ENGINEERING PROPERTIES REQUIRED FOR SNAP BEAN STRIPPING PROTOTYPE DEVELOPMENT

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ABSTRACT

The objective of this study was to determine the physical, mechanical properties and pods placement of two snap bean (Phaseolus vulgaris L) varieties Bronco and Contender which dominate bean production in Giza, Egypt. These properties were used to develop a snap bean stripping prototype. The average plant height was 43.79, 46.66 cm for 'Bronco' and 'Contender', respectively. pod characteristics were determined while pod placement shows that 56 %, 36.6% of pods on the top, 43 %, 54.5% of pods on the middle and 1 %, 8.9% of pods on bottom of the plant for Contender, Bronco respectively. The average pod detachment force was determined as: 6.57 and 12.68 N for 'Bronco' and 'Contender', respectively. The highest coefficient of static friction was obtained with a plastic surface in both varieties as 0.82 for 'Bronco' and 0.83 for 'Contender'. This was followed by steel and rubber surfaces.

INTRODUCTION

The snap bean (*Phaseolus vulgaris L*) is the most important economic species of the genus Phaseolus and is grown in many parts of the world **(Hassan, 2002)**. Among the leading producers were (in decreasing order) China, Indonesia, Turkey, India, Egypt, Morocco, Spain, Italy, Belgium, France, and USA **(FOA, 2010).** Among *Phaseolus* species, snap bean is the most widely grown, occupying more than 85% of production area sown to all *Phaseolus* species in the world. Many varieties of beans achieve high yield over a wide range of environments (**Singh, 1999). Annual Statistics (2010),** mentioned that in Egypt the cultivated area and

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production of summer, winter and nili seasons of snap bean were 17314, 39560, 5783 fed., and 84442, 158083, 28215 ton, respectively. The average yield of snap bean to 2010 seasons was 4.877, 3.996 and 4.879 ton/fed., respectively. On the other hand, **Glancey (2007)** mentioned that plant characteristics and structure (plant height , leaf width , leaf height, No. of Leaves, stem diameter, plant weight, commercial grade and plant population) play a key role in the feasibility and ultimate success or failure of mechanical harvesting systems. Research with other vegetable crops has suggested that plant architecture can affect harvester recovery (**Glancey *et al*. 1996)**. For example, lima bean recovery with a pod stripper combine was significantly higher with cultivars that set pods higher in the plant canopy, (**Glancey *et al.* 1997**). **Glancey, *et al*. (2005)** developed a mechanical harvesting index for bush-type crops that relate the pod-setting architecture of a variety to harvest loss based on the pod setting habits of several different cultivars. This index can be used by plant breeders and equipment designers to select varieties and machine configurations best suited for once-over harvest. **Glancey and Kee (2005)** stated that most vegetable crops require unique production techniques that necessitate the use of specialized equipment for mechanization. **Mesquita and Hanna (1995)** mentioned that the forces required to detach pods from stems were positively correlated with the pod location along ascendant nods, plant uprooting force, root length and stem thickness. Pod detachment force would help to define the best treatment to be applied to the crop during harvest to achieve the desired result.

The objective of this study was to determine some physical and mechanical properties for two varieties of snap beans: Bronco and Contender. These properties were used to develop a snap bean harvesting prototype.

MATERIAL AND METHODS

This research was conducted in Agricultural Engineering Department, Faculty of Agriculture, Cairo University during the year 2012.

1. Test Conditions

Freshly snap bean plants were randomly collected; the soil moisture content at harvest time was measured using Theta meter HH1. The moisture content of pods and leaves were determined in laboratory using oven method at 105°C for 24h **(AOAC, 1995)**. Laboratory measurements were performed on 50 samples.

2. Physical properties

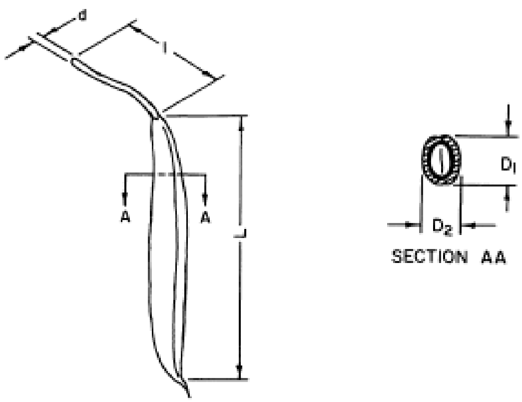
The measured snap bean physical properties included pod dimensions, mass, volume, bulk and true density, projected area and pod placements.

2.1 Plant height

The height of snap bean plant was measured using a steel tap.

2.2 Pod and Pedicel dimensions

The pod and pedicel shape as shown in Fig. (1), in terms of the three principal axial dimensions, that is length (L), width (W), thickness (T) and diameter (D) were measured using a digital caliper with an accuracy of 0.01 mm.



Note: dimensions $d_1$and d_2 taken at three positions along length of pod; mean recorded.

Fig. 1. Dimensions measured for each pod

2.3 Pod mass

The unit mass, (m) was measured by using a digital balance with accuracy of ± 0.01 g.

2.4 Volume

The volume of snap bean pod was determined by using graduated cylinder with accuracy of ± 1.0 ml.

2.5 Bulk and True density

The bulk density is the ratio of the mass of the sample to its container volume. It was measured by weighting a filled measuring box with known volume and calculated according to (***Mohsenin, 1986)***:

$$\rho_b = \frac{\mathbf{Sm}}{\mathbf{V}} \qquad \text{............ (1)}$$

Where

ρ_b	:	Bulk density, g/cm^3;
Sm	:	Mass of pods sample, g and
V	:	Volume of the box that contains pods sample, cm^3.

While, the true density is defined as the ratio of mass of the pods sample to its true volume (***Mohsenin, 1986***)

$$\rho_s = \frac{\mathbf{Sm}}{\mathbf{V_c}} \qquad \text{............ (2)}$$

Where

ρ_s	:	True density, g/cm^3;
Sm	:	Mass of pods sample, g and
V_c	:	True volume from volumetric calibration, cm^3.

2.6 Projected area

Pods projected areas were determined by image processing method. In order to obtain projected area, Scanner (Benq Deskjet F-4300) was used to make captured images for projected area of the pod. Captured images deal with computer software program (AutoCAD) to calculate the area.

2.7 Pods Placement

Glancey *et al.* (2004) determined the pod set within each zone by a pod count. In the field, A 12 cm high straight edge was placed vertically on the soil surface next to the plant stem as a means to identify three different vertical zones on the plant. Pods from each zone of each plant were pulled, and later counted in the laboratory, the percentages of pods in each zone were computed.

2.8 Mechanical properties of pods

2.8.1 Coefficient of static friction

Slippery slop method as shown in Fig (2) was used to determine the static coefficient of friction, it simply consists of increasing the angle of tilt of the plane to α when the object begins to slide down the inclined plane. Pods static coefficient of friction against different materials, namely plastic, steel and rubber were determined.

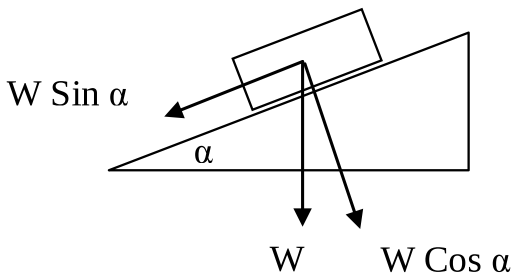


Fig. (2) Slippery slop method of measuring friction

2.8.2 Pod detachment force and pod firmness

The pod detachment force and firmness of snap beans (*Phaseolus vulgaris L*) cultivars Bronco and Contender were measured by using digital force gauge with accuracy of ± 1.0 g.

RESULTS AND DISCUSSION

The results obtained from test conditions indicated that the average soil moisture content at the harvest time was 29.83%. The moisture content at the time of harvest was 91.53%, 91.45% wet basis for Bronco and Contender pods, respectively. Results obtained from laboratory and field measurements are illustrated in Table (1). These values will be considered as data base to design the related functional subsystems of the modified stripping snap bean prototype.

Table 1. Descriptive statistics for physical properties of Bronco and Contender varieties

Physical property*	Bronco				Contender			
	Max.	Min.	Mean	Std. Dev.	Max.	Min.	Mean	Std. Dev.
H, cm	55	34	43.79	5.41	55	40	46.66	3.88
L, cm	15	12	13.33	0.77	16	12	14.37	1.19
W_a, mm	7.62	6.12	7.03	0.50	11.78	8.51	9.77	0.91
T_a, mm	6.65	4.82	5.76	0.46	6.60	4.30	5.66	0.71
Pd, mm	2.21	1.65	1.95	0.2	2.52	1.72	2.09	0.25
Pl, mm	32	10	14.8	0.28	33	13	23	0.26
m, g	6.60	3.16	4.63	0.81	10.34	4.46	6.86	1.49
Sm, g	57.03	53.21	55.61	2.09	58.73	46.75	54.33	4.77
V, cm^3	62.10	61.30	61.73	0.40	76.2	55.3	64.06	9.36
V_c, cm^3	166	150	155.33	9.24	190	170	180	10.00
ρ_s, g/cm^3	0.92	0.87	0.90	0.03	0.97	0.74	0.86	0.09
ρ_b, g/cm^3	0.38	0.32	0.36	0.03	0.35	0.26	0.30	0.03
A_p, cm^2	8.90	6.60	8.15	0.68	15.50	10.60	12.83	1.71

* Where: H: plant height; L: pod length, Wa: Average pod width, Ta, Average pod thickness, pd: Pedicel diameter, Pl: pedicel length, m: pod mass, Sm: Sample weight of pods, V: Bulk volume of the sample of pods, Vc: Calibrated or true volume of the same sample, ρ_s: true density; ρ_b: Bulk density and Ap: Projected area.

3. Physical properties of snap bean varieties

3.1 Plant height

Table (1) shows that the average values of snap bean plant height were 43.79, 46.66 cm for 'Bronco' and 'Contender', respectively. It was mentioned that the reel diameter of stripping reel and deflection unit correlated with plant height to minimize the harvesting losses, also fingers and bristle length were affected by plant height for stripping reel and deflection unit, respectively. On other hand plant height has a great effect on snap bean harvest efficiency and broken pods which need to be observed.

3.2 Pod and Pedicel dimensions

For Bronco variety: Pod length ranged from 12 to 15 cm with the mean value of 13.3 cm **(Table 1)**. The average pod width ranged from 6.12 to 7.62 mm with the mean value of 7.03 mm. The average thickness ranged from 4.82 to 6.56 mm with the mean value of 5.76 mm. **For Contender variety:** pod length ranged from 12 to 16 cm with the mean value of 14.37 cm. The average pod width ranged from 8.51 to 11.78 mm with the mean value of 9.77 mm. The average pod thickness ranged from 4.30 to 6.60 mm with the mean value of 5.66 mm. it was mentioned that pod detachment force is affected by pedicel diameter, length, pod size and direction of detachment.

3.3 Pod mass, density and projected area

The previewed data in **Table (1)** show that the average pod mass, true density, bulk density and projected area were 4.63, 6.86 g , 0.90, 0.86 g/cm^3, 0.36, 0.30 g/cm^3 and 8.15, 12.83 cm^2 for varieties Bronco and Contender receptively. Design consideration of conveying belt and cleaning unit is subjected to the previous results.

3.5 Pods Placement

Pod placement is an important characteristic of plant architecture in both snap bean varieties. The results revealed that 56 % of pods mostly concentrated on the top of the plant, 43 % of pods concentrated in the middle of the plant and 1 % of pods concentrated in the bottom of the plant for Contender variety, but for Bronco variety 54.5 % of pods mostly concentrated on the middle of the plant, 36.6 % of pods concentrated in the top of the plant and 8.9 % of pods concentrated in the bottom of the plant. It was observed that for mechanical harvest, pods should be distributed in the upper half of the plant on stiff, medium length peduncles, if pods are held too close to the main stem or are located too low on the plant, a snap bean prototype set to take these pods will also picks up unacceptable levels of trash. The average height of the first pod was 14 cm and 10 cm from the soil surface for Contender and Bronco, respectively. So, this height determines the minimum height for stripping fingers must to be set form soil surface.

3.6 Mechanical properties

The values of pod detachment force (PDF), pod firmness, static coefficient of friction (SFC) were determined and are arranged in Table (2).

Table 2. Descriptive statistics for mechanical properties of Bronco and Contender varieties

Property		Bronco				Contender			
		Max.	Min.	Mean	Stand. Dev.	Max.	Min.	Mean	Stand. Dev.
PDF, N		9.79	5.07	6.57	1.00	14.68	9.91	12.68	1.58
Pod Firmness, g_f		2564	1654	2011.12	261.94	3790	2047	2598.46	391.45
SCF*	R.	0.42	0.38	0.39	0.01	0.38	0.34	0.35	0.02
	S.	0.46	0.42	0.44	0.02	0.50	0.46	0.48	0.01
	P.	0.86	0.78	0.82	0.04	0.86	0.80	0.83	0.03

*SCF: static coefficient of friction, R: Rubber, S: Steel and P: Plastic

It was observed that Pod detachment force of pods from an individual plant could be quite variable, because PDF is affected by pod age, as reflected in pod size. However, the relationship between pod age and pod size is not always a direct one, because pod size itself can be influenced by many factors such as location on the plant, moisture stress or high temperature during flowering and pod development (**McCluskey 1996**).
From Fig (3) it is clear that the average pod detachment force is 6.57 N for Bronco variety and 12.68 N for Contender variety. Also it noticed that as the weight of pods increase the required detachment force increase.

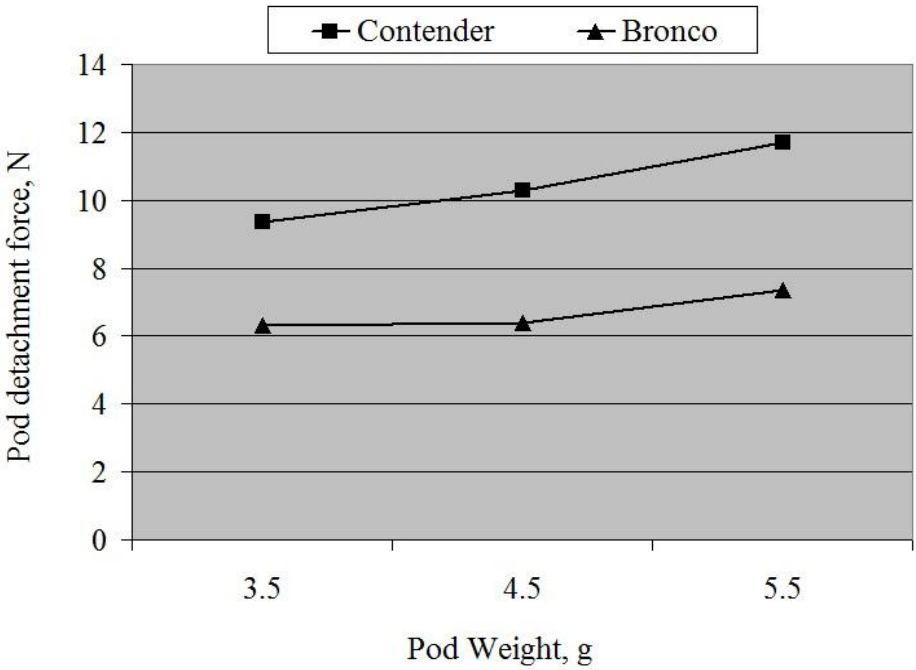


Fig. 3. Relation between pod weight and pod detachment force for snap bean varieties

The rate of pod detachment force increase was higher than the rate of pod weight increase. Detachment force for the two varieties of snap bean gives an indicator that Bronco, considered easy to harvest mechanically and requiring less detachment force than Contender.

It was found that failure of the pod-pedicel-stem structure occurred at four locations as shown in Fig (4). The resulting classes of detachment were: pedicel separated from stem (a), pod separated from pedicel (b), pod broken near pedicel (c) and stem broken with pod-pedicel-stem segment intact (d). The curve fitting program was used to derive the mathematical relationship for predicting the pod detachment force (PDF). The obtained results of snap bean PDF in Table (2) were processed to give the best fit relationship which was linear form:

Fig. 4. Failure types of the pod-pedicel-stem structure

$$PDF = a_1\ m + c_1 \qquad \text{............ (3)}$$

where:

PDF = Pod Detachment Force, N;

m = Pod wieght, g;

a_1, c_1 = Empirical constants.

Table (3) shows the empirical constants and coefficient of determination for the two varieties.

Table 3. The values of empirical constants and the coefficient of determination for equation (3) for the two varieties

Variety	a_1	c_1	R^2
Bronco	0.52	5.6367	0.8144
Contender	1.165	8.12	0.9977

It's clear from the showed values that the pod firmness varied for each variety, the average pod firmness 2011.12 and 2598.46 g for Bronco and Contender respectively. The static coefficient of friction varied on three different surfaces, the average was 0.39 and 0.35 on rubber, o.44 and 0.48 on steel and 0.82 and 0.83 on plastic with the Bronco and Contender pods, respectively. Coefficient of static friction of Bronco and Contender pods on various surfaces showed that static friction on rubber is less than steel and plastic for both varieties.

4. Prototype development

It was found that snap bean harvesting machines employ slender steel fingers or tines that comb through the plants, removing the pods and most of the leaves and throwing them onto a belt or other conveyor. A mechanical and aerodynamic means are employed on the machine to remove most of the trash.

4.1 Original prototype

Abdelrhman (2008) fabricated and evaluated the 1st snap bean stripping prototype consisted of five functional subsystems, frame and hitch, concave and stripping unit, container, transmission system and lifting stripping unit. The overall dimensions of stripping prototype were 150 x110 x 70 cm.

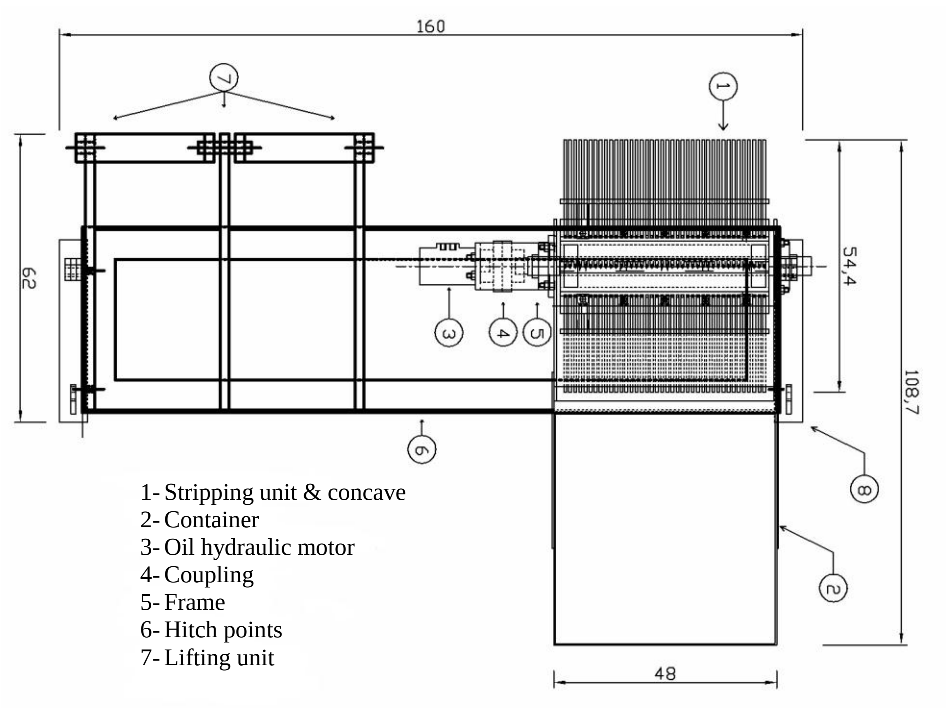


Fig. 5. Plan of the 1st snap bean stripping prototype

4.2 Development justifications

Results of testing and evaluation of the 1st snap bean stripping prototype pointed to several constraints as:

- Performance rate of the prototype at the suitable operating speed was 0.067 fed/h which is considered too low.
- Snap bean harvesting criteria were: pod removal percentage (83.39%), un-removed pods percentage (16.61%), pods losses percentage (28.23%) and damaged pods percentage (14.5%). These results given significance that it is difficult to use snap bean prototype economically.
- Snap bean stripping prototype was just tested with one variety, while the developed prototype will be used with more common varieties.

4.3 Development idea

Development idea is depending on the following:

- Adding a deflection unit to tilt snap bean plant toward the stripping unit.
- Increasing the stripping rows from 4 to 8 rows.
- Changing the distance between stripping fingers a long the same row.
- Changing direction of the stripping unit from clockwise to un-clockwise direction
- New design for installing fingers with stripping reel.

4.4 Developed prototype

It was found that snap bean stripping prototype development is affected by several factors such as:

1- Plant factors were variety characteristics, pod location along ascendant nods, pod placement, root length, stem thickness, plant erectness, plant population and plant height.

2- Machine operation variables were stripping reel speed and forward speed, the interactions of reel speed with plant size, Plant uprooting force, pod breaking and detachment forces, the height of the stripping reel from the ground surface, speed and position of the conveying device situated behind the combing fingers to assure the removal of the product from further impacts and speed of the feeding reel, conveying band or brushes, which are installed in front of the combing fingers.

So, it is required to develop a new stripping prototype profitable to the Egyptian farming environment driven by mechanical power. It should be reliable with fail safe design, high performance and safety. the components of required development were a deflection unit , Stripping reel, Conveying belt , Cleaning unit, Hydraulic transmission system, Frame and hitching and Ground roller.

1- Deflection unit

It can be designed as conveying band and reel finger as shown in Fig (6), spiral brush as shown in Fig (7) and apron belt.

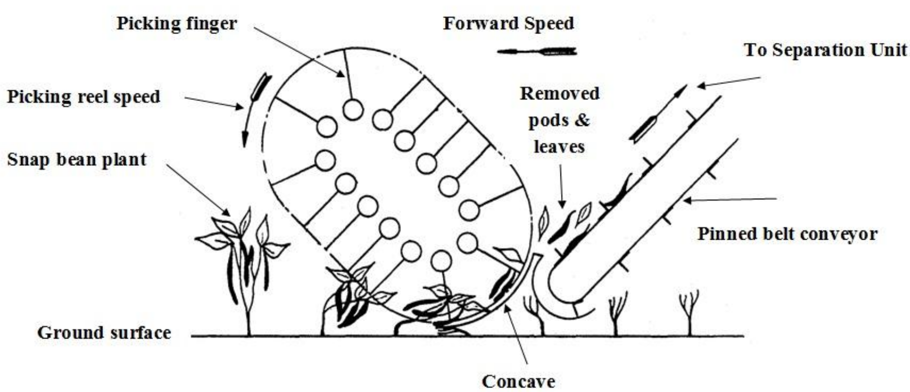


Fig. 6. Conveying band and reel fingers as a deflection unit

Deflection unit delivers the snap bean plant to stripping mechanism and holds the plants during the stripping process.

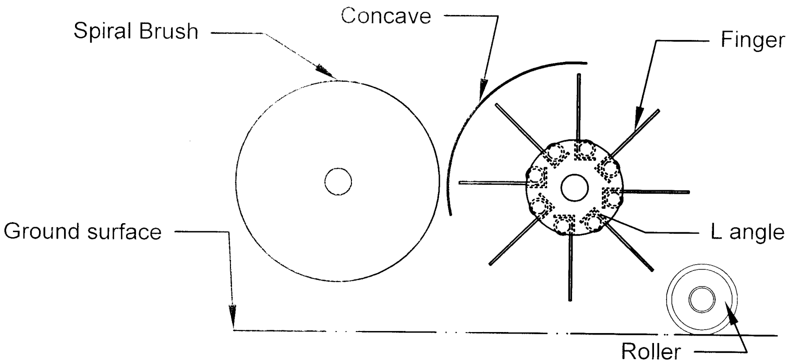


Fig. 7. Side view of spiral brush reel fingers as a stripping unit

In an ideal condition, the top of the snap bean stem experiences a deflection δ in m due to action of the spiral brush as shown in Fig. (8). It was noticed that the spiral brush design is affected by plant height and pod ultimate strength.

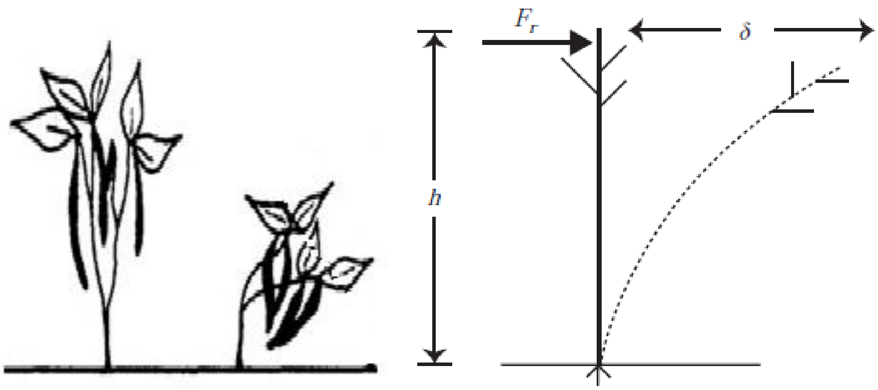


Fig. 8. A plant being deflected by spiral brush

Baruah and Panesar (2005) reported that the stem resists the deflection by generating a resisting force Fr. The following classical formula for the deflection of cantilever beam is used to estimate Fr in kN:

$$Fr = \frac{3nEI\delta}{h^3} \quad \text{............} \quad (4)$$

where:

- E = Modulus of elasticity of the snap bean stem, kPa;
- I = Geometrical moment of inertia of the transverse section of the snap bean stem, m^4;
- h = Plant stem height, m
- n= number of snap bean stems deflected by a deflection unit
- δ= Stem deflection, m.

CONCLUSION

The adaptive or developmental design takes an existing concept and seeks an incremental advance in performance through a refinement of the working principle. So, this study aimed to determine plant factors of two snap bean varieties Bronco and Contender to be considering in developing a snap bean stripping prototype. The following conclusions can be drawn:

1- To develop a modified snap bean stripping prototype, we take in consideration the force that is required for pod detachment, pods dimensions, plant height, pod placement, coefficient of static friction.

2- Pod placement were allocated as 56 %, 36.6% of pods on the top, 43 %, 54.5% of pods on the middle and 1 %, 8.9% of pods on bottom of the plant for Contender, Bronco respectively.

3- The highest coefficient of static friction was obtained with a plastic surface in both varieties as 0.82 for 'Bronco' and 0.83 for 'Contender'. This was followed by steel and rubber surfaces.

4- Pod detachment force was 6.57, 12.68 N for Bronco and Contender, respectively. Results defined that pod detachment force is in linear relationship with pod weight and indicated that Bronco is easy to harvest mechanically and Contender , may considered difficult to harvest.

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الملخص العربي

الخصائص الهندسية المتطلبة لتطوير نموذج أولى لحصاد الفاصوليا الخضراء

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تمثل معرفة الخصائص الطبيعية والميكانيكية لأصناف الفاصوليا أهمية كبيرة في تصميم وتطوير آلات حصاد الخضر ومعدات التداول لعمليات ما بعد الحصاد. لذلك تمت دراسة هذه الخصائص لصنفى الفاصوليا الخضراء (برونكو – كنتندر) لتحديد مؤشرات تطوير نموذج لحصادها.

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يعتمد تطوير النموذج على إضافة وحدة لتوجيه النبات تجاه وحدة اللقط وزيادة عدد صفوف أصابع اللقط من ٤ الى ٨ صفوف وتغيير المسافة بين الأصابع على الصف الواحد مع النظر فى طريقة تثبيت الأصابع على الاسطوانة وسهولة التحكم فى الخلوص بين أصابع اللقط والصدر بهدف رفع نسبة الفصل وخفض نسبة الفواقد والتلف للقرون وزيادة معدل آداء النموذج.

من الخصائص تم دراستها طول النبات وخصائص القرون وقوة فصل القرن وصلابة القرن وتوزيع القرون على النبات ومعامل الاحتكاك الاستاتيكى (مع أسطح مختلفة: المطاط، الحديد، البلاستيك)

و قد بينت الدراسة ما يلي:

١- تلعب المؤشرات المتحصل عليها من الدراسة دورا حيويا في تطوير نموذج لحصاد الفاصوليا الخضراء مثل القوة اللازمة لنزع القرن، توزيع القرون على النبات ، الأبعاد الهندسية للقرن والنبات، كثافة القرن ومعامل الاحتكاك.

٢- أظهر توزيع القرون على النبات قيم ٥٦% ، ٣٦,٦% بالجزء العلوى من النبات ، ٤٣% ، ٥٤,٥% بمنتصف النبات ، ١% ، ٨,٩ % بالجزء السفلى من النبات لكل من الصنفين كنتندر وبرونكو على الترتيب.

٣- أعلى قيم لمعامل الاحتكاك الاستاتيكى كانت مع السطح البلاستيك لكلا الصنفين بقيم ٠,٨٢ لصنف برونكو ، ٠,٨٣ لصنف كنتندر يليها سطح الحديد ثم المطاط.

٤- متوسط القوة اللازمة لنزع القرن ٦,٥٧ نيوتن ، ١٢,٦٨ نيوتن للصنفين برونكو وكنتندر على الترتيب. واقترحت النتائج وجود علاقة خطية بين القوة اللازمة لنزع القرن ووزن القرن، كما أنها تعطى مؤشرا لتمييز الأصناف من حيث سهولة أو صعوبه حصادها ميكانيكيا.