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Morphological-Mechanical Proprieties of Five Different Tomato Varieties in Kingdom of Saudi Arabia for High Techniques in Harvesting, Handling and Manufacturing

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ABSTRACT

Physical characteristics of five different varieties of tomato fruits were studied in order to improve design, fabricate and control tomato harvesting. The selected morphological and mechanical properties such as diameters, sphericity, surface area, volume, mass, densities, porosity, projected area and coefficient of frictions. Results showed moisture, length, width, thickness, mass, geometric mean diameter, arithmetic mean diameter, square mean diameter, equivalent mean diameter, aspect ratio, actual volume, ellipsoid volume, prolate spheroid volume, surface area, sphericity, packaging coefficient, true density, bulk density, density ratio, porosity had significant effect (P<0.05). On the other hand, results showed criteria projected area and dynamic coefficient of friction had no significant effect (P<0.05). These varieties have considerable number of attributes that required to be processed by food industries, hence and breeders for cultivation. In the current study, researchers investigated the mentioned attributes of tomatoes and then establishing a convenient reference table for tomato mechanization and processing.

دراسة بعض الخصائص الشكلية و الفزيائية لخمسة اصناف من الطماطم فى المملكة العربية السعودية لزيادة تقنيات القطف، التداول و التصنيع

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الكلمات المفتاحية:
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الخلاصة

تم دراسة الخصائص الفيزيائية للخمسة أصناف مختلفة من ثمار الطماطم من أجل تحسين عمليات التحكم فى تصميم الميكنات لصناعة و حصاد الطماطم. الخصائص المورفولوجية والميكانيكية المختارة تشمل الاقطار، الكروية، مساحة السطح، الحجم، الكتلة، الكثافة، المسامية، المساحة المسقطة ومعاملات الاحتكاك. وأظهرت النتائج ان الرطوبة، الطول، العرض، السمك، الاقطار الهندسية المتعددة، الابعاد المتزنة، الاحجام المختلفة، المساحة السطحية، معامل التعبئة والتغليف، الاحجام المختلفة و الكروية لهم معامل تاثير معنوى (P<0.05). من ناحية أخرى، أظهرت النتائج ان حساب المساحة المسقطة و المعامل الديناميكي للاحتكاك ليس لهما أي تأثير معنوى (P<0.05). هذه الأصناف اعطت العديد من السمات الهامة و المطلوبة فى مجال الزراعة و الصناعات الغذائية. تم التحقق من النتائج وجدولتها لاستخدامها فى مجال الميكنة والتصنيع لثمار الطماطم.

INTRODUCTION

Fruits and vegetables play a significant role in human nutrition. Among vegetables, tomato (*Solanum lycopersicum*) is the most important both for its large consumption and for its richness in health-related food components; it is an important source of antioxidants such as lycopene, phenolics, and vitamin C in human diet (Shao et al., 2015). Recent epidemiological studies have also shown a high correlation between lycopene consumption from tomato and protective effects against various forms of cancer, especially prostate cancer and cardiovascular diseases (Joaquina et al., 2013). Tomato fruit consists of water, soluble and insoluble solids. Soluble solids are mainly consist of sugars (sucrose and fructose) and salts. Solid tomatoes are very valuable at the factory processing (Beckles, 2011). Total dry matter content in different tomato cultivars varies from 4% to 7.5% of fruit fresh mass. Soluble solids account for 75% of the total solids and are comprised primarily of the reducing sugars, which represent 55–65% of the total soluble solids content (Audrius et al., 2016).

Tomatoes are grown extensively for fresh consumption and commercial processing use for making soups, juice, tomato powder, pickles, tomato flakes, chips, ketchup, puree, sauce, paste, etc (Manashi and Charu, 2011). They are highly perishable and large quantities of tomato fruits go as a waste due to poor storage facilities. Tomato is a climacteric and a very perishable fruit that requires the use of preservation technologies, to slow the ripening process that occurs after harvest, to maintain its quality and consequently extend produce postharvest life. The quality of fresh tomatoes is mainly determined by appearance (colour, visual aspects, size, and shape), firmness, flavor and nutritive value (Joaquina et al., 2013). Moreover, fresh fruit is not available in all parts of the country throughout the year at uniform price. Besides, consumers prefer bright colored vegetables with even weight and uniform shape. Mass grading of vegetables and fruits can reduce packaging and transportation costs, and also may provide an optimum packaging configuration (Peleg, 1985).

The processing industries demand solid specifications from its providers which affect the demanded quality. Since most quality factors are related to physicochemical properties, it is possible to develop quality evaluation methods based on these properties, in most of the cases. Data of different tomato variety properties are extremely valuable to the industry processing as a tool for choosing the better cultivars to each different tomato product it intends to produce. The most important factor affecting the quality of processed tomato products are tomato maturity, growing location and climate and processing conditions. These growing market opportunities have, however, necessitated that tomatoes be accessible in a more convenient format and thus, led to the development of technologies for the preservation and sale of the product especially in a dry format. The design of appropriate product, its quality and associated machinery for mechanizing the processing of tomato, requires knowledge of the physical and chemical properties of the fruits (Manashi, 2011).

The physical properties of tomato are important to design the equipment for processing, transportation, sorting, separation and storing. Designing such equipment without consideration of these properties may yield poor results. Therefore, the determination and consideration of these properties have an important role. Mass, volume, surface area, dimensions, geometric mean diameter, packaging coefficient, porosity, sphericity, static and dynamic frictions were measured through the experiment (Taheri-Garavand et al., 2009). Topuz et al. (2005) studied some physical properties such as dimension, volume, weight, surface picture, coefficient of friction, porosity, mass and fruit density. Among these physical characteristics, mass, volume, projected area were the most important factors in determining sizing systems (Mirzaee et al., 2009). Tabatabaeefar and Rajabipour (2005) recommended 11 models for predicting mass based on geometrical attributes. Several models for predicting mass were determined and reported by Lorestani and Tabatabaeefar (2006). Also, Khoshnam et al. (2007) used this method for predicting the mass of fruits. They suggested that there is a very good relationship between mass and measured volume for all varieties. Ebrahimi et al. (2009) studied morphological and physical characteristics and mass modeling. Moreover, they reported that among grading system based on dimensions, minor diameter model with nonlinear relation was the best and could be considered as a good model for economical and horticultural designing systems. Ismaill et al. (2016) studied the effect of vegetable proteins on physical characteristics of spray-dried tomato powders. In addition, there were several studies conducted on tomato varieties in different countries like India (Manashi and Charu, 2011), China (Zhiguo et al., 2011), Spain (Arazuri et al., 2007), Iran (Amin et al., 2011), Portugal (Joaquina et al., 2013), Australia (Liu et al., 2009), Italy (Alessandra et al., 2010; Antonella et al., 2013) and Argentine (Carlos and Norberto, 2016).

The present investigation was carried out to study the morphological and mechanical characteristics of five tomato varieties. This information provides useful insights into design of harvesting, processing, sorting, separating and packing equipments for tomato.

MATERIAL AND METHODS

Sample Preparation

In this study, the 20 fruits of each variety (Yellow Cherry, Red Cherry, Beefsteak, Eva Purple Ball and Cherokee Purple), respectively were randomly obtained from a local market in Taif, Kingdom of Saudi Arabia. The tomatoes were transferred to the Physical Laboratory of Nutrition and Food Science Department in Taif University, Kingdom of Saudi Arabia for experiments.

Determination of morphological properties

The moisture contents (M_c) of tomatoes were determined using the oven dry method, at 77°C for 4 days (Kheiralipour et al., 2008). The length (L), width (W) and thickness (T) were measured by a dial-micrometer to an accuracy of 0.01 mm (Lazaro et al., 2005). Tomato mass (M) was determined through a digitalized sensitive balance with a capacity of 0-1200 g and an accuracy of ± 0.01 g. Geometric mean diameter (D_g), arithmetic mean diameter (D_a), square mean diameter (D_s), equivalent diameter (D_e) and aspect ratio (S_p) were calculated (Shahbazi, 2011).

The actual volume (V_m) is the volume of water displaced by one tomato fruit, was calculated from the relationship (Amin et al., 2011) then the shape was assumed as a regularly geometrical shape, i.e. prolate spheroid (V_{psp}) and ellipsoid (V_{ell}) shapes and thus their volumes were calculated by the following relationships:

$$V_m = \frac{w}{\gamma} \quad [1]$$

$$V_{psp} = \frac{4\pi}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)^2 \quad [2]$$

$$V_{ell} = \frac{4\pi}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)\left(\frac{T}{2}\right) \quad [3]$$

where *w* is the weight of the displaced water, γ is weight density of water, L is length, W is width, and T is thickness.

Surface area (S) and sphericity (φ) have been calculated using the following equations (Athollahzadeh et al., 2008):

$$S = \pi D_g^2 \quad [4]$$

$$\varphi = \frac{D_g}{L} \quad [5]$$

where D_g is geometric mean diameter.

Packing coefficient was defined by the ratio of the volume of tomato packed to the total and calculated by the following formula (Topuz et al., 2005).

$$\lambda = \frac{V}{V_o} \quad [6]$$

where V is true bulk of tomatoes and V_o is bulk of the box.

The true density of samples was calculated as follows:

$$\rho_t = \frac{M}{V_m} \quad [7]$$

where M is the mass of one tomato and the V_m is the actual volume of the tomato fruit.

Bulk density was obtained (Caparino et al., 2012) as:

$$\rho_b = \frac{M_b}{V_b} \quad [8]$$

where M_b is tomato mass, V_b is tomatoes box volume

Also, the density ratio ρ_r is the ratio of true density to bulk density expressed as percentage and percentage of porosity (Jain and Bal, 1997).

The porosity (P) was determined by the following equation:

$$P = \left[1 - \frac{\rho_b}{\rho_t}\right] X100 \quad [9]$$

where ρ_t is the true density and ρ_b is the bulk density.

Determination of mechanical properties

Projected areas (PAL, PAW and PAT) in three perpendicular directions of the tomato were measured from pictures taken by a digital camera (Canon SX 210-IS, 14 Mpixels), and then comparing the reference area to a sample area, by using the Image Tool for Windows (version 7.00) program, then criteria projected area (CPA) was defined as follow:

$$CPA = \frac{PAL + PAW + PAT}{3} \quad [10]$$

where PAL, PAW and PAT is the projected areas perpendicular to length, width and thickness of tomato fruit, respectively.

The static and dynamic coefficients of friction of tomato were measured using a friction device. The coefficients of friction were determined for four different structural materials namely, steel, iron, glass and plastic. The angle tilt was read from a graduated scale as suggested by Izli el al. (2009). The static and dynamic coefficients of friction were calculated using the following equations (Youssef et al., 2007):

$$\mu_s = \tan(\theta) \quad [11]$$

$$\mu_d = \frac{F_d}{N} \quad [12]$$

where μ_s is the static coefficient of friction and θ is the tilt angle of the friction device and μ_k is the apparent dynamic coefficient of friction, F_d is the measured friction force and N is the normal force.

Statistical analysis

Data from replications of all varieties were subjected to a variance analysis (ANOVA) using SPSS 16.0 for Windows. Significant difference between the means was determined by Duncan's New Multiple Range Test ($p < 0.05$). The correlation between all studied parameters was determined by the principal compounds analysis (PCA) using XLSTAT software.

RESULTS AND DISCUSSION

Physical properties of the tested tomato fruits

The physical properties of five tomato varieties are presented in (Table 1). Among the five varieties, fresh Beefsteak had the highest moisture content of 98.04 %. This can be attributed to different water uptake capacity, texture, composition of the varieties and blanching time (Manashi and Charu, 2011). The moisture content of these tomatos was closed to the values reported by Aditi et al. (2011). The moisture content is very important because it is strongly correlated with the stability of ascorbic acid and pigment as well as any hygiene problems (Kim et al., 1982). Beefsteak produced the longest length, width and thickness 67.07, 76.07 and 75.32 mm, respectively. Manashi and Charu (2011) studied on five different common commercial varieties of Indian grown tomatoes (cv. Sel-2, Sel-3, Solam Garima, VR-415 and Pau-2374). They concluded (40.19-57.60 mm) as the mean fruit length and thickness (40.75-47.15 mm), respectively. The importance of dimensions is in determining the aperture size of machines, particularly in separation of materials (Topuz, et al., 2005). The Beefsteak variety had higher weight than the others followed by the Cherokee Purple variety. Weight results in comparison with studies of Amin et al. (2011) showed that was lower than Beefsteak variety (111.63 g) and Yellow Cherry had the lowest fruit weight. The highest fruit-yielding cultivar would be of great interest to tomato growers (Ahmed and Shivhare, 2001).

The geometric mean diameter for the five tomato varieties were obtained 26.89, 24.29, 72.28, 35.07, 36.85 mm for Yellow Cherry, Red Cherry Bell, Beefsteak, Eva Purple Ball and Cherokee Purple, respectively. Against Amin et al. (2011) results, geometric mean diameter recorded (54.83 mm). It was observed that an increase in size leads to an increase in the geometric mean diameter.

The arithmetic (D_a), square (D_s) and equivalent (D_e) mean diameter of tomatoes were resulted in different means as 27.29, 9, 21.06 mm for Yellow Cherry, 24.74, 8.42, 19.15 mm for Red Cherry, 72.82, 17.36, 54.16 mm for Beefsteak, 35.42, 10.73, 27.07 mm for Eva Purple Ball and 37.21, 11.09, 28.38 mm for Cherokee Purple tomato variety, respectively. The aspect ratio (S_p) of the tomato varieties was found to be statistically different.

Beefsteak tomato had the highest values for actual, prolate spheroid and ellipsoid volume, while Red Cherry tomato had the smallest. The mean surface area was resulted 22.81, 18.68, 164.61, 38.83 and 42.71 cm^2 for tomato varieties, respectively. Sphericity of tomato varieties was 0.82, 0.78, 1.08, 0.87 and 0.87 for Yellow Cherry, Red Cherry, Beefsteak, Eva Purple Ball and Cherokee Purple, respectively. It can be seen that the surface area and sphericity values were similar (Zhiguo et al., 2011). The high sphericity of the tomato is indicative of the tendency of the shape towards a sphere. Taken along with the high aspect ratio of 114.33, it may be indicated that the tomato will rather roll than slide on a flat surface. However, the aspect ratio value is being close to the sphericity values may also mean the tomato will undergo a combination of rolling and sliding action on a flat surface (Abbas et al., 2010). The packaging coefficient recorded the highest value 0.88 for Red Cherry variety and the lowest value 0.60 for Cherokee Purple variety.

The relationships between length, width, thickness and mass are determined by the following relations:

For Yellow Cherry variety:	L = 1.34X W = 1.36X T = 3.07X M
For Red Cherry variety:	L = 1.45X W = 1.43X T = 3.12X M
For Beefsteak variety:	L = 0.89X W = 0.90X T = 0.31X M
For Eva Purple Ball variety:	L = 1.21X W = 1.26X T = 1.68X M
For Cherokee Purple variety:	L = 1.22X W = 1.25X T = 1.47X M

The highest true and bulk densities were obtained 896.09 and 478.74 kg/m^3 for Beefsteak and Yellow Cherry variety, respectively (Table 2). The results were in agreement with (Amin et al., 2011; Zhiguo et al., 2011). Quality of food materials can be assessed by measuring their densities. Density data of foods are required in separation processes, such as centrifugation and sedimentation and in pneumatic and hydraulic transport of powders and particulates (Abbas et al., 2010). The highest value of the density ratio was for Yellow Cherry variety 80.14 and the lowest was for Beefsteak variety 38.57. Porosity of Yellow Cherry and Beefsteak was 19.86 % and 60.75 %, respectively. The porosity recorded (4.78-11.50 kg/m^3) in the previous study (Zhiguo et al., 2011).

The mechanical properties of the tested tomato fruits

The mean projected areas perpendicular to length, width and thickness were obtained as 5.49, 7.22 and 6.74 mm^2 for Yellow Cherry, 4.56, 6.98 and 6.78 mm^2 for Red Cherry, 59.15, 61.72 and 62.11 mm^2 for Beefsteak, 9.70, 11.76, 61.72 and 11.99 mm^2 for Eva Purple Ball and 10.78, 13.11, 13.26 mm^2 for Cherokee Purple variety, respectively (Table 3). It was obtained that criteria projected areas perpendicular to each three orientation for Beefsteak variety was the greatest 60.99 cm^2 and Red Cherry variety was the lowest 6.11 cm^2. The highest coefficient of static friction was obtained on iron as 0.21 for Yellow Cherry, 0.11 for Red Cherry, 0.21 for Beefsteak, 0.10 for Eva

Purple Ball and 0.12 for Cherokee Purple followed by steel (0.09-0.17), plastic (0.06-0.17) and glass (0.07-0.16).

There was a significant difference in the coefficient of friction on all surfaces. This is due to the frictional properties between the fruits and surface materials. The highest coefficient of dynamic friction was obtained on plastic as 0.97 for Yellow Cherry, 0.86 for Red Cherry, 0.89 for Beefsteak, 0.89 for Eva Purple Ball and 0.66 for Cherokee Purple followed by steel (0.83-0.93), iron (0.79-0.93) and glass (0.66-0.93). These physical results should be considered in the harvesting, handling and processing of early maturated tomato varieties.

Principal component analysis

Morphological and mechanical parameters of tomato fruits had been submitted to Principal Component Analysis (PCA) to presence of five varieties of tomatoes. From this analysis, the following axes of inertia had been withheld, as seen in (Table 4). The structuring accessions showed 88.47 % of total variation. Axes were retained because they expressed 75.92 % (axes 1), 12.56 % (axes 2). Axes 2 was made positively by project area perpendicular to length, packing coefficient, criteria projected area, static coefficient of friction on glass and dynamic coefficient of friction on (steel, glass and plastic).

Data projection on plans as defined by inertia axes of PCA from tomato samples showed significant differences between the varieties (Fig. 1). In fact, when applying principal component analysis it seemed that there was a discriminate structure. Eva Purple Ball and Cherokee Purple were grouped together. Yellow and Red Cherry were grouped together. As for Beefsteak was individualized. It indicated that tomatoes of Purple Ball and Cherokee Purple were a spherical in shape. On the other hand, the shape of Yellow and Red Cherry can be regarded as an oval.

CONCLUTION

How to prevent mechanical damage of tomato fruit and provide useful insight into designing of sizing machine and reducing the packaging and transportation costs can be a subject of interest to agricultural scientist for farm machinery engineers. In this research, several physical and mechanical properties of tomato fruits were determined. The results can be summarized as follows:

- The structural properties of tomato fruits ranged in between (82.84-98.04 %) for moisture, (30.94-67.07 mm) for length, (21.49-76.07 mm) for width, (21.80-75.32 mm) for thickness, (11.06-220.41 mm) for mass, (24.29-72.28 mm) for geometric mean diameter, (24.74-72.82 mm) for arithmetic mean diameter, (8.42-17.36 mm) for square mean diameter, (19.15-54.16 mm) for equivalent mean diameter, (69.33-114.33) for aspect ratio, (19.58-248.58 cm^2) for actual volume, (7.77-202.22 cm^2) for ellipsoid volume, (7.65-203.79 cm^2) for prolate spheroid volume, (18.68-164.61 cm^2) for surface area, (0.78-1.08) for sphericity, (0.60-0.88) for packaging coefficient, (557.91-896.09) for true density, (347.26-478.74 kg/cm^3) for bulk density, (38.57-80.14 kg/cm^3) for density ratio, (19.86-60.75 %) for porosity and (6.11-60.99 cm^2) for criteria projected area.
- The highest coefficient of static friction was obtained on iron (0.10-0.21) followed by steel (0.09-0.17), plastic (0.06-0.17) and glass (0.07-0.16).
- The highest coefficient of dynamic friction was obtained on plastic (0.66-0.97) followed by steel (0.83-0.93), iron (0.79-0.93) and glass (0.66-0.93).

The measured data can be used to design equipment for harvesting, transporting, sorting, sizing and processing machines.

Table 1. Some morphological properties of tomato varieties

Varieties	Yellow Cherry	Red Cherry	Beefsteak	Eva Purple Ball	Cherokee Purple
M_c	92.96±0.27 ^{a}	93.30±0.28 ^{a}	98.04±4.47 ^{a}	82.84±16.56 ^{b}	94.57±0.14 ^{a}
L	32.91±4.01 ^{c}	30.94±2.11 ^{c}	67.07±6.28 ^{a}	40.40±3.38 ^{b}	42.56±4.69 ^{b}
W	24.59±2.05 ^{c}	21.49±2.62 ^{c}	76.07±5.13 ^{a}	33.83±5.03 ^{b}	34.92±0.94 ^{b}
T	24.36±2.11 ^{c}	21.80±2.79 ^{c}	75.32±7.30 ^{a}	32.02±1.61 ^{b}	34.15±0.88 ^{b}
m	11.06±2.64 ^{c}	12.44±7.69 ^{bc}	220.41±28.23 ^{a}	24.32±4.04 ^{bc}	28.98±1.56 ^{b}
V_m	19.58±6.17 ^{c}	19.58±5.47 ^{c}	248.58±35.12 ^{a}	45.20±12.78	42.18±12.35
V_{ell}	10.42±2.36 ^{b}	7.77±2.46 ^{b}	202.22±37.79 ^{a}	23.20±5.91 ^{b}	26.61±3.56 ^{b}
V_{psp}	10.53±2.39 ^{b}	7.65±2.38 ^{b}	203.79±32.81 ^{a}	24.88±9.17 ^{b}	27.27±4.10 ^{b}
S_p	0.75±0.09 ^{bc}	0.69±0.05 ^{c}	1.14±0.14 ^{a}	0.84±0.11 ^{b}	0.83±0.08 ^{b}
D_a	27.29±2.14 ^{c}	24.74±2.40 ^{c}	72.82±4.64 ^{a}	35.42±2.92 ^{b}	37.21±1.84 ^{b}
D_s	9.00±0.47 ^{c}	8.42±0.56 ^{c}	17.36±0.74 ^{a}	10.73±0.58 ^{b}	11.09±0.36 ^{b}
D_g	26.89±2.06 ^{c}	24.29±2.48 ^{c}	72.28±4.59 ^{a}	35.07±2.86 ^{b}	36.85±1.70 ^{b}
D_e	21.06±1.55 ^{c}	19.15±1.81 ^{c}	54.16±3.32 ^{a}	27.07±2.12 ^{b}	28.38±1.30 ^{b}
S	22.81±3.47 ^{a}	18.68±3.88 ^{c}	164.61±20.72 ^{c}	38.83±6.46 ^{a}	42.71±3.88 ^{b}
φ	0.82±0.06 ^{bc}	0.78±0.04 ^{c}	1.08±0.08 ^{a}	0.87±0.05 ^{b}	0.87±0.06 ^{b}
λ	0.88±0.04 ^{a}	0.88±0.19 ^{a}	0.67±0.20 ^{b}	0.66±0.06 ^{b}	0.60±0.06 ^{b}
L/W	1.34±0.18 ^{ab}	1.45±0.11 ^{a}	0.89±0.11 ^{c}	1.21±0.13 ^{b}	1.22±0.11 ^{b}
L/T	1.36±0.18 ^{ab}	1.43±0.12 ^{a}	0.90±0.10 ^{c}	1.26±0.09 ^{b}	1.25±0.14 ^{b}
L/M	3.07±0.53 ^{a}	3.12±1.31 ^{a}	0.31±0.04 ^{c}	1.68±0.15 ^{b}	1.47±0.15 ^{b}
L/D_g	1.22±0.11 ^{ab}	1.28±0.07 ^{a}	0.93±0.07 ^{c}	1.15±0.06 ^{b}	1.15±0.08 ^{b}
L/φ	40.54±8.33 ^{bc}	39.49±2.51 ^{c}	62.51±9.51 ^{a}	46.67±5.61 ^{bc}	49.34±8.52 ^{b}

Each value presented as the mean ± standard deviation (n=20). Data with different uppercase superscript letters in the same column of variety respectively indicate significant difference ($P<0.05$) analyzed by Duncan's multiple range test.

Table 2. Volume and density properties

Varieties	Yellow Cherry	Red Cherry	Beefsteak	Eva Purple Ball	Cherokee Purple
ρ_t	616.51±138.73 ^{bc}	562.88±61.15 ^{c}	896.09±131.50 ^{a}	557.91±95.41 ^{c}	731.20±187.16 ^{b}
ρ_b	478.74±22.66 ^{a}	436.35±24.43 ^{b}	347.26±20.44 ^{d}	410.69±23.41 ^{bc}	382.84±43.84 ^{c}
ρ_b/ρ_t	80.14±13.89 ^{a}	78.12±7.55 ^{a}	38.57±4.41 ^{c}	75.20±11.98 ^{a}	54.63±11.69 ^{b}
P	19.86±13.89 ^{c}	21.88±7.55 ^{c}	60.75±4.29 ^{a}	24.80±11.98 ^{c}	45.37±11.69 ^{b}

Each value presented as the mean ± standard deviation (n=20). Data with different uppercase superscript letters in the same column of variety respectively indicate significant difference ($P<0.05$) analyzed by Duncan's multiple range test.

Table 3. Project area and friction properties

Varieties	Yellow Cherry	Red Cherry	Beefsteak	Eva Purple Ball	Cherokee Purple
PAL	5.49±0.93 [a]	4.56±1.08 [a]	59.15±8.67 [a]	9.70±1.72 [a]	10.78±0.84 [a]
PAW	7.22±1.38 [c]	6.98±1.78 [c]	61.72±8.86 [a]	11.76±2.00 [bc]	13.11±0.93 [b]
PAT	6.74±0.90 [c]	6.78±1.24 [c]	62.11±8.74 [a]	11.99±1.95 [b]	13.26±0.74 [b]
CAP	6.49±0.91 [ab]	6.11±1.33 [b]	60.99±8.69 [a]	11.15±1.88 [ab]	12.38±0.79 [ab]
Static coefficient of friction, μ_s					
Steel	0.12±0.04 [ab]	0.13±0.03 [ab]	0.17±0.05 [a]	0.09±0.01 [b]	0.13±0.03 [ab]
Iron	0.10±0.03 [b]	0.11±0.03 [b]	0.21±0.05 [a]	0.10±0.03 [b]	0.12±0.04 [b]
Glass	0.14±0.04 [ab]	0.11±0.03 [b]	0.16±0.03 [a]	0.07±0.02 [c]	0.11±0.03 [b]
Plastic	0.10±0.02 [bc]	0.10±0.02 [b]	0.17±0.05 [a]	0.06±0.02 [c]	0.10±0.04 [b]
Dynamic coefficient of friction, μ_d					
Steel	0.93±0.08 [a]	0.83±0.10 [a]	0.83±0.12 [a]	0.87±0.08 [a]	0.84±0.19 [a]
Iron	0.87±0.17 [a]	0.93±0.11 [a]	0.79±0.15 [a]	0.83±0.07 [a]	0.80±0.21 [a]
Glass	0.87±0.14 [a]	0.89±0.08 [a]	0.93±0.43 [a]	0.92±0.26 [a]	0.66±0.10 [a]
Plastic	0.97±0.25 [a]	0.86±0.22 [ab]	0.89±0.22 [ab]	0.89±0.19 [ab]	0.66±0.12 [b]

Each value presented as the mean ± standard deviation (n=20). Data with different uppercase superscript letters in the same column of variety respectively indicate significant difference (P<0.05) analyzed by Duncan's multiple range test.

Table 4. Discriminate variables factors of principal components analysis based on morphological and mechanical properties

	F1	F2		F1	F2
Proper value	28.09	4.65	L/T	-3.47	-
Variability (%)	75.92	12.56	L/M	-	+3.16
Cumulative %	75.92	88.47	L/D_g	-3.41	-
M_c	-	+1.84	L/φ	+3.42	-
L	+3.51	-	ρ_t	+3.19	-
W	+3.52	-	ρ_b	-	+5.92
T	+3.53	-	ρ_r	-3.11	-
M	+3.41	-	P	+3.11	-
D_a	+3.53	-	PAL	-	+15.16
D_s	+3.51	-	PAW	+3.45	-
D_g	+3.53	-	PAT	+3.46	-
D_e	+3.53	-	CAP	-	+8.81
S_p	+3.44	-	S steel	+2.22	-
V_m	+3.43	-	S iron	+3.38	-
V_{ell}	+3.43	-	S glass	-	+8.40
V_{psp}	+3.43	-	S plastic	+2.48	-
S	+3.50	-	K steel	-	+6.63
φ	+3.48	-	K iron	-	+3.21
λ	-	+13.22	K glass	-	+7.53
L/W	-3.28	-	K plastic	-	+15.47

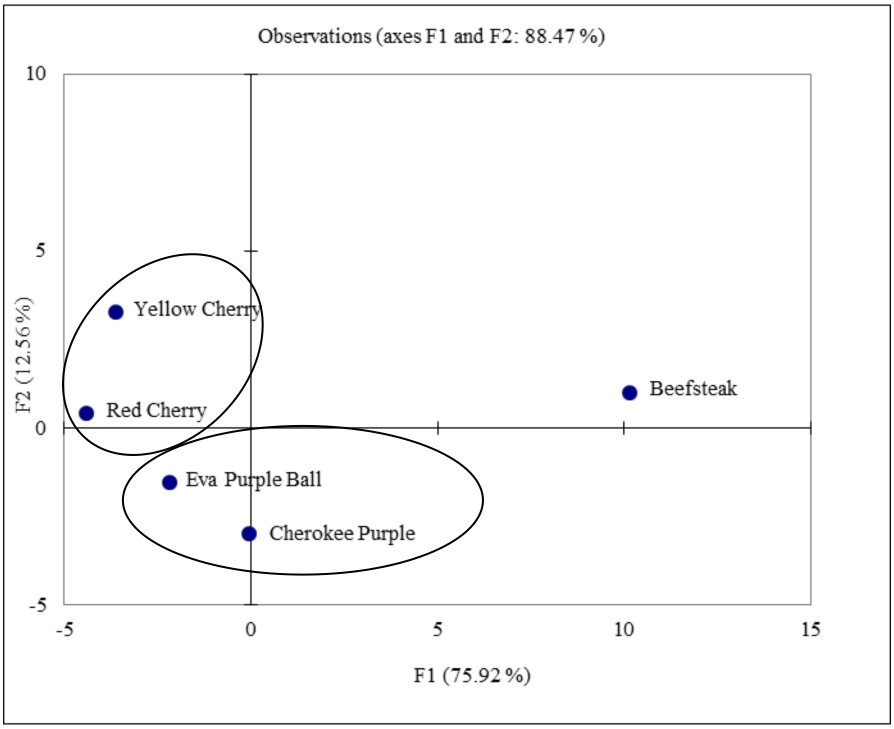

Figure 1. Principal component analysis; Dispersion of tomato varieties formed by F1 and F2 of the PCA

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