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Original Research Paper

Physio-morphological and mechanical properties of chillies for mechanical harvesting

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ABSTRACT

The plants and its produce characteristics are the basis to design a crop specific harvester. The objective of this study was to determine the physical, morphological and mechanical properties of chilli plant and fruits, that can be used in the design of harvester machine. The observations and data were collected by taking measurements at harvesting stage of three chilli cultivars. The fruit bearing behavior of plants was solitary with fruit position erect in Demon F_1 and pendent in Arka Meghana and Mahyco Tejaswini. The plant height ranged between 81.76 to 84.87 cm depending on cultivars number of fruits per plant were 170.25, 158.96 and 156.15 in Tehaswini, Arka Meghana and Menon respectively. It was observed that the length and diameter at shoulder of fruits was in the range of 4.97 to 10.44 cm and 0.8 to 1.25 cm, respectively. The moisture content reduced in leaves, stems and fruits as the maturation changed from matured green fruits bearing of plants to semi dry condition. The detachment force of fruits from plants increased as the fruits colour changed from matured green to fully ripened red and there after decreased.

Keywords: Chillies, erect, detachment force, mechanical harvester and pendent

INTRODUCTION

Chilli is a seasonal vegetable that is part of the spicy food culture in India. Chilli (*Capsicum annuum* L.) belongs to the Solanaceae family (Farhan *et al*., 2014). It is well known for its edible, colourful, juicy and crispy flesh, as well as for its nutritious contents. Red chilli is an important commercial crop used as a condiment, culinary supplement or as a vegetable, physiological matured greens, ripened red color and red dried fruits. In India, among the spices consumed, dried chilies contribute a major share and grown in different agro-ecological zones and is the largest producer in the world. During 2019-20, India produced approximately 17.52 lakh tonnes of chillies from an area of 7.03 lakh ha and the productivity was 2.49 tonnes ha^{-1} as per the report of Spice Board of India.

Chilli harvesting is not mechanized in the country and it depends entirely on the manual work force prolonging the extended period of field operation. The chilli fruit harvesting period occurs during the hot summer season, and the labour costs are very high, because the population residing in rural areas is decreasing and it is difficult to supply sufficient workforce to harvest in a timely manner. Therefore, mechanization of chilli harvesting is an urgent requirement to reduce the cost due to labour employed partly, faster operations at reduced drudgery and other production difficulties (Nam *et al.,* 2018).

To reduce mechanical damage due to harvest and post-harvest operations requires studies on the morphological, physical and mechanical properties of plants as well as fruits to design a harvesting machine. To optimize machines design and development parameters for operations such as harvesting, handling, cleaning and conveying, the morphological, physical and mechanical attributes and their

relationships play a major role (Rokayya and Khojah, 2016). Physical characteristics of agricultural crops, products are the most important parameters to determine the proper standards of grader design, conveying, processing and packaging systems (Tabatabaeefar and Rajabour, 2005). Several studies were conducted on pepper varieties in different countries, like Turkey (Ozgur *et al*., 2011; Kadri and Murat, 2010), Nigeria (Ilori *et al*., 2010), Thailand (Toontom *et al.,* 2012), Germany (Romano *et al*., 2012), Spain (Vega-Galvez *et al*., 2008), India (Nidhi *et al*., 2016) and Malaysia (Noryati and Revathi, 2006). Previous studies on chilli varieties and cultivars revealed that great variations existed in plant growth, other qualitative attributes and yield under different agro-climatic zones. In country like India, a large diversity in chilli with different quality factors and other traits is expected due to different agro ecological zones. Any developments in chilli harvesters should consider domestic cultivars and cropping systems because these are entirely different from exotic chilli varieties. Hence, more studies are required to collect data and standardize the design parameters pertinent to harvesting and post-harvest operational machines. So, the aim of the present work was to study morphological, physical attributes and mechanical properties of chilli plants and fruits of three most popular cultivars (hybrids) grown in southern states at different stages pertinent to harvesting, cleaning and grading machines.

MATERIALS AND METHODS

The chilli cultivars selected for the present study were Arka Meghana, Mycho Tejaswini and Demon F_1 and cultivated as per the recommended agronomical practices at ICAR- Indian Institute of Horticultural Research, Bangalore. The observations and pertinent data collection study were carried out between 125 to 150 days after transplanting, at which the crop reached to full growth, maximum fruiting and harvestable ripped red fruits were present in considerable number. In the identified crop rows, 50 randomly selected plants from each cultivar were tagged and from each plant 100 fruits were plucked covering all directions and from fruit bearing lower to top branches. The instruments used in this study to measure linear dimensions were steel rule, digital caliper with an accuracy of 0.01 mm and fruits weight using a digital electronic balance with an accuracy of 0.01 g.

Plant growth and morphological attributes

The plant growth habits and fruit bearing characteristics qualitative information was collected from reliable secondary sources of literature and characterization descriptors of IPGRI (1995). The plant growth attributes were measured when 100 per cent of the plants had at least certain proportion of fully ripped fruits. These attributes include plant height (cm), plant canopy spread across (cm) and along the row (cm), stem diameter (cm), stem length (cm), height of the lower most (cm) and upper most chilli fruit (cm) from ground. Plant height was measured from the ground surface to the uppermost tip of the plant using the steel rule. Plant stem girth measured at ground level and stem length was measured from the soil surface to the first internode of primary branch. The total number of fruits per plant was calculated by noting down harvested fruits at every picking from selected 50 plants. The moisture contents of three major portions of plants namely leaves, stems and fruits at different stages of fruits ripeness was collected randomly and estimated as per the standard laboratory drying procedure.

Geometrical and physical properties of fruits

The geometrical and physical properties of fruits measured were length, diameter just below the calyx part where fruit is maximum in diameter and weight of 1000 fruits.

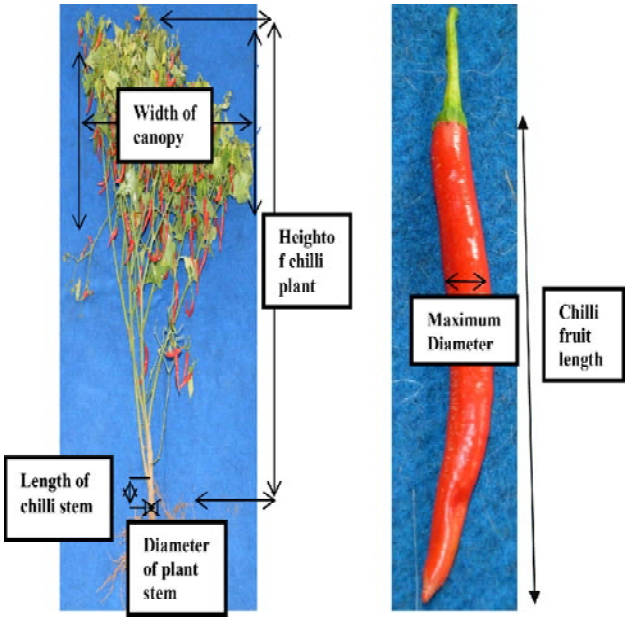

Fig. 1. Measurement standard for chilli plant and fruits

Moisture content of plant parts

As the fruits and vegetables changes from physiological maturity to full ripeness, the moisture content of various plant parts like leaves, stems and branches may change in addition to changes in textural property. This property plays a major role in harvesting, especially fruits moisture content has profound effect beyond harvesting operation. The moisture contents were measured using oven dry method at different ripeness stages of fruits by collecting samples from different plant parts randomly. The moisture content was determined by using standard procedure of AOAC (1970).

Detachment force/ pulling force of chilli fruit

The force of detachment or pulling force of fruit to separate from the chilli plants was measured using digital force gauge (Fig. 2), which can measure maximum 50 Newton (N). The digital force gauge used for the experiment was Model No. SF-50, maximum load 50N and the least count of the instrument was 0.01N. The push and pull type digital force gauge was held with one hand one side

Fig. 2. Images showing fruit detachment force with digital force gauge

hook and the other side hook was connected to the chilli fruit pedicle and the applied maximum force was noted from the display on the screen. For each cultivar detachment force of fruits was measured at four stages (i.e.) green, semi red, red/ fully ripped, partly dry and full dry condition (Fig.3).

The statistical analysis was carried out for the each observed character under the study using MS-Excel. The mean values of data were subjected to analysis of variance as described by (Gomez and Gomez, 1984).

Green Semi-red Red Semi-dry Dry

Fig. 3. Image shows different stages of Arka Meghana cultivar

RESULTS AND DISCUSSION

Plant growth characteristics

The three cultivars selected for the study were dual purpose (i.e.) useful as green vegetable and as well as dried red chilli. The Arka Meghana had branches spreading growth type and rest of two semi-spreading in nature either sparse or intermediate dense (Table 1). The stem shape was found to be round for all three. The fruits shape was determined based on comparison with the shapes proposed in the list of descriptors of the IPGRI (1995), the Arka Meghana and Mahyco Tejaswini possess elongate shaped fruits and Demon F_1 erect narrow fruits. Based on fruit position the cultivars fall in two groups *viz*., Demon F_1 erect position fruits and remaining two in pendent position. As per the fruit bearing characteristic all the three falls in solitary behaviour.

The plant growth, branching pattern, physical structure of fruits and other biological features have a significant impact on machine harvesting efficiency. Low plant structure and small branch angles make positive impact on machine harvesting efficiency. High canopy density vegetable crops need vigorous shaking of the branches by harvesting devices, which causes the high quantity of foreign material like tender branches, twigs in the harvested produce. This cause makes the quality produce separation process more energy intensive, because of necessary additional strength required for the mechanism to separate and transmit the unwanted material out of the harvesting machine.

Table 1. Plant growth characteristics of selected three cultivars of chilli

Characteristics	Arka Meghana	Tejaswini	Demon F_1
Utility - Green / Dried red / Dual purpose	Dual purpose	Dual purpose	Dual purpose
Plant growth habit	Medium height and spreading	Medium height and Semi spreading	Medium height and Semi spreading
Branching habit	Dense	Sparse	Intermediate
Stem Shape	Round	Round	Round
Fruit shape	Elongate	Elongated	Erect narrow
Fruit position	Pendent	Pendent	Erect
Fruit bearing	Solitary	Solitary	Solitary

Arka Meghana **Tejaswini** **Demon F_1**

Fig. 4. Fruit shape and fruit position of different cultivars of chilli

Chilli cultivars morphological attributes

The distance from the ground level to the upper most tip of the plant is measured as the height of the plant. The average height of the plants was found as 82.20 cm, 84.87 cm and 81.76 cm for Arka Meghana, Mahyco Tejaswini and Demon F_1, respectively (Table 2). The height of the plants varied from 64 to 115 cm and maximum height 115 cm observed in Demon F_1 and minimum of 64 cm in Arka Meghana.

Plant canopy width across and along the rows

The minimum and maximum distances between the tips of the lengthiest branches spread in the tagged plant samples across the row (canopy width in East- West direction) ranged from 59 to 98 cm and along the row (canopy width in North - South direction) from 56 to 93 cm in Mahyco Tejaswini. Generally, in crops sown in rows, the harvesting machine being operated along the rows, so the spread width of canopy across the row plays a critical role in deciding the harvester head size to cover entire canopy for maximum harvesting efficiency.

Plant stem length, stem diameter and number of fruits per plant

The stem lengths of the chilli cultivars varied from 2 cm to 13 cm and the mean value of stem lengths recorded varied from 5.44 to 8.99 cm. The higher mean stem length to first bifurcation was recorded in Demon F_1. The stem diameter of the chilli cultivars varied from 1.82 to 2.16 cm. The plant stem diameter is higher 2.16 cm in Arka Meghana and lower in 1.82 cm in Demon F_1. The minimum and maximum number of fruits per plant ranged from 61-343 number for Demon F_1 with lowest mean value of 156.15 number of fruits per plant. Among the three cultivars, a maximum mean value 170.25 fruit per plant was recorded for the Mahyco Tejaswini.

Table 2. Morphological characteristics of different chilli cultivars

Characteristics	Plant height (cm)	Across row EW (cm)	Along row NS (cm)	Plant stem length (cm)	Stem dia meter (cm)	Number of fruits per plant	Height of the lower most fruit (cm)	Height of the upper most fruit (cm)
Arka Meghana								
Mean	82.20	79.55	76.18	6.35	2.16	158.96	21.46	84.71
Minimum	64.00	63.00	59.00	3.00	1.60	76.00	10.00	62.00
Maximum	108.00	97.00	93.00	13.00	2.72	243.00	31.00	100.00
Standard deviation	9.28	7.46	7.90	1.90	0.63	39.91	4.24	10.43
Standard error	0.92	0.74	0.79	0.19	0.06	3.97	0.80	1.97
Mahyco Tejaswini								
Mean	84.87	75.16	72.17	5.44	1.90	170.25	20.83	67.66
Minimum	69.00	59.00	56.00	2.00	1.06	73.00	12.00	65.00
Maximum	108.00	98.00	93.00	11.00	2.52	234.00	32.00	98.00
Standard deviation	14.98	11.35	1.99	1.99	0.34	36.47	4.71	18.14
Standard error	1.50	1.14	1.10	0.23	0.04	4.27	0.87	3.37
Demon F_1								
Mean	81.76	73.40	63.89	8.90	1.82	156.15	28.11	98.56
Minimum	65.00	60.00	57.00	4.00	1.44	61.00	17.00	90.00
Maximum	115.00	92.00	88.00	13.00	2.68	343.00	36.00	112.00
Standard deviation	9.52	9.47	9.67	1.85	0.31	50.28	6.29	7.02
Standard error	0.94	0.93	0.95	0.18	0.03	4.93	2.10	2.34

Height of the lower most and higher most fruits bearing branches

Though there is not much considerable variation in the mean plant heights among the three cultivars, but considerable variation was observed in fruits bearing canopy zone lengths. The fruits bearing canopy spread height was maximum (70.45cm) for Demon F_1 and the least 46.83cm for Mahyco Tejaswini. The average height of the lowermost chilli fruits bearing was observed 20.83 cm in Mahyco Tejaswini and highest value 28.11 cm in Demon F_1.

Fruits geometrical and physical properties

The size and shape of fruits play major role in separation of unwanted biomass and also immature harvested ones from the quality produce and otherwise more prone to storage disease in crop like chillies. The fruit shape description of chilli grown for dual purpose use in India is difficult, however in general it is triangular in shape with obtuse truncated shape pedicel attachment portion and blunt sunken at blossom end portion. Maturation is indicative of the fruit being ready for harvest and after full maturation, there will not be much change in fruit size and shape, since the edible part of the fruit or vegetable is fully developed. Dependence on colour parameter alone to harvest the matured vegetables at green colour stage may mislead in certain vegetables. Rather than decision taken based on fruit size, shape and colour may yield best results. Apart from that, fruits and vegetables geometrical parameters like length, width, thickness or diameter will give us an idea to design and develop sieve set to separate the discard able biomass from produce and graded marketable produce based on size.

In chilli the total fruit length and diameter at shoulder are two geometrical dimensions, based on which the separation and grading of produce equipment could be planned. The fruit length measured without pedicle for the selected chilli crops ranged from 2.60 to 14.70 cm and for the same the mean length values varied 4.97 to 10.44 cm. The maximum mean fruit length was observed in Arka Meghana (10.44 cm) and minimum value 4.97 cm in Demon F_1.

Fruit diameter and 1000 fruits weight

In certain fruits the shape can change during maturation and can be used as a characteristic to determine harvest maturity. As the fruit or vegetable matures on the plant the relationship between the shoulders of the fruit and the point at which the stalk is attached may change. The shoulders of immature ones slope away from the fruit stalk and on full maturity the shoulders become level with the point of attachment, and in certain cases the shoulders may be raised above this point also.

As per the forgone discussion, in chilli the size of fruits is maximum at shoulders, so the diameter was measured at this point. For the selected chillies, overall fruit diameter varied from 0.51 to 1.58 cm and the mean values were ranged from 0.80 to 1.25 cm (Table 3). The maximum values in all respects were observed in Arka Meghana and minimum in Demon F_1.

The weight of 1000 ripened chilli fruits widely ranged from minimum 1.24 kg to maximum 9.21 kg. The mean weight of 1000 ripped fruits was 1.96 to 6.97 kg. The maximum 1000 chilli fruits weight was recorded in Arka Meghana 6.97 kg and minimum value in case of Demon F_1 (1.96 kg).

Table 3. Ripened chilli fruits geometrical and physical properties

Cultivars	**Arka Meghana**			**Mahyco Tejaswini**			**Demon F_1**		
Properties	**Fruit length (cm)**	**Fruit dia meter (cm)**	**1000 fruits weight (kg)**	**Fruit length (cm)**	**Fruit dia meter (cm)**	**1000 fruits weight (kg)**	**Fruit length (cm)**	**Fruit dia meter (cm)**	**1000 fruits weight (kg)**
Mean	10.44	1.25	6.97	7.74	0.92	3.81	4.97	0.80	1.96
Minimum	6.20	0.81	4.13	4.30	0.69	2.40	2.60	0.51	1.24
Maximum	14.70	1.58	9.21	9.80	1.18	5.43	10.50	1.05	2.98
Standard deviation	2.00	0.16	1.02	1.30	0.09	0.64	1.06	0.11	0.30
Standard error	0.20	0.02	0.10	0.13	0.01	0.08	0.10	0.01	0.03

Moisture content

The moisture contents data of different plant parts at different ripeness stages was presented in Table 4. At full matured green stage of fruits, the moisture content of the leaves was about 72% (db) and fruits possessed considerably higher amount of moisture about 80%.As the fruits maturation changes from physiological mature green colour to full red and beyond, all the plant parts namely leave, stems and fruits moisture contents decreased. When compared to other parts, the per cent of moisture loss was more rapid in leaves followed by stems and minimum gradual reduction was observed in fruits. The moisture content trend is more or less same in all the three cultivars.

Moisture content is an influential factor in all the crop processing operations and greatly influences other physical and mechanical properties (Ilori *et al.,* 2010). In harvesting stage of crops, excessive loss of moisture may lead to the structural parts of the plant to become softer. The softer plant parts cling to the rotating or oscillating or jolting components which shake or vibrate or comb or push the plant branches reducing its effectiveness thus reducing harvesting efficiency of the fruits and vegetables. In certain species, reduced moisture contents in plant parts result in excessive detachment of leaves, twigs in considerable quantity thus increasing energy expenditure in cleaning and grading unit of harvesting machine.

Table 4. Moisture content of plant parts at different maturity stages of different cultivars

Plant part	Green	Semi-red	Red	Semi-Dry	Dry
Arka Meghana					
Leaf	71.33±2.08	54.04±0.47	40.78±0.64	33.63±0.64	20.53±0.87
Stem	68.90±0.87	66.54±0.76	49.15±0.31	46.15±0.75	39.71±1.27
Fruit	81.29±2.85	84.35±0.81	77.86±0.31	79.77±0.78	72.70±0.82
Mahyco Tejaswini					
Leaf	72.17±2.13	62.96±2.63	48.66±1.16	33.33±1.53	18.23±1.09
Stem	63.69±2.29	54.45±1.27	53.83±2.40	53.16±1.04	38.05±2.10
Fruit	77.86±0.31	76.72±0.46	74.85±0.17	74.76±1.57	72.17±1.02
Demon F_1					
Leaf	71.78±1.65	54.16±2.13	45.59±0.94	33.30±1.20	18.21±1.20
Stem	60.85±1.57	58.83±1.22	52.87±1.57	44.12±0.58	37.12±1.50
Fruit	77.58±0.59	76.96±0.93	74.79±1.40	72.49±0.69	71.04±1.72

Detachment force of chilli fruits at different stages of ripeness

The principles dictating at what stage of maturity the fruits or vegetable should be harvested are crucial to its subsequent drying /storage and marketable life and quality. Post-harvest physiologists distinguish different important stages in the life span of fruits and vegetables namely maturation (green), semi – ripeness, ripened, semi dried, dried and crop senescence (ageing) itself. All these stages have its own importance depending on how and where the produce being used and strategies being followed in collection, transportation, storing and marketing. Ripening follows or overlaps maturation, rendering the produce edible, as indicated by colour and taste in majority of fruits and vegetables. In certain crops plant senescence (ageing) also considered as indicative of crop harvest. Senescence is the last stage, characterized by natural degradation of the plants, as in loss of texture, colour, etc. In case of certain fruits and vegetables colour and moisture content are two majorly determining factors to harvest the produce that are to be dried to preserve for round the year use as it is or in size reduction form with or without pre-treatment.

Ripening stage has an important effect on the force required for removal or detachment of fruits or vegetables or nuts from the branches of plants or trees and on relative susceptibility to mechanical damage. Some researchers reported that the holding force of fruits and vegetables to pedicle decreased as the fruit

Table 5. Force (N) required to detach chilli fruit at different growth stages

Different stages	Arka Meghana					Mahyco Tejaswini					Demon F_1				
	Green (N)	Semi red (N)	Red (N)	Semi Dry (N)	dry (N)	Green (N)	Semi red (N)	Red (N)	Semi dry (N)	Dry (N)	Green (N)	Semi red (N)	Red (N)	Semi Dry (N)	Dry (N)
Mean3.45	4.07	5.85	2.36	1.08	2.43	2.11	4.92	1.52	0.87	5.19	6.39	8.58	1.98	0.98	
Minimum	0.78.	1.04	1.90	0.39	0.75	0.99	0.45	1.23	0.50	0.69	1.18	1.02	1.20	0.93	0.78
Maximum	9.86	11.30	17.49	6.21	1.43	8.79	5.80	13.18	4.47	1.13	13.82	12.21	15.65	5.95	1.32
Standard deviation	2.11	2.19	2.80	1.51	2.32	1.53	0.93	2.23	0.80	0.95	2.31	2.21	2.07	1.15	1.76
Standard error	0.19	0.22	0.28	0.15	0.19	0.15	0.09	0.22	0.08	0.14	0.21	0.22	0.21	0.11	0.34

matured, due to cork that is formed in the stem holding place. The detachment force required to pluck the fruits of selected cultivars of chillies at various stages of ripeness is presented in Table 5. The results indicates that, the detachment force increased as the fruits maturation increased from green to full red and there after it decreased. This may be due to the fact that up to full maturation of fruits, pedicle contains more fibre content compared to remaining stages and at dry stage pedicle contain less fibre content. It was observed that, the average force required to pluck the chillies at green stage for Arka Meghana, Mahyco Tejaswini and Demon F_1 was found to be 3.45± 2.11 N, 2.43±1.53 N and 5.19± 2.31 N, respectively. Similarly, in fully ripped red stage maximum plucking force noted, 5.85± 2.80N, 4.92± 2.23N and 8.58± 2.07N, respectively.

The data also indicates that, specifically the cultivars having pendent position fruits have recorded lower plucking force than erect position. These observations concur with the findings of Funk and Walker (2010), pendant fruit position with minimum fruit attachment force in green chilli genotypes aides for better mechanical harvesting. When mechanical harvesting components designs involving working principles such as rotating, oscillating, push-pull, combing and jolter actions are employed to harvest fruits and vegetables; fruit/ vegetable detachment force, size properties, mass and puncture property against mechanical damages must be known. Polat *et al.,* (2010) reported that for pistachio nut the pod detachment force decreased from 436 to 118 N within 100 days prior to harvesting to harvest date of partially dried nuts.

CONCLUSIONS

Red chilli is an important commercial crop, besides its wide spread use in Indian food culture. However, the fruits harvesting still being carried manually at increased harvesting costs and in hot weather conditions. So, important morphological attributes, physical and mechanical properties of three popularly grown cultivars were studied to provide an idea about these for harvester developers, researchers. The results have revealed the importance of the difference among cultivars, while designing and manufacture of machines. These properties are highly useful in harvesting machine development and as well as post harvesting like cleaning and grading equipment.

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