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Effect of Fruit Size and Maturity on Selected Mechanical Properties of Tomato

B. Sanjeeva Reddy* and P. Srinivas

ICAR - Central Research Institute for Dryland Agriculture, Hyderabad - 500 059, India

*Corresponding Author E-mail: bs.reddy@icar.gov.in

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ABSTRACT

The losses in fruits and vegetables in various postharvest operations remained high in which tomato is one of the major vegetable fruit. Tomato is a sensitive vegetable whose quality is substantially reduces due to physical damage encountered by various mechanical forces in harvesting, handling and other postharvest operation. In this study an attempt was made to determine mechanical properties such as fruit picking force, coefficient of friction, impact energy force and fruit failure stress which play a major role in design and development of production operations, handling and processing machinery and equipment. The results showed that the fruit picking force increased with increase in size of fruit, recoding highest force 13.60 N with fruit size 55.82 ± 5.09 mm. The fruit size and ripening stage individually influenced the static coefficient of friction significantly. The impact energy force decreased from 37.30 to 35.11 N as the fruit size decreases large to small. The tomato fruit failure stress decreased 56.35%, indicating green tomatoes were more firm than the full red tomatoes. This is an indication for internal structural changes in cell walls of fruits due to various chemical changes as maturity stages increases causing the fruits more susceptible to physical damage due to mechanical force factors which occurs in harvesting and handling processes.

Key words: *Tomato, Mechanical properties, Quality loss, Coefficient of friction, Shear stress.*

INTRODUCTION

India is second highest producer of vegetables, next only to China with an annual production of about 87.53 million tones from 5.86 million hectares with a share of 14.4 per cent to the world production. Adoption of high yielding cultivars and F1 hybrids and better crop production management practices has largely contributed for higher production and productivity. Different kinds of vegetables belonging to different species / groups are grown in varied agro-climatic zones of the country. Tomato occupies second position amongst the vegetable crops in terms of production in the country, with a total production of 16.53 million tonnes from an area of 0.46 million hectares. The information available indicates that, 30% of all the vegetable crops the country produces, about worth of Rs 14,100 crores are lost due to lack of appropriate management practices at post harvest and handling stages in the form of wastage and value destruction[15].

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Field observations over the past 40 years have reported that 40 to 50 per cent of horticultural crops produced in India are lost before they can be consumed, mainly due to high rates of mechanical bruising and subsequent decay in quality during postharvest handling (Kitinoja 2010). Studies conducted in India on post-harvest losses of various vegetables show that, maximum loss of 23% was reported in tomatoes when compared with other vegetables[16]. In spite of this, tomato cultivation has become a major agricultural activity round the year in and around peri-urban areas of India among various categories of farmers. This activity besides meeting domestic demand of growing population, also creating considerable amount of employment opportunity on account of domestic market sales and in other postharvest services. In fruits harvesting, handling and transportation stages mechanical damage is very common, and is defined as fruits deformations, superficial rupture and destruction of tissue due to external forces[7]. Fruits are subjected to physical impacts at various stages in transitory movements to dissipate energy and consequently subjected to mechanical damage, which ultimately reduces the quality of fruits. To find out ways and means to reduce mechanical damage, research on physical and mechanical properties of fruits and vegetables needs to be studied on priority basis to optimize the proper design and control of various devices and equipment used while in harvesting and post harvest process operations. The past research work carried on physical and mechanical properties of tomatoes can be summarized and categorized into two broad aspects. First one, physical and mechanical properties of whole tomato fruits (Viswanathan et al.[18]; Jahns et al.[8]; Thiagu et al.[19]; Varshany et al.[17].The second aspect is relationship between mechanical properties and injury of tomatoes (Desmet et al.[4] ; Devaux et al[6]; Linden et al.[11]; Zeebroeck, et al.[20]; Li et al.[10]. The tomato is a sensitive vegetable fruit that may be easily destroyed subjected to various forces in harvesting and handling. Lot of research and many development programs were focused on these aspects in developing countries, but very little attention was paid in India in spite of one fourth of produce being lost in different postharvest handling stages. Hence, any knowledge development in this area contributes in design and development of appropriate machines, improvements in existing devices and machines in harvesting, handling and preservation to avoid value degradation. So, the present study was taken up in order to investigate some important mechanical properties in relation with fruit size and maturity of tomato which play major role in harvesting and handling processes.

MATERIALS AND METHODS

The experiments were conducted in February, 2017 at Central Research Institute for Dryland Agriculture, Hyderabad. Tomato fruits of cultivar 'Hybrid Himsona 'transplanted in October,2016 in black cotton soil of Rakamcherla village was selected for the study. To carry the studies on mechanical parameters, three ripening stages of tomato fruits namely, stage 1 – green (S1), stage 3 – turning (S2) and stage 6 – red (S3) as specified by United States Department of Agriculture standards (USDA, 1991) and three different well defined physical size (fruit diameter) grades viz large (L - size range 50 – 65mm), medium (M- size range 40 – 47mm) and small(S- size range 30 – 37mm) were selected. Throughout the experiments, same set of persons were involved from tagging of fruits to conducting various tests, to avoid personal judgmental variations. In addition to this, each batch of different matured category of fruits were photographed using a digital camera, kept in a folder and compared with next batch of similar matured category to avoid any major variations in ripening colour differences.

Tomato picking force:

Since fruit maturity, size, pedicel size influences picking force in some fruits, an attempt was made in present study to measure these factors. The tomato fruits in the selected ripening stages and size grades were identified on the standing crop and tagged with numbers. The picking force was measured with a digital pull gauge (measuring range 0 – 150 N(Newtons) and sensitivity 0.1N).The individual fruit pedicle base was tied with one end of a non elastic cord and other end to the hook of pull gauge, slowly pulled at a constant rate by holding fruit bearing vine in one hand and the pull gauge handle in other hand until the fruit detached. The detached fruit surface was cleaned gently and diameter was measured at the equatorial region with dial type vernier caliper having sensitivity of 0.01mm. All the fruits picked in a particular trial were transported to the Farm machinery laboratory and further tests were conducted for other parameters as described below within 6 h at room temperature (20 ± 1º C ; RH 62 - 66%). In all, 15 fruits of each ripening and size category were studied for each selected parameter or a combination of parameters as is possible.

Coefficient of Friction:

The coefficients of static friction of fruits were measured with respect to galvanized steel surface by using an inclined plane fitted with angle scale. The fruit was placed on the positively driven surface and the plain raised gently with the fruit. The angle of inclination at which the tomato started sliding on the surface of plane was recorded. The Tangent of the angle was reported as the coefficient of friction[13]. In measuring coefficient of friction, the longitudinal axis of fruit was perpendicular to the slope.

$$\mu = \mathrm{Tan}\theta$$

Where μ is the coefficient of friction and θ is the tilt angle of the device.

Falling mass Impact and fruit firmness tests:

Texture is a collective term that encompasses the structural and mechanical properties of any food material. In fact, both fruit strength and breakdown characteristics are two important components of texture. Hence, it implies that fruits mechanical damage resistance can be measured by using controlled tests which measure pertinent mechanical properties. These include response to loading at different rates and fruit firmness (shear or failure stress). The maximum force generated during falling mass impact energy test and fruit firmness forces were determined using the test devices described by Anonymous (2013).The falling mass impact device consists of a stand made of flat metal, cylindrical free falling mass with guide rod and mechanical push – pull plunger gauge fitted with spring whose force calibrated and marked as linear scale on plunger rod (0 - 60 N), which traverses in plunger under falling mass impact. While in test, suitable thick packing plates are placed on the test stand base plate followed by push–pull gauge and test object to receive the impact energy force. In our tests, 500 gm falling mass and 20cm free fall height were found to be optimum for testing the selected tomato cultivar. The fruit firmness is defined as maximum force needed to penetrate the fruit in constant depth, which other way also called as fruit shear stress or failure stress. The fruit firmness test device consists of base stand which also resembles like falling mass impact test device stand, a low weight portable hydraulic jack fitted on the base plate of test stand to apply uniform quasi-static loading on fruits in testing, a self indicating penetrometer (S - 170 Model, CEP Services PTE Ltd, Singapore) equipped with a 6.36 mm diameter steel probe to record the fruit firmness in terms of force per unit area units. The object is placed in between the hydraulic jack elongated head and penetrometer steel probe while tests being conducted, loaded until the probe pierced into the fruit up to a depth of 10 mm. The tests for all parameters were conducted in five replicates. The data was analyzed for statistical significance by variance analysis in factorial design using drysoft software developed by CRIDA.

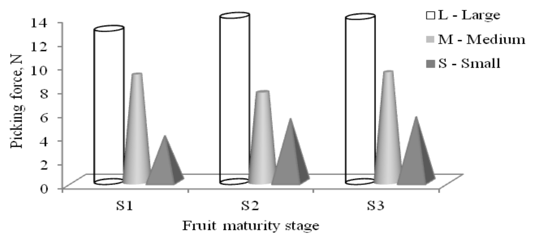
RESULTS AND DISCUSSION

Fruit bruising is one of the most important factor limiting mechanization and automation in harvesting, sorting and in transport of fruit and vegetables[3]. The three factors which can cause physically fruit bruising are impact, vibration and compression load. Hence, some of these effects were studied in the present experiments with pertinent measurable parameters. The fruit picking force in respect of fruit size and stage of maturity indicates that tomato fruit picking force very significantly influenced by size rather than fruit maturity stage (Table 1). Highest mean picking force of 13.60 Newton (N) was recorded in bigger fruits, 8.67 N in medium size and lowest force 4.90 N in smaller fruits selected in the present experiments. As the fruit size changed from small (35.21±2.15mm) to medium size (44.3± 2.07 mm) the picking force increased 76.9 % and medium size to larger (55.82 ± 5.09 mm), the same was increased by 56.8% (Fig.1). Over all, as the fruit size increased picking force increased in decreasing rate. The interaction effect of fruit size and maturity stage on fruit picking force was also found non significant. These results clearly indicates that for tomato cultivar ‘ Himsona ‘ the fruit size and maturity stage differ in measurable fruit picking / detachment force. It may be noted that, in this study we always applied the pulling force in the same direction in which the fruit pedicle is projected and the pedicle was intact with the fruit in more than 90% of the fruits picked. However, any deviation in pulling force application direction reduced the fruit detachment force in picking, leaving pedicle with the vines, which is out of boundary of present investigation. This may be true in other fruits and vegetables also. That is why, in some fruits and vegetables harvesting, the harvester apply twisting or bending force or a combination of forces to ease the operation and avoid mechanical damage to fruits in plucking.

Table 1: Influence of fruit size (FS) and maturity stage (MS) on picking force and Coefficient of friction

Picking force, Newton (N)		Coefficient of Friction	
Fruit Size	Maturity stage	Fruit Size	Maturity stage
L - 13.60	S1 - 8.63	L - 0.18	S1 - 0.17
M - 8.67	S2 - 8.93	M - 0.14	S2 - 0.15
S - 4.91	S3 - 9.57	S - 0.12	S3 - 0.12
F - test 43.57**	NS	F - test 19.04**	12.77**
SEm 0.933		SEm 0.009	0.009
LSD(P=0.05) 1.89		LSD(P=0.05) 0.019	0.019
FS X MS : NS		FS X MS : NS	

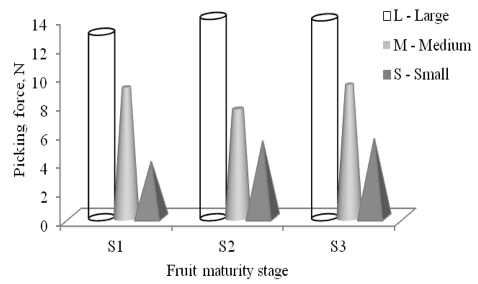
Fig. 1 Fruit size and maturity effect on picking force



The coefficient of static friction variation on a galvanized steel sheet metal with fruit size and stage of maturity is presented in Table 1. The two-factor analysis of variance showed that fruit size and maturity stage had a significant effect ($P \leq 0.05$) on the coefficient of static friction of tomato fruits according to the F test. However, the interaction effect of Fruit Size (FS) X Maturity Stage (MS) is non significant. The highest coefficient of friction 0.18 was recorded with larger size fruit and less matured fruit 0.17, whose means were ranged from

0.18 to 0.12 and 0.17 to 0.12 respectively. In larger fruits, higher coefficient of friction might have primarily resulted due to fact that the fruit surface area in contact with inclined plain is large because of higher curvature of fruit. As fruit maturity stage is concerned, in low stage matured fruits the undulation on fruit surface are more at locular portion which is in touch with measuring surface, the adhesion force between fruit samples and surface materials increase when using rough materials. Similar results were reported by Onder Kabas et al.[14] for pears. In addition to above factors, the differences in friction coefficients can also be attributed to little differences in shape, water content and firm texture of tomato fruits according to the observation found by Alayunt *et al*[1].The force produced between an object of a given mass and some standard varies with stiffness of the object. Generally a firmer object under test will produce a larger impact force. Therefore, the impact force measured may be taken as a measure of tomato stiffness under impact or high speed loading energy conditions. It is not yet reported in Indian conditions what forces and resultant stress, are required to cause bruising damage of the tomato under impact. The impact force under the falling mass drop test varied within the ranges of 35.11 – 37.30 N as the fruit size increased from smaller to larger and 36.23 – 36.60 N as the fruit maturity stage changed from green to full read. The effect of fruit size (FS) and interaction effect of fruit size and fruit maturity (FS X FM) on impact drop force were found to be significant with probability ≤ 0.05 (Table 2). Therefore, it is quite possible that smaller fruits may be damaged at lower impact force than the larger fruits. In the present study, an important result is that the drop impact force did not vary much with maturity. This degree of stiffness may be a desirable texture characteristic in damage resistance of red tomato of the cultivar under the present study. In Indian conditions, it is common practice that the tomato growers harvest the produce one or two days early than the fruit turned to full red to give leverage to transportation time, rather than harvest full red tomato and transport to avoid damage due impact forces. However, the effect of impact drop force factor need to be further investigated in details with major popular varieties of tomato that are grown in India to pass any concrete recommendations in tomato fruit harvesting and transportation practice. The study results on the fruit firmness (shear force or failure stress) are presented in Table 2 and Fig 2. A higher firmness or failure stress for any fruit means, that they are more resistant to mechanical damage or bruising. The observation show that the fruit firmness decreased as the fruit size decreased and maturity status increased. The decrease in fruit failure stress with increase in ripeness was highly significant (P ≤ 0.01).Whereas, effect of fruit size and interaction effect of fruit size and maturity were found to be non significant. The decrease in fruit firmness with fruit ripeness might have resulted due to changes in fruit texture, which occurs due to number of physical and chemical factors in the internal structure of fruits.

Fig. 1 Fruit size and maturity effect on picking force

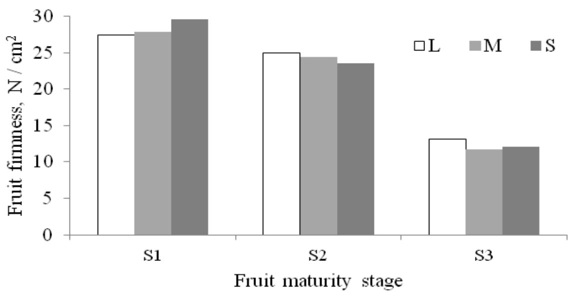


The maximum firmness 28.23 N/cm^2 recorded when fruits were green and minimum 12.32 N/cm^2 when the fruit turned in to full red ripening stage. The decrease in failure stress when the tomato fruit ripeness changed from green to turning, full red were in the order of 21.1 and 56.36% respectively. The strong reason for decrease in firmness with ripening progress in fruits could be due to internal textural changes. It was reported that loss of pectate from the middle lamellae is considered to cause softening of fruit as maturation progresses. Kattan[9] reported significant difference in firmness of fruits harvested green mature stage and fruits harvested at red stage and similar results were also reported from India[5]. Further investigations by selecting wide ripen stages of tomato lead to determine the best period of handling operation with minimal rejection of un-ripened fruits, where the lowest rate of mechanical damage could be obtained.

Table 2: Influence of fruit size (FS) and maturity stage (MS) on impact force and Fruit firmness

Impact force, N		Fruit firmness, N/cm^2	
Fruit Size	Maturity stage	Fruit Size	Maturity stage
L - 37.30	S1 - 36.23	L - 22.79	S1 - 28.23
M - 36.76	S2 - 36.60	M - 21.32	S2 - 24.27
S - 35.11	S3 - 36.34	S - 20.73	S3 - 12.32
F - test : 5.32*	NS	F -test : NS	78.63**
SEm 0.70			SEm 1.32
LSD(P =0.05) 1.42			LSD(P=0.05) 2.68
FS X MS		FSXMS : NS	
F - test : 3.46*			
SEm 1.21			
LSD(P=0.05) 2.47			

Fig. 2 Effect of fruit size and maturity on firmness



CONCLUSIONS

The losses in fruits and vegetables in various crop production and postharvest operations remained high in India. The tomato is most commonly grown vegetable crop whose fruit quality reduces substantially due to bruise damage encountered by various types of mechanical forces in handling and other postharvest operations. In this study tomato fruits mechanical properties were determined with relevant measurable units which play key role in fruits bruising which ultimately cause undesirable changes in quality and marketability. The following conclusions can be drawn from the study carried with " Himsona" variety of tomatoes. The fruit picking force reduced with respect to fruit size for this variety and fruit maturity showed no influence at all. Higher hardness values also recorded at larger fruit sizes with drop impact energy tests showing more resilience to fracture damage than smaller ones. The low stage ripened fruits though most vulnerable to marketable losses, in terms of firmness quality they stand ahead of the ripened ones (higher percentage loss of firmness) when faced with identical shear failure mechanical forces. These similar behavior trends can be expected from tomatoes in transportation, handling and postharvest processes.

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