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Design and development of a chickpea stripper harvester

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Abstract

Saving cost and time was a motivation to develop a mechanized harvesting system for chickpeas, which are manually uprooted on fallow fields in developing countries. A tractor-pulled harvester with a modified stripper header was designed and fabricated, in which passive fingers with V-shaped slots removes chickpea pods from anchored plant; batted reel sweeps the pods across the platform. Field experiments were conducted to determine the effect of slot width and reel speed on machine performance in terms of harvesting losses. Minimal losses were found when the design was configured with a slot width of 4 cm, reel speed of 50 rpm and reel kinematic index of 1.6. The prototype harvester with a 1 m working width produced the work rate of 0.18 ha h^{-1} and exhibited acceptable working quality. The main conclusion is that the modified stripper harvester can work in unevenness ground where other machines cannot operate.

Additional key words: *Cicer arietinum;* losses; mechanized harvesting; performance; stripper header.

Introduction

The mechanization of chickpea (*Cicer arietinum* L.) harvesting has been a long-term objective of farmers on fallow fields in developing countries. Low yield of the crop, low stature of the plant, uneven ripening and high probability of shattering losses at maturity are challenging for cutting-bar headers. Haffar *et al.* (1991) and Siemens (2006) applied conventional combine harvesters for chickpeas but losses were high. Chakraverty *et al.* (2003) reported that the optimum losses for mechanized chickpea harvesting were 5.5%. A major shortcoming of combines is a wide header that does not adapt to unevenness in the ground, which causes excessive pod shattering losses.

The crop has been traditionally harvested manually by pulling the stems to avoid excessive losses (Bansal & Sakr, 1992; Konak *et al.*, 2002). Hand-picking laborers collect the chickpea bushes by hand and then place them on the ground in a heap; they collect all of the materials and transport them to a stationary thresher to separate the grain. The process of pulling the entire plant by hand and uprooting the plant from the soil has many disadvantages: the nodules of nitrogen-fixing bacteria are lost, the quality of the plant residue for feeding animals is decreased due to a salty taste and the laborer costs are increased compared to other harvesting systems.

Stripping mechanism and methodology have potential to become an effective system for chickpea harvesting. Stripper headers have rotating rotor and teeth to detach pods from anchored plant, and an adjustable hood to deliver materials. Behroozi-Lar & Huang (2002) designed and developed a chickpea harvester with a Shelbourne Reynolds' stripper header and reported that the losses were high. The main disadvantage of stripper headers is that they have excessive losses in low harvest yield and/or immature crops (Tado *et al.,* 1998).

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Abbreviations used: D (reel diameter, m); H_m (weight of removed pods with the stem, kg); H_p (weight of harvested pods on the header, kg); L (total losses, %); L_p (weight of remained pods on the plant, kg); L_s (weight of shattered pods on the ground, kg); MOG (material other than grain); n (speed of the reel, rpm); v (forward speed, km h^{-1}); V (peripheral speed of the reel km h^{-1}); λ (reel kinematic index, dimensionless).

Redesign and modification of the stripping mechanism increase the work quality. The design of the system must take the performance and cost into account (Kutzbach & Quick, 1999; Rovira-Más *et al.*, 2010). Less losses than typical losses of conventional harvesting methods in separation and threshing units (Srivastava *et al.*, 2006), less material other than grain (MOG), and greater throughput and forward speed (Hanna & Quick, 2007) are the advantages of stripper headers.

The main merit of this work was to design and evaluate a modified stripper harvester that is suitable for harvesting chickpeas cultivated on fallow fields in developing countries. The functional requirements were to harvest relatively dry chickpeas with negligible losses, and to operate at a low working height to maximize recovery of pods.

Material and methods

The design procedure for the development of the harvesting system and improvements the performance of the functional operators were depicted in Fig. 1. Field experiment analysis, computer aided design, machine elements design and expert knowledge strategy were used to develop a modified stripper harvester.

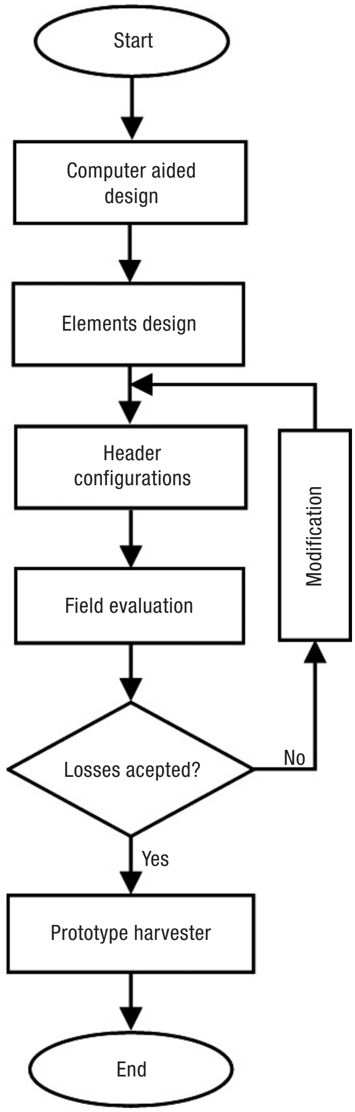

Figure 1. Flow chart of the design for a chickpea harvester.

Prototype harvester

A model was designed using AutoCAD 2007 for the development of the stripper harvester (Fig. 2a). A platform with forward-opening fingers produces a modified stripper system in which the plants move through the V-shaped slots and are stripped. The platform supports the passive fingers and delivers the harvested material. The upward direction of the finger tips enables them to pick up lodged crops. A reel with three bats and peripheral diameter of 60 cm sweeps the pods across the platform and pushes the top of the chickpeas over the header. A chain and a sprocket system produce different reel speeds, ranging from 30 to 110 rpm.

Gauge wheels guides the header and allows the platform to float the fingers over the terrain; provides the power utilized includes rolling resistance of the machine, and the power to detach, transfer and convey pods. A conveyor with an endless chain sweeps the harvested material which falls onto the header, along the inclined surface of the conveyor bottom into the sacker unit to a height of 1 m above the ground. An adjustable screw sets the working height range from 2 to 10 cm for the header. Fig. 2b shows the actual view of the tractor-pulled harvester developed for chickpeas.

Experimental area and layout

Experiments were conducted on the Dooshan farm at University of Kurdistan and Gerizeh farm of Agricultural Research Station during the summers of 2007 and 2008 using Kabuli, a very common chickpea varie-

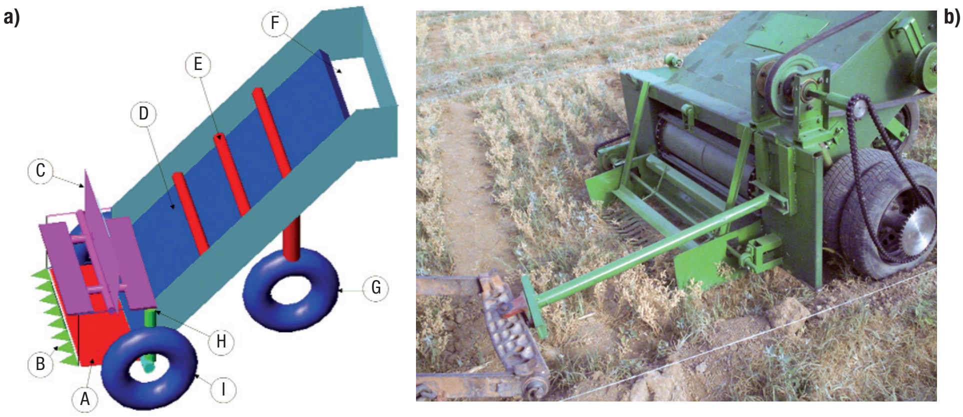

Figure 2. (a) 3-D model of a prototype chickpea harvester. A, platform; B, finger; C, reel; D, conveyor bottom; E, endless chain; F, sacker unit; G, steering wheel; H, adjustable screw; I, gauge wheel. (b) Tractor-pulled for chickpea stripper harvester.

ty on a typical fallow field. Half a hectare was ploughed and disk-harrowed for sowing chickpeas using local laborers. Experiments were performed with row spacing and distance of 35 cm between individual plants. The spacing between the plants is high and there is not any interaction between the plants. The yield was 300 kg ha^{-1}, which is typical of this area. Crop properties relevant to harvesting were measured during trials and are presented in Table 1.

The experimental harvester was operated along the rows by 6 m and losses, excluding pre-harvest losses, were measured after harvesting. Pre-harvest losses were measured by collecting pods from ground prior to experiment. Loss sampling was performed using a 50 × 50 cm frame. Total losses (L), which are the kilograms of pods shattered by the header (L_s) in addition to those remained on the plant (L_p), were measured by collecting them in field and calculated by the following equation:

$$L = \frac{L_p + L_s}{L_p + L_s + H_p} \times 100 \qquad [1]$$

Table 1. Physical properties of chickpea (Kabuli) during harvest

Crop properties	Measured value	Range	SD
Grain weight (g)	0.25	0.12-0.52	0.10
Moisture content (% w.b.)	12.5	10.9-16	1.62
Plant height (cm)	22.4	10-33	0.55
Pod weight (g)	0.38	0.21-0.69	0.12

The measured values are average of 100 samples in two years.

where H_p, L_s and L_p are the weight (in kg) of harvested pods on the header, detached pods on the ground (shattering losses) and remained pods on the plant after harvesting, respectively.

The working height was adjusted at 5 cm (above the ground), to reduce interference of soil with the platform, and to harvest maximum pods. The experimental harvester was operated at an average forward speed of 3 km h^{-1}. The distance between reel baths and fingers was fixed at 1 cm to avoid the narrow entrances be blocked by the stems and weeds.

These arrangements were used in the two years of trials and, in addition, five experiments were conducted to design and evaluate the prototype harvester: two for platform design, two for different configurations of the header, and the fifth to compare the losses between the fabricated chickpea harvester and the manual harvesting.

Stripper header

Reel

An essential requirement for continuous working of the header arrangement is that the reel speed must be greater than the ground speed (Sidahmed & Jaber, 2004; Golpira, 2013):

$$\lambda = \frac{V}{v} \succ 1 \qquad [2]$$

where λ is the reel kinematic index (dimensionless), v the forward speed of tractor in km h^{-1}, and V the peripheral speed of the reel in km h^{-1}. V can be obtained:

$$V = 0.1884 \cdot D \cdot n \qquad [3]$$

Table 2. Reel variables at machine forward speed of 3 km h^{-1}

Reel variables	Values			
Kinematic index (λ)	0	1.6	2.4	3.4
Reel speed (km h^{-1})	0	5	7.3	10.3
Reel speed (rpm)	0	50	73	103

where D is the reel diameter in m, and n the speed of the reel in rpm.

For the machine forward speed of 3 km h^{-1} and kinematic index of 1, the Eq. [3] can be modified:

$$D \cdot n = 15.91 \quad [4]$$

According to the Eq. [4], the critical speed of the reel is 26.5 rpm for the reel diameter of 0.6 m. Critical speed ($\lambda = 1$) was avoided to reduce shattering losses. Therefore, the reel speed should be > 26.5 rpm. The performed reel speeds of 50, 73 and 103 rpm produce the kinematic indexes of 1.6, 2.4 and 3.4, respectively (Table 2).

Platform

Field experiments were performed using five different slot widths (3, 4, 5, 6 and 7 cm) on the 25th, 27th and 29th of June 2007 to determine optimum slot spacing. Plants were stripped by slot widths followed by a measurement of the pods remained on plant (L_p) and those removed with the stem (H_m). The first one is considered a true loss, while the second one may block the fingers spacing to produce shattering losses. Furthermore, the H_m requires more energy to separate the pods from MOG during the threshing process. The experiment was conducted based on a randomized complete block design with three replications.

Header configurations

Field experiments were carried out on two platforms (with 4- and 5-cm slot widths) and four reel speeds (0, 50, 73 and 103 rpm) on the 2nd and 4th of July 2008. The trial was conducted as a factorial (2 platforms × 4 reel speeds) based on a completely randomized design with three replications.

Harvester evaluation

Total losses for prototype harvester were compared with those for hand harvesting performed by local laborers. Trial was conducted on the 25th, 26th and 28th of July 2008 based on a randomized complete block design with three replications.

Statistical analysis

The experimental data were analyzed using a variance analysis to determine the total losses based on L_s and L_p. The means of the treatments (L_s and L_p) were compared with LSD analysis at a 5% level of probability for the different header configurations.

The analysis of variance was performed to determine the difference (10% level of probability) in losses for the hand and prototype harvesting. Furthermore, the means of the treatments (L_p and H_m) were compared

Table 3. Percentage (three repetitions) of total yield of pods remained on anchored plants (L_p) and pods removed with the stem (H_m) using five different slot widths

Slot width	L_p			H_m		
	1	2	3	1	2	3
3 cm	0	3	1	9	5	9
	0	3	1	9	4	0
	0	3	7	9	9	9
4 cm	2	3	1	7	1	0
	2	3	2	1	4	0
	5	3	6	1	2	0
5 cm	3	5	8	1	0	0
	7	4	4	3	0	0
	8	10	6	5	0	0
6 cm	11	19	17	0	4	0
	17	19	11	0	4	0
	9	9	9	0	1	0
7 cm	10	9	15	0	0	0
	18	18	17	0	0	0
	19	11	15	0	0	0

Table 4. Yield of pods remaining on the plant (L_p) and pods removed with the stem (H_m) at five slots spacing

	Slot width				
	3 cm	4 cm	5 cm	6 cm	7 cm
L_p (kg ha^{-1})	6.5^b	9.76^b	19.5^b	42.6^a	45.88^a
L_p (%)	2	3.2	6.5	14.2	15.2
H_m (kg ha^{-1})	22.79^a	6.51^b	3.25^b	3.25^b	0^b
H_m (%)	7.5	2	1	1	0

Values with the same letter in each row are not different at a 10% level of significance.

Table 5. Percentage of L_p (total yield of pods remained on anchored plants), L_s (total yield of pods removed with the stem) and total losses using two slot widths and four reel speeds

Rees speed	Slot widht					
	4 cm			5 cm		
	L_p	L_s	Total losses	L_p	L_s	Total losses
0 rpm	19	29	48	33	50	83
	38	31	69	25	18	43
	10	27	37	29	19	48
50 rpm	14	13	27	31	6	37
	10	12	22	24	6	30
	14	22	36	32	7	39
73 rpm	9	3	12	14	5	19
	5	4	9	13	14	27
	4	2	6	10	9	19
103 rpm	12	18	30	35	21	56
	11	42	53	17	11	28
	15	37	52	15	55	70

with Duncan's multiple range tests at a 10% level of probability for the platform trial.

Results and discussion

The analysis of variance (ANOVA) for determining the slot width demonstrated that the slot width significantly affected losses in the L_p and H_m (Table 3). A wider spacing resulted in more L_p and less H_m comparing to narrower slots which resulted in more H_m and less L_p. A comparison of the means indicated that the slots with a 3-, 4- and 5-cm width had the lowest L_p compared to the slots with a 6- and 7-cm spacing (Table 4). In contrast the slot with a 3-cm spacing had the highest percentage of the H_m. A combination of the results demonstrated that the slots with a 4- and 5-cm width were optimal to minimize the losses.

The results of the variance analysis from the header configurations experiment indicated that the slot width did not have a significant effect on the total losses (Table 5). Furthermore, the interaction between the slot spacing and reel speed did not have significant effect on losses. Significant differences in total losses were detected as a function of reel speed. Means comparison of the total losses for the prototype harvester showed significant difference between the reel speeds of 73 and 103 rpm, while the difference between 50 and 73 rpm was not significant (Table 6).

The experiment result indicate that the chickpea stripper header with a slot width of 4 cm, reel speed of 50 rpm and kinematic index of 1.6 had the least losses with better stability and more energy saving (Figs. 3a,b). By this performing configuration, harvesting losses were accepted as compared to manual harvesting. The harvester performed well in separating pods from the plant while leaving the stems on the ground. Furthermore, the stripper header with a 1-m working width and working height of 5-cm reduced the effect of unevenness of the ground and low stature of chickpea plants.

This prototype, which was adapted at an early stage of the study as a simple, robust and inexpensive structure suitable for the development phase of the chickpea harvester, causes the wheels to interfere with the rows resulting in shattering. Tractor-mounted harvester with a pneumatic conveying system, floating header, keyhole-added platform and power take-off (p.t.o.) powered reel is an alternative arrangement, which is now being considered in the second phase of the study.

For a forward speed of 3 km h^{-1}, a 1 m working width and field efficiency of 60% the field capacity of the

Table 6. Effect of the reel speed on the total losses for the prototype harvester

	Reel speed			
	0 rpm	50 rpm	73 rpm	103 rpm
Losses (kg ha^{-1})	61.56^{a}	42.2^{ab}	24.5^{b}	74^{a}
Total losses (%)	20	16.4	8.1	24

Values with the same letter in the same row are not different at a 5% level of significance.

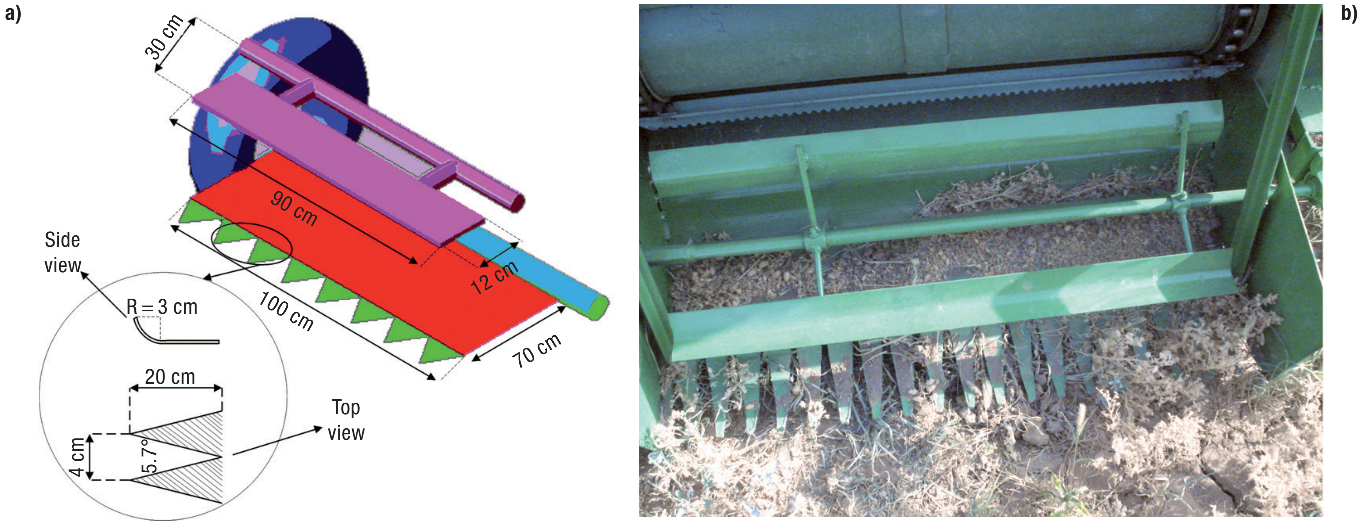

Figure 3. (a) 3-D model of a prototype chickpea harvester header. (b) Experimental chickpea harvester header.

harvester is 0.18 ha h^{-1}. For manual harvesting, 8 labor-days were needed to harvest a hectare, which correspond to the field capacity of 0.015 ha h^{-1}. This means that one hour operation of this prototype is equivalent to 12 man-hours. This ratio justifies the price of the equipment which is $ 3,000, hence it will be compensated during the economic life (~10 years) of the harvester.

In conclusion, the designed prototype harvester has potential to improve chickpea harvesting systems with saving cost and time. It can provide an alternative to manual harvesting. Future research needs to be focused on the decrease of losses for the commercialization of the stripper harvester.

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