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PHYSICAL AND MECHANICAL PROPERTIES OF "MINNEOLA" FRUITS AND APPLICATION TO JUICING DEVICE

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Abstract

The aim of this research is to study some physical and mechanical properties of Minneola. Minneola is a citrus fruit that originated from cross of Duncan grapefruit and Dancy tangerine. Physical and mechanical properties of Minneola are very important for design of handling machines. For example, the volume and diameter of fruit are used in the design of running and holding parts in juice extracting machines. Fruit mass and juice ratio are used to compute extracting rates; and friction and rolling angles are used to design handling machines (calculation of slope angles and volume capacity), etc.

The main results in this study can be summarized in the following points:

Physical properties of Minneola fruits: diameter = 62 - 89 mm, height = 68 - 104 mm, mass = 201 - 345 g, volume = 120 - 342 cm^3, projected area = 54 - 108 cm^2, peel thickness = 3 - 5 mm, peel mass = 52 - 73 g, number of segments/fruit = 9 - 12, number of seeds/fruit = 2 - 8, juice volume/fruit = 96 - 168 cm^3, and juice volume/fruit mass = 0.41 - 0.59 L/kg.

Mechanical properties of Minneola: The maximum firmness was 22 N/cm^2 at 30 - 45 mm along fruit and the minimum was N/cm^2 at the fruit bottom. The deformation range increased from 2.75 - 3.09 to 8.52 - 10.02 mm by loading from 1 to 5 kg. Meanwhile, the deformation range increased from 2.75 - 8.52 to 3.09 - 10.02 by increasing loading time from 15 to 60 s.

Some application to processing machine is given also in the paper as a case study.

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1. Introduction

Citrus are the major horticultural crops in Egypt. The cultivated area of citrus is 346.24 thousand feddans in 2002. The areas of orange, tangerine and lemon are about 210, 94 and 38 thousand feddans respectively. The total production of citrus in Egypt is about 2.8 million ton in 2002. The productions of orange, tangerine and lemon are about 181, 602 and 334 thousand tons respectively. Egypt citrus exports quantity increased from 195 to 416 thousand tons which gave 53.6 to 99.8 million U. S. $ from 2000 to 2003 (H. R. I., 2004).

Minneola is a citrus fruit that originated in 1931 from cross of Duncan grapefruit and Dancy tangerine by USDA in Florida. The Minneola is large in size. The fruit shape is essentially round, with a pronounced and distinctive neck, which leads to its immediate recognition by consumers. The rind has not only exceptional color, being reddish-orange, but also has a particularly fine, smooth texture. Mature Minneola may feel slightly soft, giving the puffy impression, somewhat overmature and wilted; which is not often the case. The peel is thin in relation to fruit size, and is not difficult to remove since it is only moderately tightly adhering. However, care is needed during peeling to avoid puncturing the extremely delicate segment walls. Minneolas have a unique, delicious and distinctive flavor, bieng rich, tart and aromatic. Minneola fruit has a few seeds and low sugar content, which favours diabetic persons (Saunt, 1990).

Agamia et al. (1982) reported that the average mass of fruit ranges from about 95 to 140 g, the fruit volume from 100 to 154 cm^3 and the diameter from 4 to 6.5 cm for Nareng, Clementine, Satsuma, Cleopatra, Mallawi and Baladi Mandarins.

Sharawy (1992) found that the number of segements per fruit was about 10 - 11 for Baladi orange, 12 - 13 for Ruby Red grapefruit and 10 - 11 for Baladi mandarin.

Kinawy (1995) found that the average peel thickness, number of segments per fruit, number of seeds per fruit, mass of 100 seeds, and juice percentage were 3.2 mm, 11, 17.9, 12.5 g and41.5 % respectively for Baladi mandarin; and were 3.9 mm, 10.3, 11, 12.8 g and 34.2 % respectively for Ponkan tangerine.

Bello et al. (1989) found that juice percentages were 48.85 and 43.57 for clementine and Dancy respectively.

Mousa (1998) found that the mean values of diameter ranged from about 69 to 84 mm; height ranged from about 57 to 87 mm; mass ranged from about 160 to 208 g; volume ranged from 188 to 241 mm for Navel, Baladi, Acidless and Valencia orange varieties. The height values limited the distance between grading lines and shape and size of the distributed buckets on the conveyor belt. According to that, the bucket design was: length of 650 mm and diameter of 100 mm more than the biggest height of orange fruits.

Yehia (2001) found that the ranges of peel thickness, number of segments and bulk density were 3.21 - 3.5 mm, 10 - 12 and 440 - 450 kg/m^3 respectively for Baladi orange. The average friction angles were 12.68, 12.9, 12.73, 12.84 for non-galvanized, galvanized, aluminum and stainless steal respectively for Baladi orange. The physical and mechanical properties were incorporated in the design of the feeding mechanism (fruit dimensions, bulk density and friction and rolling angles), orange tube (fruit dimensions), holding mechanism (fruit dimensions and peel thickness) and press mechanism (fruit dimensions and peel thickness) of the designed automatic-juicer.

The objective of this present research is to study some physical and mechanical properties of Minneola, as promising fruits, to help the design of handling machines. The physical and mechanical properties are incorporated in the design of the feeding mechanism, chute tube, holding and press mechanisms of the designed automatic-juicer as a case study.

2. Materials and Methods

2a. Fruits.

Minneola crop was dealt with in this study. All measurements were done using a random sample of 100 fruits. The samples were taken randomly from Minneola trees and from "El Oboor Market سوق العبور"; and the measurements were taken in the same day.

2b. Instrumentation:

2b1. Digital caliper with vernier: with accuracy of 0.01 mm, to measure different dimensions of Minneola fruits and components.

2b2. Digital balance: with accuracy of 0.2 g, to measure mass of Minneola fruits and constituents (peel, seeds and juice).

2b3. Graduated cylinder: of 1000 mL with accuracy of 25 mL to determine the real density and volume of fruit by immersion in water.

2b4. Friction and rolling-angle measuring device: An inclined plane was used to measure friction and rolling angles.

2b5. Friction angle measurement: the fruits are placed as a group bounded together on a horizontal surface then the angle of inclination is gradually increased until the fruits begin sliding without rolling. For each fruits group of an average sample of (10), the friction angles were determined.

2b6. Rolling angle measurement: the fruits are placed on a horizontal surface one by one then the angle of inclination is gradually increased until the fruits begin roll. For each fruit of an average sample (50), two angles of rolling are determined: for the maximum stable (with their base down) and minimum stable positions.

2b7. Bulk density and angle of repose: Sample of Minneola of not less than 20 kg, was put into a box with transparent walls. The box is kept on its side position "a" (fig. 2-1). Box dimensions are at least 1000 x 300 x 200 mm. The free surface of Minneola is leveled and height "L" is measured. By multiplying "L" by the area of the side wall, the sample volume is found and the bulk density is calculated in the usual manner. After this, the box is gradually tilted into a horizontal position. The free surface of mass then makes an acute angle "□" with respect to the horizontal. "H" and "l" are measured with a ruler scale and angle of repose is calculated by the expression

" tan □ = H/l". The experiment was repeated 5 times and the mean value of "□" is calculated from these values.

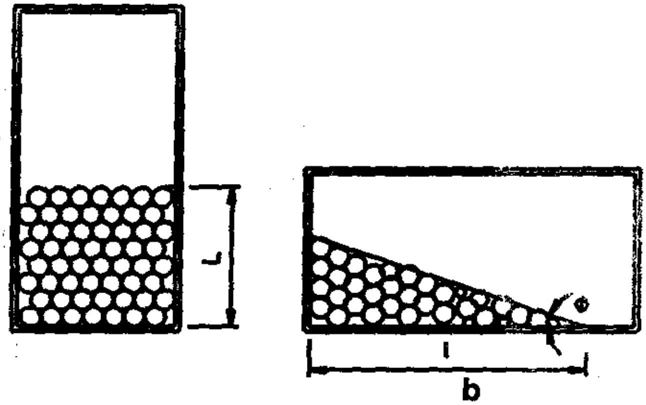


Fig. 2-1: Bulk density and angle of repose measuring box.

2b.8 Penetrometer: Penetrometer, made in Italy, with accuracy of 0.1 N was used to measure penetration force of Minneola fruits. The firmness of fruit was obtained by dividing the penetration force by the area (0.28 cm^2) of cylindrical probe, which had 0.6 cm diameter.

2b9. Deformation tester: The non-destructive deformation tester was developed and constructed according Atta-Aly and Awady, 1994. Its shape and dimensions are shown in fig. 2-2. Stainless steal was used for constructing basic elements. Tester was designed with an accuracy of 0.01 mm strain and an open scale to accept loads ranging from 1 g up to 10 kg. Both arm and height adjustments can be manually set to fit any fruit size when different fruit species or cultivars are used.

2c. Equations and calculations:

The following equations were used to calculate sphericity, projected area and real density according to Mohsenin, 1986 (fig. 2-3).

Sphericity ratio = fruit height (H) / fruit diameter (D) ---------------- (1)

Projected area = 4/□ (D * H) --- (2)

Real density = Mass / Volume -- (3)

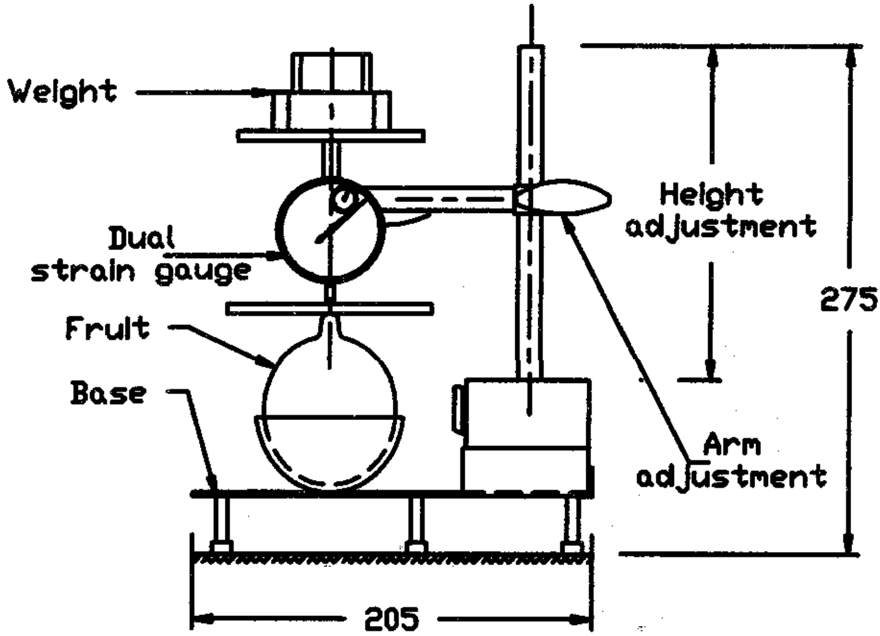


Fig. 2-2: Diagram of deformation tester.
(Atta-Aly and Awady, 1994).

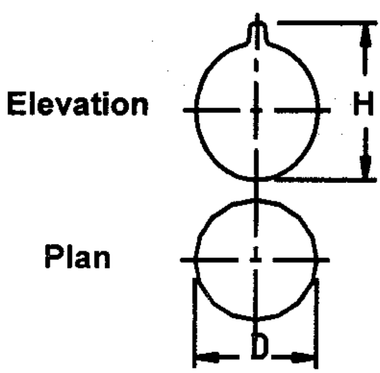


Fig. 2-3: Views of Minneola fruit.

2d. The developed Minneola juicer:

Fig. 2-4 shows a scematic diagram of the juicing device. Such device was constructed by Yehia (2001) for orange. Parameters shown on the figure are essentially those to be determined for Minneola through this work, for modifying the device to operate efficiently on this fruit.

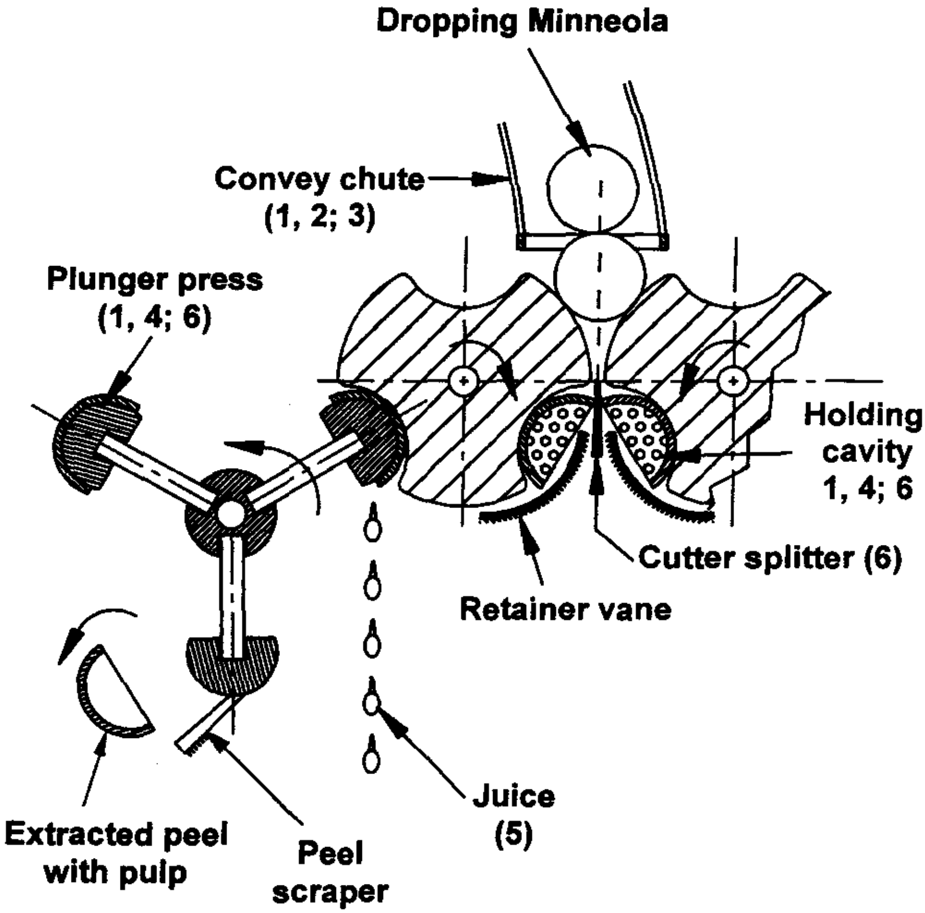


Fig. 2-4: Schematic of the auto-juicing device, with the sought parameters necessary for design of different parts.

Associated parameters:

(1) fruit dimensions, (2) Bulk density, (3) Friction and rolling angles, (4) Peel thickness, (5) Juice/volume ratio, (6) fruit firmness.

3. Results and Discussion

3a. Physical properties of Minneola fruits.

Table 2-1 shows dimensions, sphericity, mass, volume, real density, projected area, peel thickness and mass, juice volume, juice volume/fruit mass ratio and juice density of Minneola fruits. These data were measured on 100 fruit sample, according to the standards set in (Mohsenin, 1986).

Table 2-1: Physical properties of Minneola fruits.

Physical properties	Max.	Min.	Average	S. D.[1]	C. V.[2]
Height, mm	104	68	84.7	7.0	5.29
Diameter, mm	89	62	77.9	5.3	6.79
Neck height, mm	22	2	7.8	4.9	63.3
Neck diameter, mm	38	15	26.6	5.1	19.3
Sphericity	1.3	0.9	1.1	0.1	6.6
Mass, g	345	201	272	35.2	13
Volume, cm^3	342	120	207	49.4	23.91
Real density, g/cm^3	0.99	0.77	0.96	0.2	34.7
Bulk density, kg/m^3			775		
Projected area, cm^2	108	54	83.8	11.1	13.25
Peel thickness, mm	5	3	3.9	0.5	12.46
Peel mass, g	73	52	64.2	6.5	10.05
No. of segments/fruit	12	9	11	1.0	8.26
No. of seeds	8	2	5	1.9	37.71
Juice volume cm^3	168	96	133.2	23.6	17.26
Juice volume/fruit mass, L/kg	0.59	0.41	0.50	0.05	9.78
Juice density, g/cm^3	1.05	1.01	1.02	0.01	1.17

(1) S. D. is standard deviation.
(2) C. V. is coefficient of variation.

3a1. Dimensions of fruit:

Fig. 3-1 indicates that the fruit height and diameter ranges of sample were 68 - 104 mm (average 84.7 mm) and 62 - 89 mm (average 77.9 mm) respectively. The most frequent percent (90.12 %) of Minneola fruits in the sample have 75 - 95 mm height and (93.83 %) of Minneola fruits in the sample have 75 - 90 mm height.

Fig. 3-1 also shows that the fruit neck height and diameter ranges of sample were 2 - 22 mm (average 7.8 mm) and 15 - 38 mm (average 26.6 mm) respectively. The most frequent percent (83.95 %) of Minneola fruits in the sample had 25 - 35 mm height, and (88.89 %) of Minneola fruits in the sample had 5 - 15 mm height.

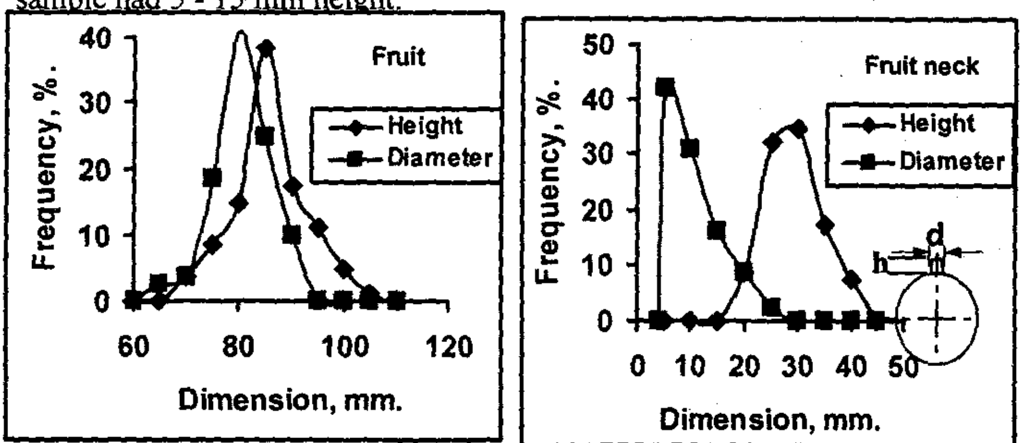


Fig. 3-1: Frequency curves distribution of fruit dimensions of Minneola fruits.

3a2. Shape and size of fruit:

If sphericity is less than 0.9, the fruit belongs to oblate group; if sphericity is greater than 1.1, it belongs to oblong group. The remaining fruits with intermediate index values are considered to be round (Buyanov and Voronyuk, 1985).

Fig. 3-2 indicates that the fruit spericity ranged in sample between 0.9 and 1.3. The most frequent percent (82.7 %) of Minneola fruits in the sample was round (sphericity 0.9 - 1.1) and (16.3 %) of Minneola fruits in the sample were oblong (sphericity 1.2 - 1.3).

3a3. Mass and volume of fruit:

Fig. 3-3 indicates that the fruit mass and volume ranges of sample were 201 - 345 g (average 272 g) and 120 - 342 cm^3 (average 207 cm^3) respectively. The most frequent percent (71.4 %) of Minneola fruits in the sample had 250 - 300 g mass and (83.3 %) had 200 - 300 cm^3 volume.

Fig. 3-4 shows the best fitted curves and the relation between fruit mass (M) and volume (V) of Minneola as follows:

$$M = -0.0032 V^2 + 2.0092 V, R^2 = 0.80 \text{ --------------------------- } (4)$$

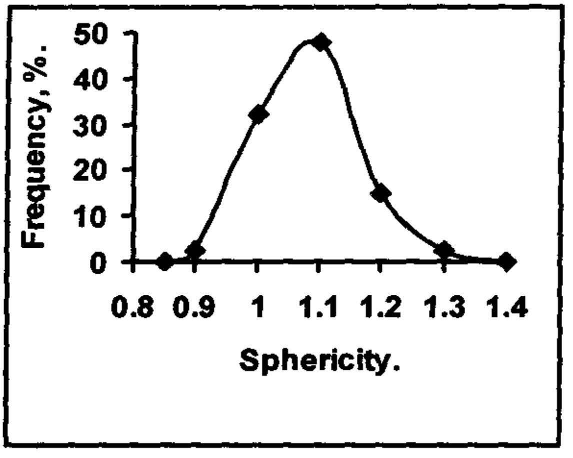


Fig. 3-2: Frequency distribution of fruit sphericity of Minneola fruits.

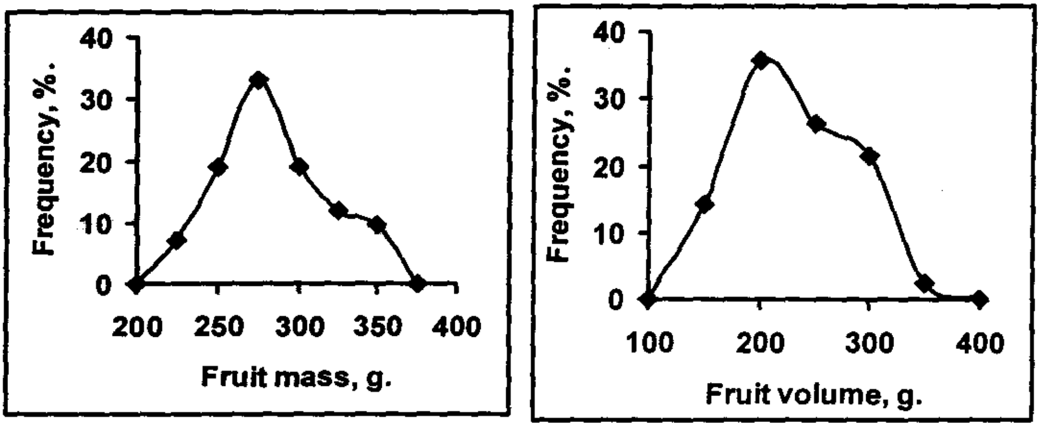
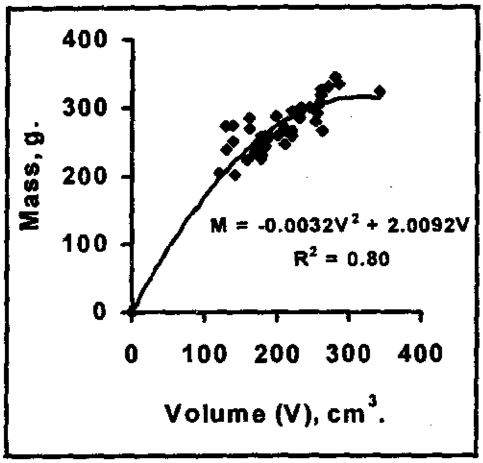


Fig. 3-3: Frequency curves distribution of fruit mass and volume of Minneola fruits.

2a4. Real density of fruit:

Fig. 3-5 indicates that the fruit real density of sample ranged between 0.77 and 0.99 g/cm^3 (average 0.96 g/cm^3). The most frequent percent (76.2 %) of Minneola fruits in the sample had 0.96 - 0.99 g/cm^3 real density.



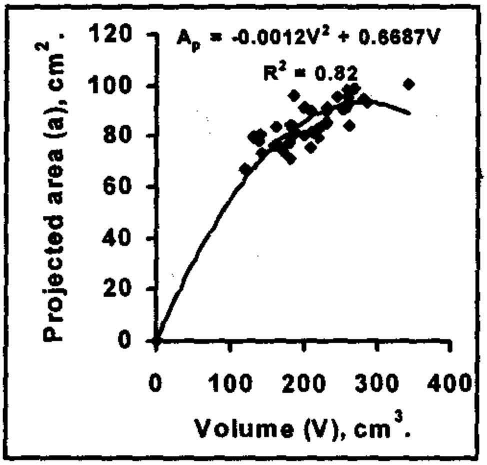


Fig. 3-4: The best fitted curves shows the relations between fruit volume and mass and projected area of Minneola fruits.

3a5. Projected area of fruit:

Fig. 3-5 indicates that the fruit projected area of sample ranges between 54 and 108 cm^2 (average 83.8 cm^2). The most freqüent percent (86.4 %) of Minneola fruits in the sample have 80 - 100 cm^2 projected area.

Fig. 3-4 shows the best fitted curves and the relation between fruit projected area (A_p) and volume (V) was as follows:

$A_p = -0.0012\ V^2 + 0.6687\ V,\ R^2 = 0.82$ -------------------------- (5)

3a6. Peel thickness and mass:

Fig. 3-6 indicates that the peel thickness and mass ranges of sample were 3 - 5 mm (average 3.9 mm) and 52 - 73 g (average 64.2 g) respectively. The most frequent percent (81.8 %) of Minneola fruits in the sample have 3.4 - 4 mm thickness and (90.9 %) have 60 - 75 g mass.

3a7. Number of segments and seeds per fruit:

Fig. 3-7 indicates that the number of segments and seeds ranges of sample were 9 - 12 (average 11) and 2 - 8 (average 5) respectively. The most frequent percent (92.3 %) of Minneola fruits in the sample had 10 - 12 segments/fruit and (77.8 %) had 4 - 6 seeds/fruit.

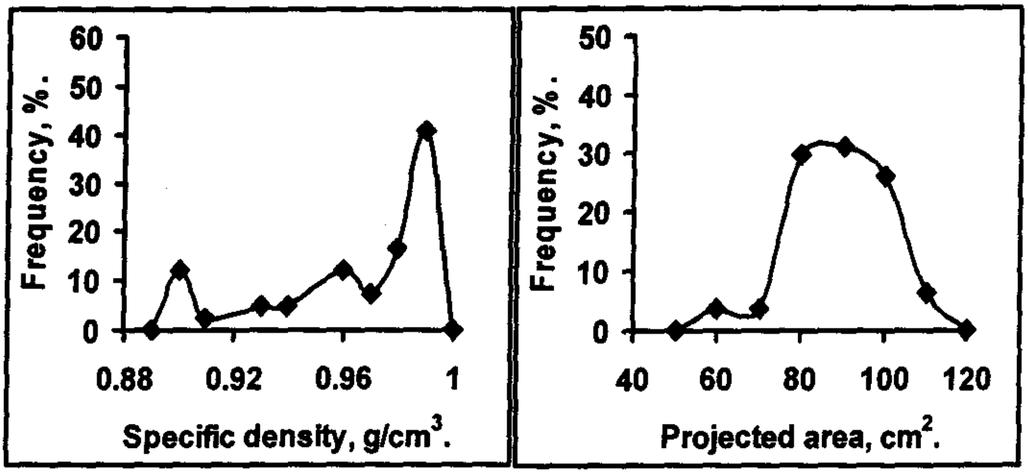


Fig. 3-5: Frequency curves distribution of fruit mass and volume of Minneola fruits.

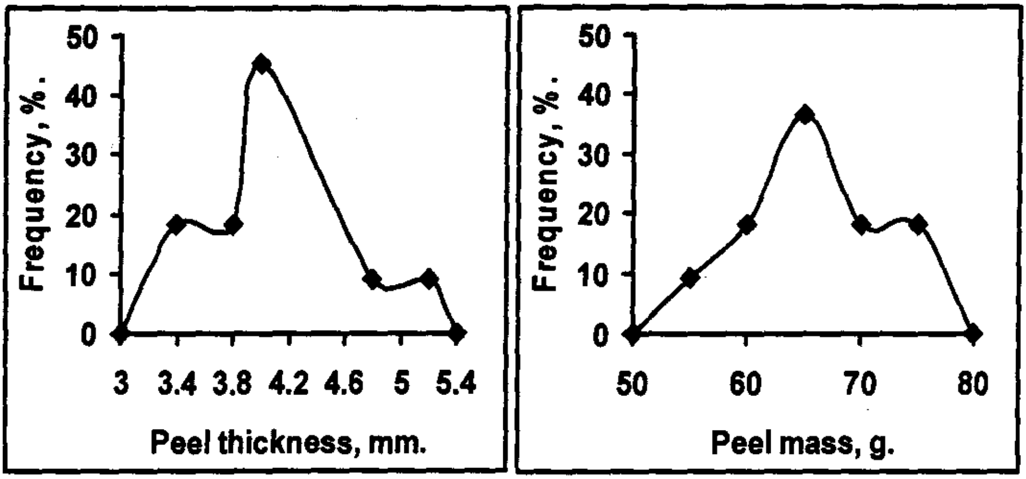


Fig. 3-6: Frequency curves distribution of peel thickness and mass of Minneola fruits.

3a8. Juice volume and juice volume/fruit mass ratio:

Fig. 3-8 indicates that the juice volume and juice volume/fruit mass ratio ranges of sample were 96 - 168 cm^3 (the average is 133.2 cm^3) and 0.41 - 0.59 L/kg (average 0.50 L/kg) respectively. The most frequent percent (77.8 %) of Minneola fruits in the sample had 120 - 160 cm^3 juice volume/fruit and (77.8 %) of Minneola fruits in the sample had 0.48 - 0.52 L/kg juice volume/fruit mass.

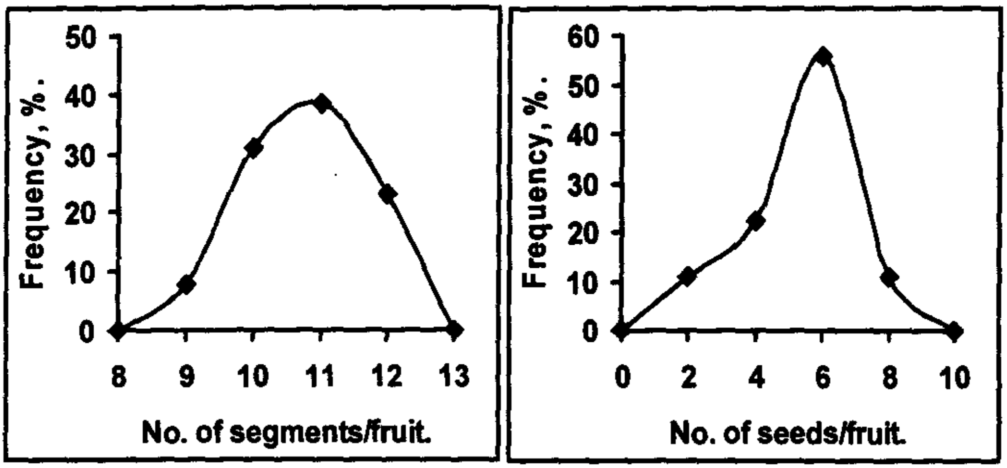


Fig. 3-7: Frequency curves distribution of number of segments and seeds/fruits of Minneola fruits.

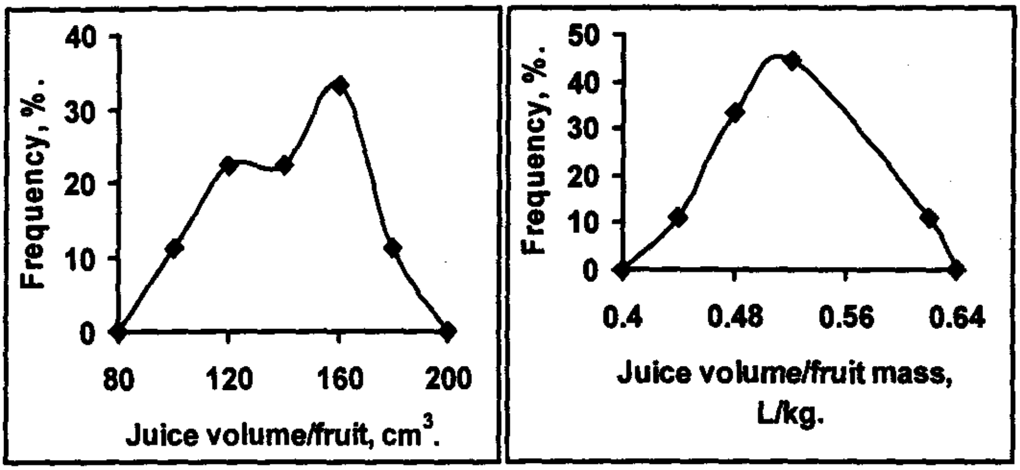


Fig. 3-8: Frequency curves distribution of juice volume/fruit and juice volume/fruit mass ratio of Minneola fruits.

3b. Mechanical properties of Minneola fruits.

3b1. Friction, rolling and repose angles of Minneola fruits:

Table 2-2 shows friction and rolling angles of Minneola fruits. The maximum friction angle (40 - 41 degree) and rolling angle ranges (17 - 30 degree) were obtained with wood surface. Whereas, the minimum ranges of friction and rolling angles (13 - 15 and 10 - 22 respectively) were obtained with aluminium surface.

3b2. Deformation of fruits:

Fig. 3-9 shows the average deformation of Minneola fruit at different loading weights and times. The deformation range increased from 2.75 - 3.09 to 8.52 - 10.02 mm by increasing loading from 1 to 5 kg. Meanwhile, the deformation range increased from 2.75 - 8.52 to 3.09 - 10.02 by increasing loading time from 15 to 60 s.

Table 2-2: Friction and rolling angles for Minneola fruits with different surface types.

Surface type	Friction angle, degree			Rolling angle, degree					
				Maximum			Minimum		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
Wood	41	39	40	30	21	25.8	20	17	18.8
Metal	15	14	14.7	22	21	21.7	12	11	11.7
Galv. I.	15	14	14.8	22	21	21.8	12	11	11.8
Alum.	15	13	14.4	22	20	21.4	12	10	11.4
SS	15	14	14.5	22	21	21.5	12	11	11.5

Galv. I.: Galvanized iron; Alum.: Aluminium; and SS.: Stainless steal.

The average repose-angle was about 39.3 degree.

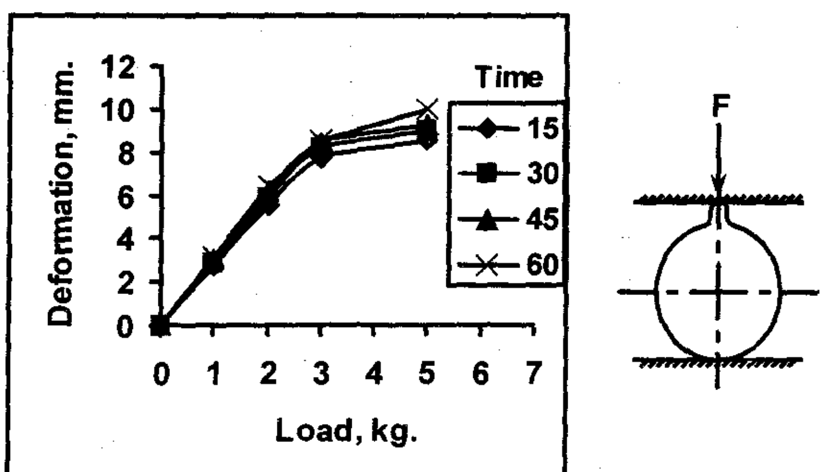


Fig. 3-9: Relation between loading weight and deformation at different loading time for Minneola fruit.

3b3. Firmness of Minneola fruits:

Fig. 3-10 shows the average firmness distribution along Minneola surface. The maximum firmness was 22 N/cm^2 at 30 - 45 mm along fruit and the minimum was 17 N/cm^2 at the bottom of fruit.

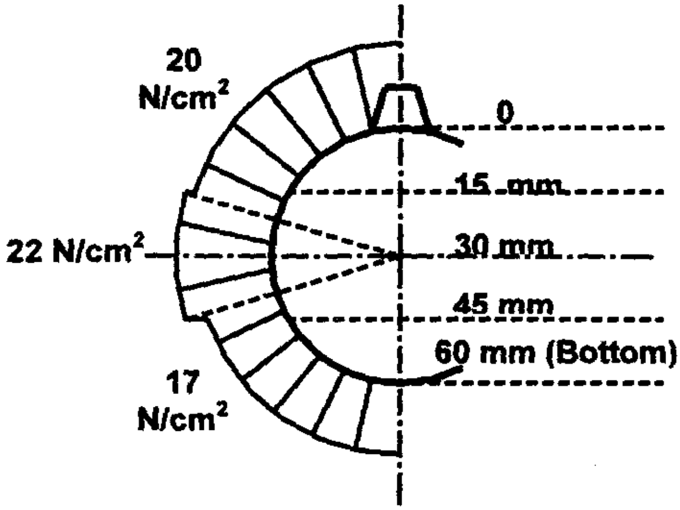


Fig. 3-10: Firmness distribution along Minneola fruit.

3c. Application of the theory to the development of the Minneola juicing device:

Parameters required for development of the new design have been explained in the part 2d in the section on "Materials and Methods". Fig. 2 - 4 shows the parameters. Some results of this investigation point out to the following:

The physical and mechanical properties are incorporated in the design of the feeding mechanism, orange tube, holding mechanism and press mechanism of the designed automatic-juicer as follows:

3c1. Holding mechanism (Fig. 2-4):

Groove diameter = Maximum height of Minneola fruits = 10.5 cm.

Groove depth = Maximum height of Minneola fruits / 2 = 5.25 cm.

3c2. Pressing mechanism:

Half ball diameter = Groove diameter - 2 x peel thickness

= 10.5 - (2 x 0.5) = 9.5 cm

Half ball height = Groove diameter / 2

= 10.5 / 2 = 5.25 cm

The overlap between half-balls and grooves = groove depth + peel thickness = 5.25 + 0.5 = 5.75 cm

Orange chute tilt angle = more than maximum friction angle between Minneola fruits and stainless steal surface = more than 15^0.

Conclusion

The main results in this study can be summarized as follows:

Physical properties of Minneola fruits: diameter = 62 - 89 mm, height = 68 - 104 mm, mass = 201 - 345 g, volume = 120 - 342 cm^3, projected area = 54 - 108 cm^2, peel thickness = 3 - 5 mm, peel mass = 52 - 73 g, number of segments/fruit = 9 - 12, number of seeds/fruit = 2 - 8, juice volume/fruit = 96 - 168 cm^3, and juice volume/fruit mass = 0.41 - 0.59 L/kg.

Mechanical properties of Minneola: The maximum firmness was 22 N/cm^2 at 30 - 45 mm below top along fruit and the minimum was 17 N/cm^2 at the bottom. The deformation range increased from 2.75 - 3.09 to 8.52 - 10.02 mm by increasing loading from 1 to 5 kg. Meanwhile, the deformation range increased from 2.75 - 8.52 to 3.09 - 10.02 by increasing loading time from 15 to 60 s.

Physical and mechanical properties were incorporated in the design of the orange chute, holding and pressing mechanisms of the designed automatic-juicer as follows:

Holding mechanism: Groove diameter = Maximum height of Minneola fruits = 10.5 cm.

Pressing mechanism: Half ball diameter = Groove diameter - 2 x peel thickness = 9.5 cm

The overlap between half-balls and grooves = groove depth + peel thickness = 5.25 + 0.5 = 5.75 cm

Orange chute tilt angle = more than maximum friction angle between Minneola fruits and stainless steal surface = more than 15^0.

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الملخص العربى

الخواص الطبيعية والميكانيكية لثمار المنيولا واستخدامها لجهاز العصير

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تهدف هذه الدراسة إلى تعيين الخواص الطبيعية والميكانيكية لثمار المنيولا (نوع من الموالح الوافدة حديثا إلى الزراعة المصرية)، للاستفادة منها فى تصميم وتشغيل آلات معدات وآلات تداول ثمار الموالح، وتم تصميم بعض أجزاء آلة عصر البرتقال الأتوماتيكية كمثال. وتم الحصول على النتائج التالية:

(1) الخواص الطبيعية:

(أ) أبعاد الثمرة: وجد أن ارتفاع ثمار "المنيولا" يتراوح بين 68 و104 مم، والقطر بين 62 و 89 مم.

(ب) الشكل والحجم: وجد أن 82 % من الثمار الموجودة فى العينة تأخذ الشكل الكروى، 16.3 % تأخذ الشكل الكمثرى المنبعج. وتراوح الحجم بين 120 و342 $سم^3$

(ج) كتلة وكثافة الثمار: وجد أن كتلة ثمار "المنيولا" تتروا ح بين 201 و345 ج، وكثافتها الحقيقية تتراوح بين 0.77 و0.99 $ج/سم^3$.

(د) المساحة المعرضة: وجد أن المساحة المعرضة تتروا ح بين 54 و108 $سم^2$.

(هـ) سمك وكتلة القشرة: وجد أن سمك القشرة يترلوح بين 3 و5 مم، وكتلة القشرة بين 52 - 73 ج.

(و) عدد الفصوص والبذور: وجد أن عدد الفصوص/الثمرة تراوح بين 9 و12، وعدد البذور/الثمرة بين 2 - 8 بذرة.

(ز) حجم العصير ونسبة حجم العصير/كتلة الثمرة: وجد أن حجم العصير/ثمرة تراوح بين 96 و 168 $سم^3$، بينما تراوحت نسبة حجم العصير/كتلة الثمرة بين 0.41 و 0.59 لتر/كج.

(2) الخواص الميكانيكية:

(أ) زاوية الاحتكاك والتدحرج والتكويم: وجد أن متوسط زاوية الاحتكاك لثمار "المنيولا" هى 40، 14.7، 14.8، 14.4، 14.5 درجة على أسطح خشب، صاج عادى، صاج مجلفن، ألومنيوم، ستانلس ستيل على الترتيب. بينما كان متوسط أقصى زاوية تدحرج هى 25.8، 21.7، 21.8، 21.4، 21.5 درجة للأسطح السابقة الذكر على الترتيب. ووجد أن متوسط زاوية التكويم حوالى 39.3 درجة.

(ب) صلابة الثمار: وجد أن متوسط أقصى صلابة لثمار "المنيولا" هو 22 $نيوتن/سم^2$ عند قمة الثمرة، على بعد 15 - 30 مم من قمة الثمرة، ومتوسط أقل صلابة هو 17 $نيوتن/سم^2$ عند قاعدة الثمرة.

(ج) تشوه الثمار تحت أحمال وأزمنة تحمل مختلفة: وجد أن متوسط تشوه ثمار "المنيولا" زاد من 2.75 - 3.09 إلى 8.52 - 10.02 مم بزيادة الحمل من 1 إلى 5 كج، كما وجد أن التشوه زاد من 2.75 - 8.52 مم بزيادة زمن التعرض للحمل من 15 إلى 60 ث.

وبالدراسة تطبيق لبعض النتائج على تطوير جهاز عصير البرتقال ليناسب ثمرة "المنيولا".

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