Design of a seed extractor using the physical and mechanical properties of cucumber fruits

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Abstract: The aim of this investigation is to study some physical and mechanical properties of cucumber fruits to help the design of handling machines for seed production. The physical and mechanical properties of cucumber fruits are used to develop of a seed-extractor. The main results of this study can be summarized as follows: Physical properties of cucumber fruits: fruit diameter = 50 - 68, 60 - 76 and 56 - 75 mm, fruit length = 169 – 291, 230 – 315 and 180 – 295 mm, fruit mass = 210 – 540, 235 – 595 and 290 – 585 g/fruit, number of seeds per fruit in = 350 – 580, 410 – 590 and 355 – 560, bulk density = 1.37, 1.30 and 1.40 g cm^{-3} and a real density = 0.49, 0.44 and 0.45 g cm^{-3} for "Beta-alpha", "Hayel" and "Bahi" varieties respectively, bulb mass per fruit = 250 – 550 g/fruit, seed mass per fruit= 15 – 40 g/fruit, rind thickness = 7 – 10 mm and fruit volume = 200 – 500 cm^3 for all tested varieties., Mechanical properties of cucumber fruits: penetration forces = 39.2 – 42.5, N, firmness = 90.1, 99.1 and 100.9 N cm^{-2} and axial shear-force = 41.5 - 43 N for testing "Beta-alpha", "Hayel" and "Bahi" varieties. The physical and mechanical properties are used to design of a seed-extractor is given also in this paper.

Keywords: extraction machine, cucumber fruits, seeds.

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1 Introduction

Plant breeding and biotechnology research on cucumber (Cucumis sativus L.) often requires that mature fruits be harvested for seed recovery from controlled pollinations. Cucumber seed extraction has become more mechanized in the last few years following the design of machines such the seed sluice for small plots (Steiner and Letizia, 1986) and the bulk seed extractor (Wehner et al., 1983).

The single-fruit seed extractor is similar in purpose to the bulk seed extractor, but operates on different principles. The bulk seed extractor (suitable for large quantities) crushes the fruit, creating a pulp. After using the bulk extractor in a field isolation block, the mound of pulp and fragments of discarded fruit can be disked into the field. In contrast, the single-fruit seed extractor bores into the end of the fruit, leaving the fruit mostly intact for easy disposal from greenhouse or laboratory where extractor often is used.

Wehner and Humphries (1995) designed and construct a single-fruit extractor for cucumber which consists of extractor cone or auger for excavating the

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seed cavity and means to drive it, a pail or containment both hands of the operator for other tasks. The designed machine increases the speed and ease of removing seeds from individual, mature cucumbers for later drying and planting. The machine saves about 47 second/fruit compared to hand methods and is suited to handling single fruit (or batches of up to 50) by researchers needing seeds from controlled pollinations. In 5 years of use, no reduction in seed recovery or germination has been observed using the seed extractor relative to hand harvest.

The cucumber crop for seeds is ready for harvest when the fruits have turned pale yellow or golden. The seeds are obtained by cutting individual fruits in half, longitudinally, and scraping them out with knife. At the time of extraction, the seed will not separate completely from the pulp surrounding it. Its adherence to this material is broken by one of three methods: (a) Fermentation, (b) Mechanical means and (c) Chemical extraction. Fermentation: In this method, the pulp is poured into wooden barrels where it is allowed to ferment for several days. The fermenting material is occasionally stirred to prevent any discoloration or blackening of seed from mold, which may form on the material floating at the surface.

As the seed is separated from the disintegrating pulp, it tends to sink to the bottom of the container. The seeds are then washed and dried in the sun to moisture contents below seven per cent, before storage. Mechanical means: Seed can be extracted by the use of special machines also. In these machines, the fruits are not only cut and macerated, but also the pulp is squeezed so that the seed is forcibly separated from it. In this operation, considerable water is used for washing towards the end of the operation. The seeds are later washed and dried to moisture content below seven per cent. Chemical extraction: Either an acid or an alkali may be used to speed up the extraction of cucumber seed. 100 cm^3 of hydrochloric acid per 11 to 12 kg of pulp, or 12 parts of 25 percent technical grade ammonia per 1000 parts of material, is thoroughly stirred into the pulp. After about thirty minutes, water is added while stirring. The pulp, other impurities, and empty seeds will float and mature seeds will sink to the bottom. Later, the seeds are washed anddried to moisture content below seven per cent. The average seed yield is about 110 to 130 kg per hectare (Desai et. al., 1997).

Abd-Alla (1993) found that the cucumber fruits variety Beta-alpha properties were: fruit length = 20 – 26 cm, fruit diameter = 5 – 6.5 cm, fruit mass = 500 – 650 g and seed number per fruit = 200 – 600.

Moradi et al. (2020) Measurement of physical properties of different common cucumber fruits can be accounted for as a useful tool to design the post-harvesting unit operations. Therefore, the proposed mathematical model for the description of the terminal velocity of cucumber could be approached in pickle production units. Also, the obtained properties are usable in hydro transport and sorting of the fruit.

Yehia et al. (2011) studied some physical and mechanical properties of cucumber fruits variety “Beta-alpha” and designed a seed extractor. It is concluded that the physical properties of cucumber fruits were: diameter of 52.15 – 229.5 mm, length of 52.15 – 68.87 mm, mass of 273.8 – 470.4 g, volume of 380 - 860 cm^3, projected area of 250 - 500 cm^2, a real density of 0.94 -1.10 g cm^{-3}, bulk density of 0.41 g cm^{-3}, and sphericity of 3.13 – 3.77, and mechanical properties are: cucumber-fruit firmness = 64 – 100.9 N cm^{-2}, the axial cutting- force = 30 - 70 N. The physical and mechanical properties are incorporated in the design of the fruit hopper, reciprocating arm for fruit feeding (length and diameter), fixed cutting-knife to cut the cucumber fruit in axial direction (dimensions and sharpness) and two wings with a scraper to extract the seeds from each fruit half and exit of the designed extractor. It was found that Reciprocating arm stroke =

Maximum fruit-length + 30 mm ≈ 233 mm. Knife height = more than maximum fruit diameter = > 7 cm = 7.2 cm. Scraper diameter = minimum fruit diameter – 2 x maximum pulp thickness = 52 – 2 x 10 = 32 mm.

Abu El-Maaty (2016) developed and tested a cucumber seed extractor. It is concluded that the optimum parameters of developing cucumber-seed extraction machine were: feeder speed of 18 rpm, cutting length of fruit edge of 5 mm, oriented plate angle of 55 degree and plunger speed of o.17 m s^{-1}, the results obtained at optimum parameters were: The machine productivity was 618 Kg h^{-1} fruits and 19 kg h^{-1} seeds. Extraction efficiency of the extraction machine was 86%. The first idea of the seed-extraction mechanism of cucumber-seed extractor which developed in this study was by Yehia et al., (2011). And feeding and cutting mechanism was developed by Abu El-Maaty, (2016).

The objective of this investigation is to study some physical and mechanical properties of cucumber fruits, as a data base, to help the design of handling machines for seed production. The physical and mechanical properties are used to design of a cucumber-seed extractor.

2 Materials and methods

2.1 Fruits

Cucumber "Beta-alpha", "Hayel" and "Bahi" crop varieties were used in this study. All measurements were done using a random sample of 100 fruits. The samples were taken randomly from cucumber plants (special farm at Assiut, Assiut Governorate during acceptable seeds-harvesting date); and the measurements were taken in the same day.

2.2 Instrumentation

(1) Digital caliper vernier: with an accuracy of 0.01 mm was used to measure different dimensions of cucumber fruits.

(2) Digital balance: with accuracy of 0.2 g was used to measure mass of cucumber fruits and constituents (fruits and seeds).

(3) Graduated cylinder: of 1000 mL with accuracy of 25 mL was used to determine the volume of fruit by immersion in water.

(4) Friction and rolling-angle measuring device: an inclined plane was used to measure friction and rolling angles.

(5) Friction and repose 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 and repose angles were determined.

(6) 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), rolling are determined for the maximum stable position.

(7) Bulk density: sample of cucumber of not less than 20 kg, was put into a box. Bulk density is calculated in the usual manner.

$$\textit{Bulk density} = \textit{fruit mass / box volume kg } m^{-3} \quad (1)$$

(8) Penetrometer: penetrometer, made in Italy, with accuracy of 0.1 N was used to measure penetration force of cucumber 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.

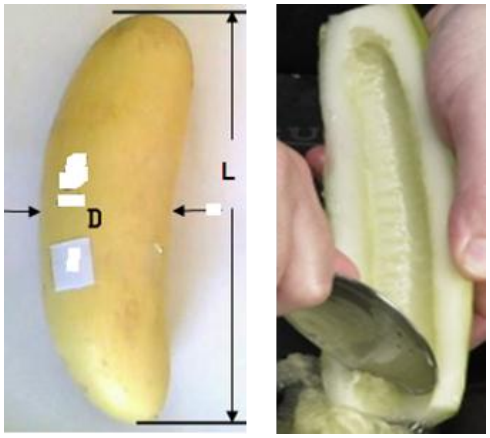


Figure 1 View of cucumber fruit for seeds (L: length, D: diameter and T: pulp thickness)

2.3 Equations and calculations

The following equations were used to calculate sphericity, projected area and real density according to Mohsenin (1986) (Figure. 1).

Sphericity ratio = fruit length (L)/ fruit diameter (D) (2)

Projected area = D ×L m2 (3)

Real density = mass / real volume kg m^{-3} (4)

2.4 The developed seed extractor

Figure. 2 shows a model photograph demonstrating the design-idea of the seed extractor of cucumber fruits. Parameters shown in the figure are essentially those to be determined for cucumber through this work.

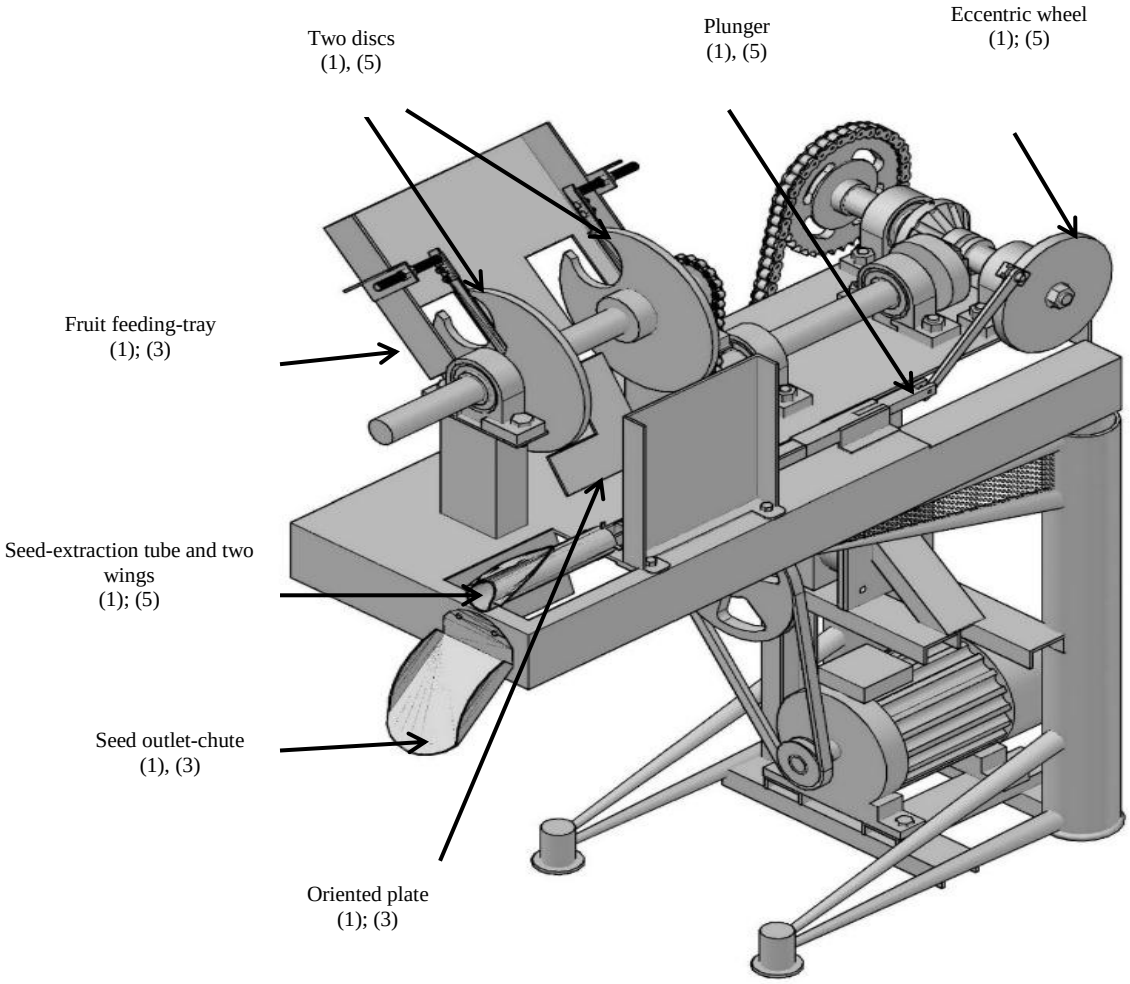


Figure 2 Machine views demonstrating the design idea of a seed extractor, with the numbers in brackets indicating parameters necessary for design of different parts.

Associated parameters:(1) Fruit dimensions, (2) Bulk density, (3) Friction and rolling angles, (4) Fruit mass, and (5) Fruit firmness.

Other physical and mechanical properties in this paper were conducted as a data base to help the design of some handling machines.

3 Results and discussion

3.1 Physical properties of cucumber fruits

Table 1 shows dimensions, mass, volume, real density, rind thickness and bulb mass and seed number and mass per fruit of cucumber fruits. These data were measured on 100 fruit sample, according to the standards set in (Mohsenin, 1986).

3.1.1 Fruit diameter

Table 1 and Figure. 3 indicate that the ranges of cucumber-fruit diameter in sample were 50 - 56, 56- 61, and 61 - 68 mm for three categories “Beta-alpha” variety,

60 - 66, 66 - 70 and 70 - 76 mm for three categories of "Hayel" variety, and 56 - 62, 62 - 69 and 69 -75 mm for three categories of "Bahi" varieties respectively.

The most frequent percent of 71% - 76%, 83% - 86% and 80% - 82% of cucumber fruits in the sample have 56 - 68 mm diameter for "Beta-alpha", "Hayel" and "Bahi" varieties respectively.

3.1.2 Fruit length

Table 1 and Figure. 3 indicate that the ranges of cucumber-fruit length in sample were 196 – 291, 230 – 315 and 180 – 295 mm for "Beta-alpha", "Hayel" and "Bahi" varieties respectively.

The most frequent percent of 60% - 76%, 66% - 72% and 63% - 74% of cucumber fruits in the sample have 210 - 260 mm length for "Beta-alpha", "Hayel" and "Bahi" varieties respectively.

Table 1 Physical properties of cucumber fruits (maximum and minimum values).

Variety	Category	*D* mm	*L* mm	Pulp dia mm	Mass g	Rind thickness mm	Bulk density g cm^{-3}	Real densitym g cm^{-3}	No. of seeds/fruit	Seed mass/fruit g
Beta-alpha	First	50 - 56	196 - 210	30 - 35	210 - 350	9 - 10	0.49	1.37	380 - 420	12 - 21
	Second	56 - 61	230 - 262	35 - 40	350 - 460	8 - 9	0.49	1.37	420 - 510	21 - 32
	Third	61 - 68	262 - 291	40 - 45	460 - 540	7 – 8	0.49	1.37	510 - 580	32 - 42
Hayel	First	60 - 66	230 - 260	35 - 40	235 - 390	7 - 8	0.44	1.3	410 - 445	14 - 25
	Second	66 - 70	260 - 290	40 - 45	390 - 455	8 - 9	0.44	1.3	443 - 530	25 - 37
	Third	70 - 76	290 - 315	45 - 50	455 - 595	9 - 10	0.44	1.3	530 - 590	37 - 49
Bahi	First	56 - 62	180 - 200	35 - 40	290 – 450	9 - 10	0.45	1.4	355 - 400	15 - 22
	Second	62 - 69	195 - 215	40 - 45	450 - 530	8 - 9	0.45	1.4	400 - 525	22 - 35
	Third	69 - 75	250 - 295	45 - 50	530 - 585	7 – 8	0.45	1.4	505 - 560	35 - 44

3.1.3 Bulb mass per fruit

Fig.4 indicates that the ranges bulb mass per cucumber-fruit of sample were 250 – 550 g/fruit for "Beta-alpha", "Hayel" and "Bahi" varieties.

The most frequent percent of 87% - 91%, 75% - 87% and 87% - 89% of cucumber fruits in the sample have 300 - 500 g bulb mass per fruit for "Beta-alpha", "Hayel" and "Bahi" varieties respectively.

3.1.4 Seed mass per fruit

Figure. 4 indicates that the range of seed mass per cucumber-fruit in sample was 15 - 40 g/fruit for "Beta-alpha", "Hayel" and "Bahi" varieties.

The most frequent percent of 80% - 82%, 86% -87% and 77% - 81% of cucumber fruits in the sample have 20 - 35 g seed mass per fruit for "Beta-alpha", "Hayel" and "Bahi" varieties respectively.

3.1.5 Number of seeds per fruit

Table 1 indicates that the number of seeds per cucumber-fruit in sample were 350 - 580, 410 - 590 and 355 - 560 for “Beta-alpha”, “Hayel” and “Bahi” varieties respectively.

3.1.6 Fruit mass

Table 1 indicates that the ranges cucumber-fruit mass of sample were 210 - 540, 235 - 595 and 290 -585 g/ for “Beta-alpha”, “Hayel” and “Bahi” varieties respectively.

Table 2 Friction and rolling angles for cucumber fruits on different surface types

Variety	Surface type	Friction angle, Degree			Rolling angle, degree		
		Min.	Max.	Av.	Min.	Max.	Av.
Beta-alpha	Wood	25	28	26.5	22.5	26.5	24.5
	Metal	24	26	25	13	22	17.5
	Galvanized. Iron	21	24	22.5	10	21	15.5
	Aluminum	16	21	18.5	13	21	17
	Stainless Steel	17	21	19	12	20	16
Hayel	Wood	26.5	28.5	27.5	24	25	24.5
	Metal	25	26	25.5	15	23	19
	Galvanized. Iron	24	26	25	12	20	16
	Aluminum	17	24	20.5	14	22	18
	Stainless Steel	19.5	22.5	21	15	23	19
Bahi	Wood	26	28	27	23	25	24
	Metal	24.5	26.5	25.5	14	23	18.5
	Galvanized. Iron	22	25	23.5	11	20	15.5
	Aluminum	16.5	23.5	20	14	20	17
	Stainless Steel	18	22	20	13	21	17

Note: Wood: wood sheet No. 2. Galvan.: galvanized.

3.1.7 Rind thickness

Figure. 5 indicates that the range of rind thickness cucumber-fruit in sample was 7 - 10 mm for “Beta-alpha”, “Hayel” and “Bahi” varieties.

The most frequent percent of 100% of cucumber fruits in the sample have 7 - 10 mm rind thickness for “Beta-alpha”, “Hayel” and “Bahi” varieties respectively.

3.1.8 Fruit volume

Figure. 5 indicates that the range of cucumber-fruit volume of the sample was 200 -500 cm3 for “Beta-alpha”, “Hayel” and “Bahi” varieties, respectively.

The most frequent percent of 72% - 76%, 70% - 75% and 70% -76% of cucumber fruits in the sample have volume of 300 - 450 cm3 for “Beta-alpha”, “Hayel” and “Bahi” varieties respectively.

3.1.9 Bulk density of cucumber fruits

Table 1 indicates that the averages bulk density cucumber-fruit in sample were 1.37, 1.30 and 1.40 g cm-3

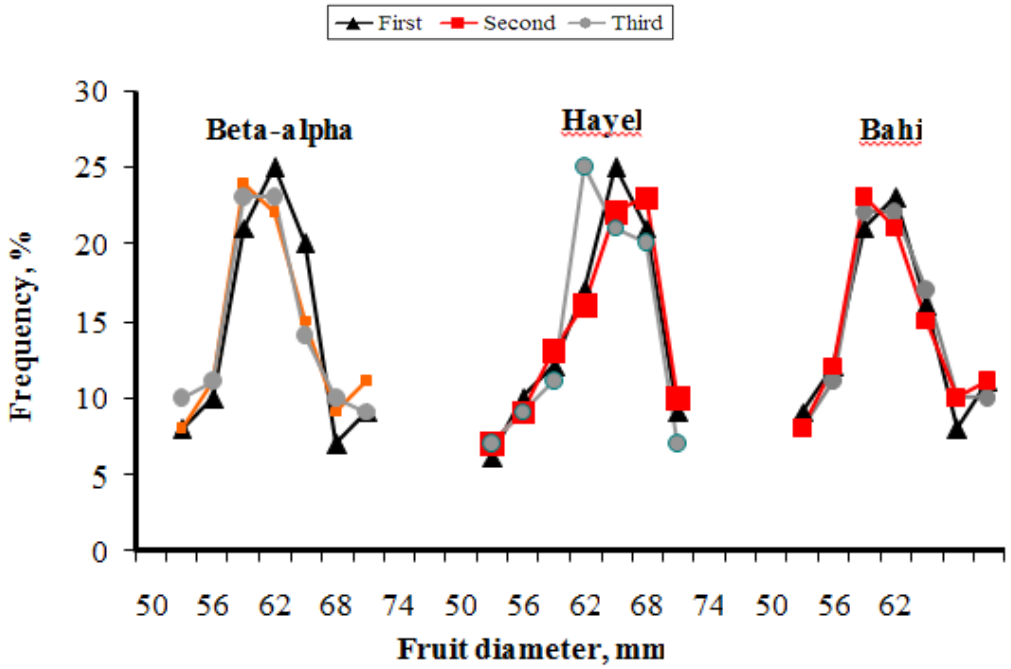
for "Beta-alpha", "Hayel" and "Bahi" varieties respectively.

3.1.10 Real density of cucumber fruits

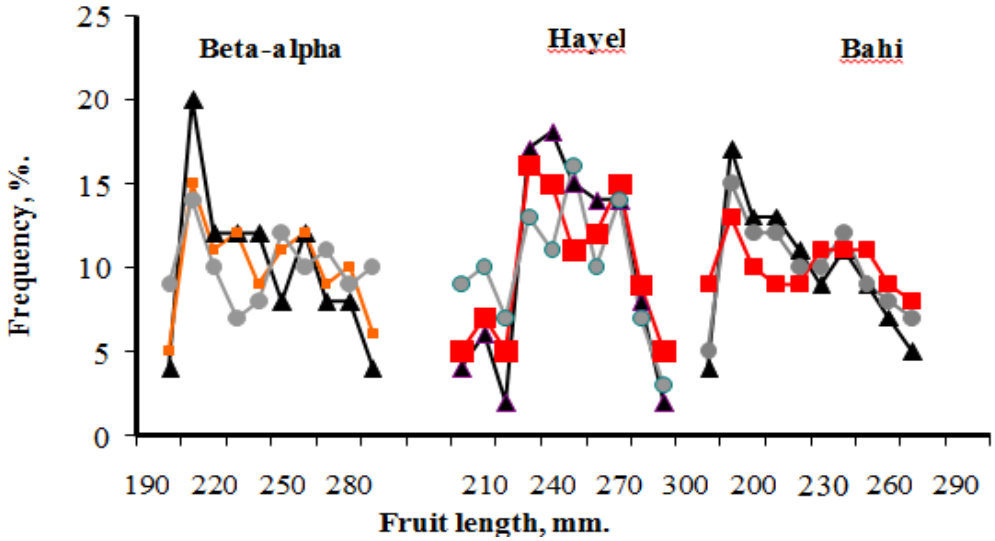
Table 1 indicates that the averages real density cucumber-fruit in sample were 0.49, 0.44 and 0.45 g cm-3 for "Beta-alpha", "Hayel" and "Bahi" varieties respectively.

Table 3 Averages of penetration force, Firmness and axial shear force of cucumber fruits

Varity	Penetration force, N.	Firmness, N cm^{-2}	Axial shear force, N.
Beta-alpha	42.5	99.1	43
Hayel	39.2	90.1	41.5
Bahi	40.3	92	42.4

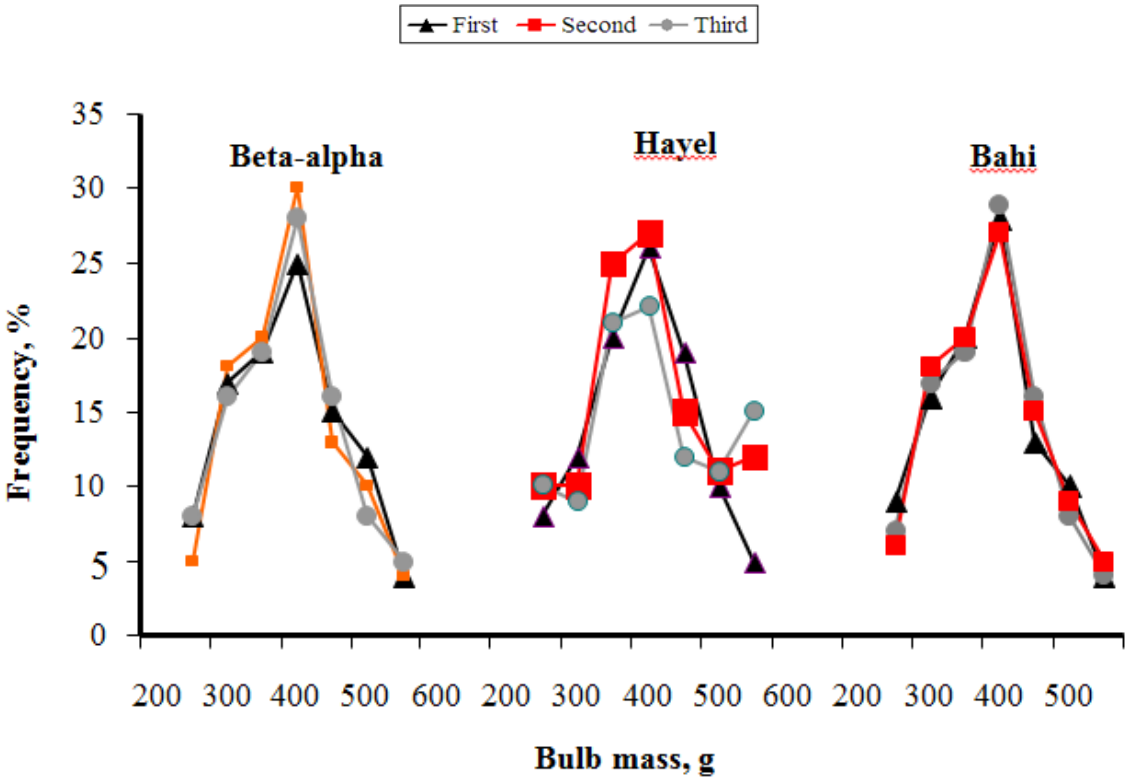


(a) Frequency curves distribution of fruit diameter

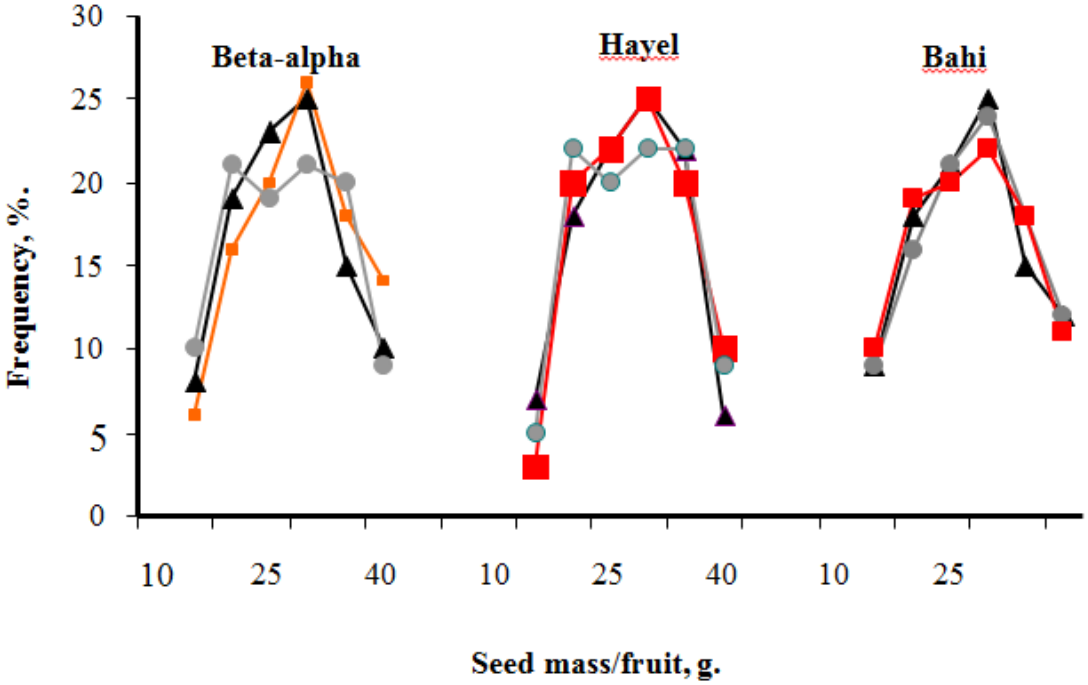


(b) length of cucumber fruits

Figure 3 Frequency curves distribution of fruit diameter and length of cucumber fruits



(a) Frequency curves distribution of bulb



(b) Seed mass per fruit of cucumber fruits

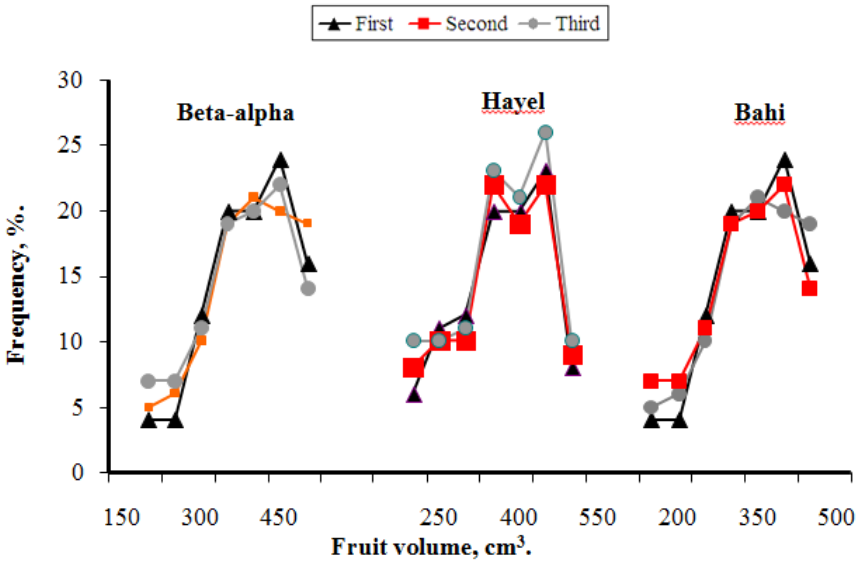
Figure 4 Frequency curves distribution of bulb and seed mass per fruit of cucumber fruits

3.2.1 Friction, rolling and repose angles of cucumber fruits.

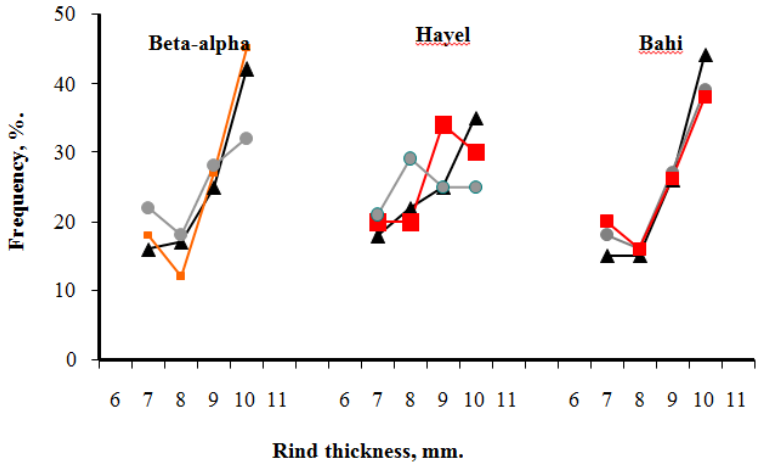
Table 2 shows friction and rolling angles of cucumber fruits. The maximum friction angle of 26.5 - 28.5 degree and rolling angle of 22 - 24.5 degree were obtained with wood surface for "Beta-alpha", "Hayel" and "Bahi" varieties. Meanwhile, the minimum friction and rolling angle of 16 - 20.5 degree were obtained with aluminum surface for "Beta-alpha", "Hayel" and "Bahi" varieties.

3.2.2 Penetration force, firmness and axial shear-force of cucumber fruits.

Table 3 shows the averages of penetrating force, firmness and axial-shear force of cucumber fruits. The ranges of penetration force of 39.2 - 42.5 N, firmness of 90.1 99.1 100.9 N cm^{-2} and axial shear-force of 41.5 - 43 N were found with "Beta-alpha", "Hayel" and "Bahi" varieties.



(a) Frequency curves distribution of fruit volume



(b) rind thickness

Figure 5 Frequency curves distribution of fruit volume and rind thickness of cucumber fruits.

3.2 Mechanical properties of cucumber fruits

Table 3 Averages of penetration force, Firmness and axial shear force of cucumber fruits

Varity	Penetration force, N.	Firmness, N cm^{-2}	Axial shear force, N.
Beta-alpha	42.5	99.1	43
Hayel	39.2	90.1	41.5
Bahi	40.3	92	42.4

3.3 Application of the theory to the design of the cucumber seed-extractor using the physical and mechanical properties

Parameters required for development of the design of cucumber seed-extractor have been explained in the part 2d in the section on "Materials and Methods". Fig. 2 shows the parameters. Some results of physical and mechanical properties in this investigation are incorporated in the design of the cucumber-seed extractor are as follows.

The developed cucumber-seed extractor consists of frame, feeding mechanism, fruit edge-cutting knives, seed-extraction mechanism, pressing mechanism, and two-wings ejector.

Feeding mechanism:

Feeding mechanism consists of fruit feeding-tray, two feeding-discs and oriented plates. Two oriented plates (tilted and vertical) make the cucumber fruit slowly dropped and oriented in the right position to be facing the seed-extraction plunger.

Fruit feeding-tray:

Fruit feeding-tray dimensions: to suit feeding rate, fruit length and bulk density of fruits = 30 ×25 ×10 cm in length, width and height, respectively.

Fruit hopper bottom-slope = more than maximum friction and rolling angles of cucumber fruits with stainless steel surface (> 23^o) = 30^o.

Two feeding-discs:

Two feeding-discs dimensions: to suit fruit length and diameter were:

Feeding discs spacing = Maximum fruit length = 315 mm for first category of "Beta-alpha".

Feeding-disc groove diameter = Fruit diameter + 4 mm = 76 + 4 = 80 mm.

Two oriented plates:

Oriented-plate width = Maximum fruit-length – two-edges length = 315 - 40 = 275 mm.

Oriented-plate height = Maximum fruit-diameter = 76 mm.

Oriented-plate angle = more than maximum friction and rolling angles = 450.

Cutting knives of fruit edges: Two knives cut two edges of cucumber fruit. The knives are hinged with two sides of the hopper. The horizontal distance between each knife and feeder-disc edge can be adjusted by hinged rod. Also, the vertical distance can be adjusted by grooved plate which is connected with the knife.

Cutting knives spacing = Maximum fruit length – {(Maximum fruit length – Minimum fruit length) + two-edges length}

= 210 – {(210 – 196) + 40} = 210 – 54 = 156 mm for first category of "Beta-alpha".

= 262 – {(262 – 230) + 40} = 190 mm for second category of "Beta-alpha".

= 291 – {(291 – 262) + 40} = 222 mm for third category of "Beta-alpha".

Cutting knife height = more than the maximum diameter of cucumber fruit = 200 mm.

Cutting knife thickness = 2 mm.

Pressing mechanism: Cucumber-fruit pressing mechanism consists of plunger, eccentric wheel and connected rod. Reciprocating arm is used to press the fruit to seed-extraction tube.

Reciprocating arm stroke = Maximum fruit-length + 30 mm ≈ 345 mm.

Pressing-arm groove:

Groove length = Maximum fruit-length – Minimum fruit-length= 210– 196 = 14 mm for first category of "Beta-alpha".

Groove diameter = > maximum fruit-diameter = > 7.6 cm ≈ 8 cm.

No. of stroke per min to suit machine productivity = 18 to give 618 kg fruits h^{-1} and about 35 kg seeds h^{-1}.

Seed-extraction tube: Cucumber-seed extraction tube used to hold the seeds inside it. Cucumber-seed extraction tube has cross welded on circumference of the extraction tube to cut fruit peel. The seeds of second fruit push the seeds of the first one. Then, the seeds dropped in the end edge of the extraction machine. The seeds are collected in the box.

Seed-extraction tube diameter = Maximum fruit diameter – 2 × maximum rind thickness= 56 - 10 = 46 mm for first category of "Beta-alpha" variety.

= 61 – 10 = 51 mm for second category of "Beta-alpha" variety.

= 68 – 10 = 58 mm for third category of "Beta-alpha" variety.

Knife thickness = 1 mm.

Ejector wings: Two wings eject the two hollow-half of cucumber fruit at two sides of extraction tube. The two halves of cucumber fruits dropped into the gate underneath the extraction tube. The two halves of cucumber fruit are collected in a box under the gate.

Ejector-wing height = 0.5×minimum fruit-diameter – maximum rind-thickness= 0.5 × 56 - 10 = 18 mm for first category of "Beta-alpha" variety.

= 0.5 × 61 – 10 = 20.5 mm for second category of "Beta-alpha" variety.

= 0.5 × 68 – 10 = 24 mm for second category of "Beta-alpha" variety.

4 Conclusion

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

Physical properties of cucumber fruits: fruit diameter = 50 - 68, 60 - 76 and 56 - 75 mm, fruit length = 169 – 291, 230 – 315 and 180 – 295 mm, fruit mass = 210 – 540, 235 – 595 and 290 – 585 g/ fruit, number of seeds per fruit in = 350 – 580, 410 – 590 and 355 – 560, bulk density = 1.37, 1.30 and 1.40 g cm^{-3} and real density = 0.49, 0.44 and 0.45 g cm^{-3} for "Beta-alpha", "Hayel" and "Bahi" varieties respectively, bulb mass per fruit = 250 – 550 g/fruit, seed mass per fruit= 15 – 40 g/fruit, rind thickness = 7 – 10 mm and fruit volume = 200 – 500 cm^3 for all tested varieties..

Mechanical properties of cucumber fruits: penetration forces = 39.2 – 42.5, N, firmness = 90.1 99.1 100.9 N cm^{-2} and axial shear-force = 41.5 - 43 N for tested "Beta-alpha", "Hayel" and "Bahi" varieties.

The physical and mechanical properties were used in the design of the cucumber-seed extractor such as feeding mechanism, fruit edge-cutting knives, seed-extraction mechanism, pressing mechanism, and two-wings ejector.

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