defined as the vertical distance measured from the base of the plant to the highest point of the plant. This measurement encompassed the complete vertical extent of the cauliflower plant, offering valuable insights into its overall size and growth characteristics. In the context of harvester design, the plant height served as a relevant parameter to consider when determining the appropriate frame height.

Curd diameter

Cauliflower head diameter was defined as the length of a straight line passing through the center of the head, perpendicular to the direction of the stem, after all wrapper leaves were removed. This measurement represented the maximum width of the cauliflower head and served as a reliable indicator of the crop's maturity. This single measurement was adequate to describe the stage of development of the cauliflower crop (Fig. 2a).

Curd depth

Curd depth was measured from the base of the curd, where it emerged from the stem, to the highest point of the curd. The curd depth or height offered valuable insights into the size and maturity of the cauliflower head. It represented the maximum height of the cauliflower curd and proved to be a crucial measurement in designing the variable cutting height adjustment system.

Stalk diameter

Cauliflower plant stem diameter referred to the diameter of the stem at the region where the leaves were attached to the stem. At this point of attachment, the leaves were oriented horizontally, which made it more challenging to insert a cutting device into the stem. This property was utilized in the calculation of the cutting force required to sever the stalk (Fig. 2b).

Stalk length

In the study, the stem length of a cauliflower plant was defined as the distance between the base of the plant, where the stem emerged from the ground, and the highest point of the stem before it branched out into the foliage or curd. This property played a significant role in determining the cutting height of the harvester as well as in designing the wheels of the harvester (Fig. 2b).

Stalk moisture content

The determination of stalk moisture content was car-

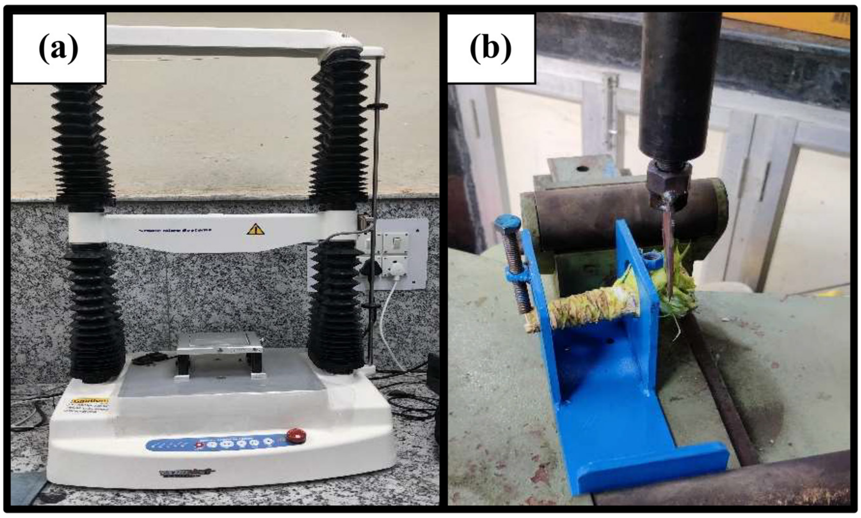


Fig. 3. Measurement of mechanical property.

ried out following the established standard procedure. Six samples, varying in length from 10 to 15 cm, were randomly chosen from the field and meticulously sealed in envelopes to prevent any moisture loss. Subsequently, these samples were weighed using an electronic balance and subjected to an oven-drying process at a temperature of 70ºC for a period of 48 hrs (Fig. 2c).

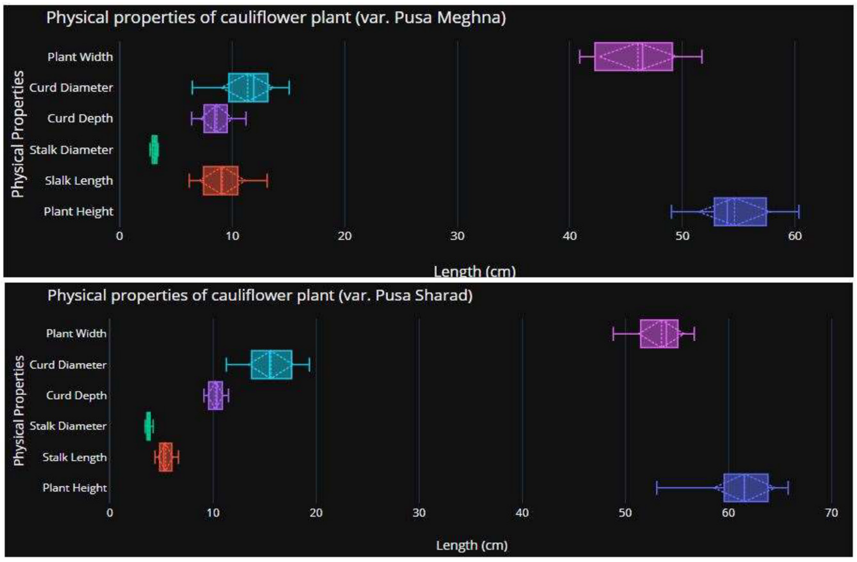
Mechanical property measurement

To design the parameters for the cutting unit, specifically the power of the brushless direct current motor to run the cutter, the measurement of cutting force becomes essential. The cutting force is precisely measured using a texture analyzer with a force capacity of 100 kgf (Fig. 3a). The cutting zone, located approximately 5 mm to 40 mm away from the top leaves as identified by Li *et al.* (2013), exhibits lower fiber content, resulting in reduced resistance offered by the stalk. To conduct the measurement, the cauliflower stem is securely fixed on a holder positioned beneath the texture analyzer, while the knife operates at a speed of 10 mm/sec (Fig. 3b).

RESULTS AND DISCUSSION

Physical properties

The distribution of the physical properties of both varieties have shown the normal distribution (Fig. 4). The data presented in Table 1 indicated that with the exception of stalk length, all physical properties of Pusa Sharad were greater than those of Pusa Meghna. This discrepancy can be attributed to Pusa Sharad belonging to the mid cauliflower variety group, known for its more vigorous growth habit (Verma *et al*. 2017). Specifically, the Pusa Meghna cultivar exhibited a lower plant width of 46.06 ± 3.46 cm, whereas the Pusa Sharad cultivar demonstrated a higher plant width of 53.50 ± 2.19 cm. Based on these findings, it can be inferred that the main frame of the harvester should have a width greater than 56 cm to prevent any damage to the leaves of the plants during the harvesting process (Fig. 5a) (Lenker *et al.* 1976). In terms of plant height, a majority of the plants in the Pusa Meghna variety fell within the range of 51 to 57 cm, while for the Pusa Sharad variety, the majority of plants had heights ranging from 59 to 63 cm. Considering the significance of plant height in determining the appropriate height of the main frame in the selective cauliflower harvester, it could be inferred that the main frame should have had a height greater than 70 cm. This consideration took into account the height of the bed at the time of harvest, ensuring that there was no damage to the leaves of the plants as they passed through the harvester (Fig. 5a). For the curd (head) diameter, the mean values were calculated as 11.36 cm for Pusa Meghna and 15.62 cm for Pusa Sharad. To enable manual feeding of the desired harvesting diameter, a maturity detection unit



Fig, 4. Pattern of physical properties for both varieties.

was incorporated with the help of image processing. This provision ensured that the harvester exclusively harvested cauliflower curds with diameters exceeding the manually set value. The mean curd depth value for Pusa Meghna was determined to be 8.61 ± 1.39 cm, and for the Pusa Sharad variety, the curd depth ranged from 9.14 cm to 11.51 cm, with a mean value of 10.24 ± 0.74 cm. The curd depth and stalk length of the cauliflower plant played a critical role in determining the maximum variable height of the cutting blade. For Pusa Meghna and Pusa Sharad varieties, the mean values of stalk diameter were 3.11 ± 0.22 cm and 3.75 ± 0.18 cm, respectively. The specific measurements for stalk length ranged from 6.2 cm to 13.1 cm for Pusa Meghna and 4.38 cm to 6.66 cm for Pusa Sharad. Analysis revealed that the stalk height or length varied from 5.4 cm to 9.1 cm, covering a significant range of varieties. Therefore, the cutting

Table 1. Physical properties of cauliflower varieties.

Variety		H_p (cm)	L_s (cm)	D_s (cm)	DP_c (cm)	D_c (cm)	W_p (cm)
Pusa	Min	49.01	6.20	2.72	6.40	6.46	40.88
Meghna	Max	60.34	13.10	3.43	11.23	15.06	51.72
	Range	11.33	6.90	0.71	4.83	8.60	10.84
	Mean	54.64	9.13	3.11	8.61	11.36	46.06
	Mode	53.87	6.2	3.38	7.12	10.07	49.58
	Median	53.98	9.00	3.14	8.44	11.92	46.47
	SD	3.17	2.04	0.22	1.39	2.31	3.46
	COV	5.81	22.34	7.08	16.13	20.36	7.51
Pusa	Min	53.04	4.38	3.44	9.14	11.29	48.85
Sharad	Max	65.79	6.66	4.21	11.51	19.36	56.68
	Range	12.75	2.28	0.77	2.37	8.07	7.83
	Mean	61.57	5.40	3.75	10.24	15.62	53.50
	Mode	63.62	4.92	3.71	9.59	14.85	55.95
	Median	61.54	5.22	3.71	10.38	15.49	53.98
	SD	2.98	0.70	0.18	0.74	2.17	2.19
	COV	4.84	12.99	4.70	7.27	13.86	4.10

Min: Minimum, Max: Maximum, SD: Standard deviation, COV: Coefficient of variation.

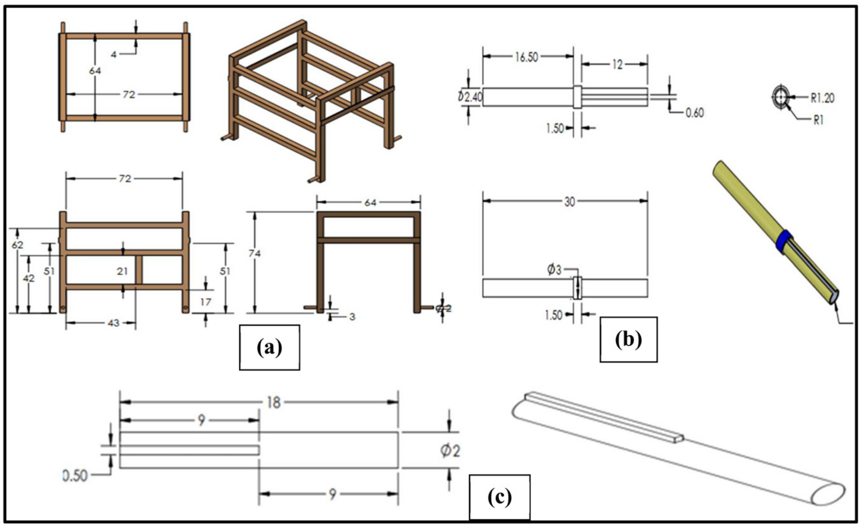


Fig. 5. Design values of the frame of selective harvester (All dimensions in cm).

blade was mounted on a telescopic assembly to vary the cutting height (Figs. 5b -5c). In the harvester design, the top rod (Fig. 5c) was securely attached to the main frame. On the other hand, the bottom rod (Fig. 5b) was designed to slide into the top rod, providing a telescopic assembly feature. This telescopic mechanism allowed for adjustable cutting height based on the requirements of the cauliflower plants. At one end of the bottom rod, the cutting unit was firmly fixed, ensuring stability and precision during the cutting process. The average moisture content of the stalk for Pusa Meghna was determined to be 75.51 ± 1.4% on a wet basis. Similarly, for Pusa Sharad, the average moisture content of the stalk was measured to be 77.01 ± 0.9% on a wet basis. These values indicated that both varieties exhibited similar moisture content in their stalks during the harvesting stage. The dimensions of the selective harvester based on the physical properties were shown in Fig. 5.

Cutting force

The graph illustrates the variation in cutting force recorded at equal time intervals for the Pusa Sharad variety (Fig. 6). The graph clearly indicates that the stalk diameter of the Sharad variety is larger compared to the Meghna variety (Fig. 4). Consequently, the design for the cutting unit of the harvester is optimized for the maximum stalk diameter observed in the Sharad variety. As evident from the graph, a peak value of 87 N is observed at the initial contact of the blade with the stalk. This peak can be attributed to the internal structure of the cauliflower stalk, particularly the presence of fiber content in the outermost layer. The high fiber content contributes to the peak in cutting force (Du *et al.* 2015, Li *et al*. 2013). Following the initial peak, the graph shows a consistent average cutting force of 70 N. This average force requirement is in line with the findings reported by Zhao *et al.* (2022) and indicates the force needed by the cutting unit to sever the cauliflower stalk efficiently. The cutting process to completely sever the stalk takes approximately 2.30 seconds, as measured from the start of the contact between the blade and the stalk

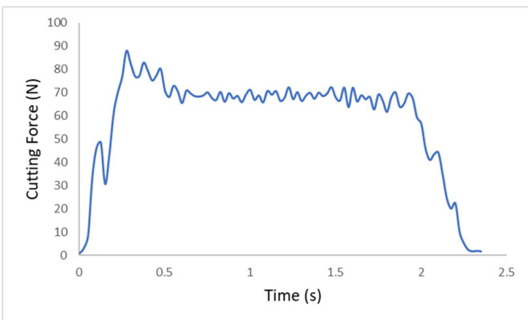


Fig. 6. Cutting force versus time.

until the stalk is fully cut.

CONCLUSION

In summary, this research paper explores the physical and mechanical properties of cauliflower plants to design an efficient and selective cauliflower harvester. The study revealed that the design parameters of the harvester, such as frame height, frame width, frame length, cutter length, and cutter height, should be based on a thorough understanding of the cauliflower plant's physical properties. Furthermore, the measurement of cutting force for the cauliflower stalk provided essential information for designing the cutting unit of the harvester. This research paper can serve as a foundation for the advancement of agricultural robotics and engineering, facilitating the development of advanced selective harvesting technologies. The selective harvester aims to optimize cauliflower harvesting, reduce labor costs, and improve overall crop productivity, contributing to sustainable agriculture and meeting the increasing demand for this nutritious vegetable.

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