

# Conceptual design of a chickpea harvesting header

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## Abstract

Interest in the development of stripper headers is growing owing to the excessive losses of combine harvesters and costs of manually harvesting for chickpeas. The design of a new concept can enhance the mechanized process for chickpea harvesting. A modified stripper platform was designed, in which passive fingers with V-shape slots remove the pods from the anchored plant. The floating platform was accompanied by a reel to complete the harvesting header. Black-box modeling was used to redesign the functional operators of the header followed by an investigation of the system behavior. Physical models of the platform and reel were modified to determine the crucial variables of the header arrangement during field trials. The slot width was fixed at 40 mm, finger length at 40 mm, keyhole diameter at 10 mm and entrance width at 6 mm; the batted reel at peripheral diameter of 700 mm and speed at 50 rpm. A tractor-mounted experimental harvester was built to evaluate the work quality of the stripper header. The performance of the prototype was tested with respect to losses and results confirmed the efficiency of the modified stripper header for chickpea harvesting. Furthermore, the header with a 1.4 m working width produced the spot work rates of 0.42 ha h<sup>-1</sup>.

**Additional key words:** black-box modeling; chickpea harvesting; design; losses; stripper header.

## Introduction

Chickpea (*Cicer arietinum* L.) harvesting has remained unchanged for many centuries. As the available varieties do not have adequate height, most Iranian farmers harvest and handle chickpeas manually (Suppl. Fig. 1 [pdf online]). Furthermore, manually harvesting of the crop was reported in Turkey (Konak *et al.*, 2002). Low height of plant, low yield and low pod detaching force (8.3 N in 12% moisture content, w.b.); high shattering losses and high shear strength (2.8 to 9 MPa for different stem diameters) are the main challenges for chickpea harvesting equipments (Golpira *et al.*, 2009).

Additionally, the crop moisture content and friction coefficient of header-stem have an effect on harvesting performance. For the black steel surface, by increasing the moisture content of chickpea grains from 7.5% to 15% (wet basis), the value of the friction coefficient

was increased. For the galvanized steel surface at sliding velocity of 5 and 20 mm min<sup>-1</sup>, by increasing moisture content, the values of friction coefficient was decreased. For velocities of 100 and 500 mm min<sup>-1</sup>, the behavior was similar to that of the black steel surface (Tavakoli *et al.*, 2002). The minimum and maximum coefficient of friction was 0.28 and 0.33 for galvanized steel and fiberglass, respectively (Tabatabaefar *et al.*, 2003).

The sparse literature regarding the mechanical harvesting of chickpeas demonstrates that the conventional headers of combine harvesters suffer from excessive pod losses. The working height, reel position and forward speed influence the losses, which, according to Chakraverty *et al.* (2003), must be less than 5.5% for chickpea harvesting. The major shortcoming of the grain combines used for chickpea harvesting is a wide header that does not adjust to unevenness of the ground which causes excessive pod

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Abbreviations used: MOG (material other than grain); p.t.o. (power take-off). Nomenclature:  $D$  (reel diameter, m);  $n$  (speed of the reel, rpm);  $n_w$  (speed of the ground wheel, rpm);  $T$  (number of tooth on reel gear);  $T_w$  (number of tooth on ground gear);  $v$  (forward speed, km h<sup>-1</sup>);  $V$  (peripheral speed of the reel, km h<sup>-1</sup>);  $W_{dp}$  (weight of detached pods on the header, kg);  $W_{pg}$  (weight of detached pods on the ground, kg);  $W_{ud}$  (weight of remained pods on the plant, kg);  $\dot{I}$  (reel kinematic index, dimensionless).

shattering losses. Furthermore, the low height of plant during chickpea harvesting is inappropriate for conventional headers.

Detachment of pods from the plant with no stem has been suggested as a feasible method for chickpea harvesting. Some research has been done on chickpea strippers, in which rotating comb detaches pods from anchored plant, but success has been rather low. Behrooz-Lar & Huang (2002) developed a Shelbourne Reynolds' stripper header for chickpea harvesting and reported that the losses were high. Though stripper headers had excessive losses in low yields (Tado *et al.*, 1998), modification of the method improves the chickpea harvesting systems (Golpira & Tavakoli, 2011).

The design of the system must take the performance, cost, size and weight into account (Rovira-Más *et al.*, 2010). Losses, MOG-throughput and machine capacity are performance factors for harvesting equipments (Kutzbach & Quick, 1999). Preventing material other than grain (MOG) from entering the stripper headers allow for greater throughput and forward speed (Hanna & Quick, 2007). To improve machine performance a modification of the mechanical systems can be performed by mathematical, physical and/or numerical methods.

Sometimes mathematical or soft computing is rather complex and may be impractical, so black-box modeling can be employed to improve system performance. Black-box modeling is often used for conceptual design of a system in which experience-based performance characteristics are assigned to components of the machine, followed by an investigation integrated system behavior, without much regards for the details within the "black boxes" (Collins *et al.*, 2010). Conceptual design is an engineering activity where complete and exact information and knowledge of requirements and constraints are difficult to obtain (Hsu & Woon, 1998).

Since a harvesting mechanism for chickpeas does not exist in the study area, the design of a stripper header was planned. Modification was achieved through modeling, elements design, machine development and field testing of the header arrangement.

## Material and methods

### Design procedure

To develop and modify the existing technology for chickpea harvesting equipments, some physical and

mechanical properties of grain and MOG were studied. Modeling techniques, harvesting machinery fundamentals and experience-based knowledge were used to design the functional operators of the header. Header was modeled as a black-box with two inputs of platform and reel, and an output of harvesting losses. Field evaluation results of the harvesting losses were used for the machine improvements. The slot width, finger length, keyhole diameter and entrance width are the crucial variables of the platform which were optimized. Additionally, the speed, diameter and number of bats for the reel were determined. The design procedure for development of the harvesting header is depicted in Fig. 1.

### Conceptual design

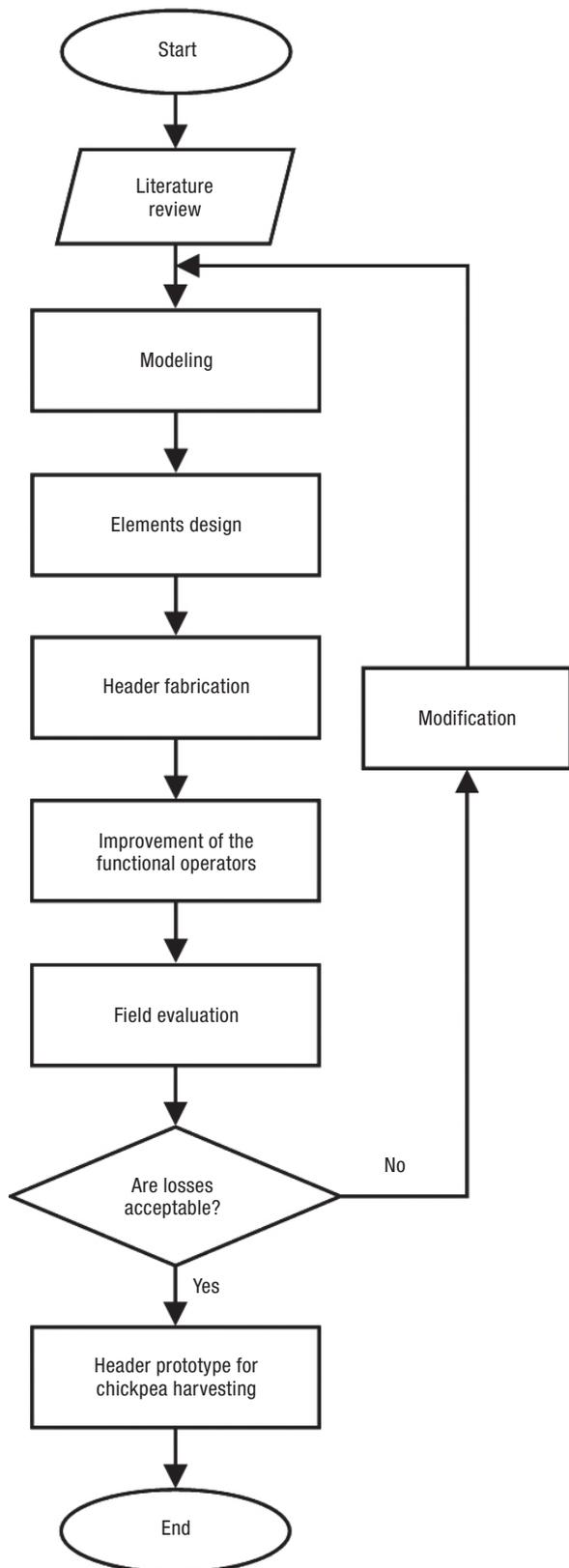
A modified stripper header was designed using AutoCAD 2007 for chickpea harvesting (Fig. 2). A platform was accompanied by a reel to transfer detached pods and reduce losses. Platform detaches pods from the plant and the reel sweeps the material. The platform, with forward-opening fingers, and reel are the functional operators of the chickpea harvesting header.

A ground wheel guides the header and transmits power to the reel. An adjustable screw sets the working height and an arm connects the header frame to the harvester chassis for operational safety. When the platform is pushed back by an obstacle, the arm joint cracked, the support released and the header rotates partially around the hitch point. If the machine failed to pass the object, the hitch point breaks and the header is released and rotated safely.

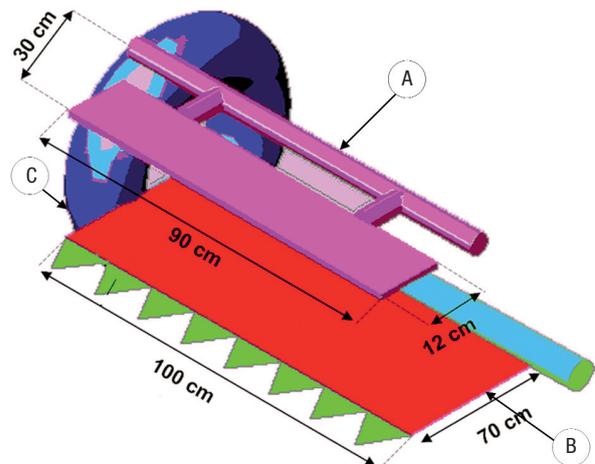
### Reel

The reel speed, peripheral diameter, and the number of bats are the operational characteristics for the reel. An essential requirement for reel operation is that the reel speed must be greater than the ground speed (Bosoi *et al.*, 1991; Tado *et al.*, 1998; Kutzbach & Quick, 1999; Srivastava *et al.*, 2006; Hanna & Quick, 2007). If reel speed is fixed at the optimum setting, the reel bats sweep and deliver separated pods. To determine the reel speed, the theoretical analysis can be calculated as follows:

$$\lambda = \frac{V}{v} > 1 \quad [1]$$



**Figure 1.** Flow chart of the conceptual design for a chickpea harvesting header.



**Figure 2.** The modified stripper header for chickpea harvesting. A: Reel; B: platform; C: ground wheel.

Moreover, the peripheral speed of the reel ( $V$ , in  $\text{km h}^{-1}$ ) can be obtained as follows:

$$V = 0.1884 Dn \quad [2]$$

where  $\lambda$  is the reel kinematic index (dimensionless),  $v$  the forward speed of tractor in  $\text{km h}^{-1}$ ,  $D$  the reel diameter in m, and  $n$  the speed of the reel in rpm.

By substituting [1] for [2], the critical speed ( $\lambda = 1$ ) of the reel for the machine forward speed of  $3 \text{ km h}^{-1}$  can be calculated as below:

$$Dn = 15.91 \quad [3]$$

According to Eq. [3] for the reel, the speed should be more than 23 and 53 rpm for the diameters of 700 mm and 300 mm, respectively.

The design was a reel with three bats and adjustable diameter which varied from 20 to 70 cm (Fig. 3a,b), whereas the redesign was the following reels: (i) four bats, and peripheral diameters of 700 mm; (ii) four bats, and peripheral diameters of 300 mm. The values of  $\lambda$ , ranging from 1.3 to 3.4, were provided by a chain and sprocket system which was modified to a cassette and derailleur mechanism with eighteen speeds. The reel speed, according to the gears ratio, can be calculated from the following equation:

$$\frac{n}{n_w} = \frac{T_w}{T} \quad [4]$$

where  $n_w$  is the speed of the ground wheel in rpm,  $T$  the tooth number of the reel gear, and  $T_w$  the tooth number of the ground gear.

The reel was adjusted so that it sweeps the harvested material and clean the entire keyhole surface (Fig. 3c). The distance between reel bats and fingers was fixed

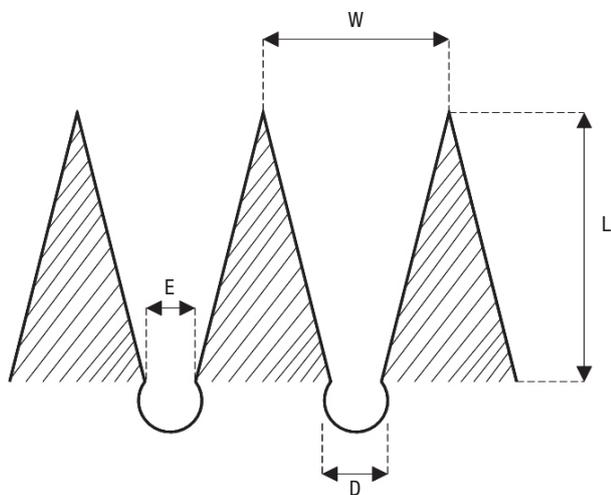


**Figure 3.** Physical models of the platform (a) and reel (b) for chickpea pod harvesting. Delivering performance of the reel (c).

at 1 cm in which the passive fingers with the narrow entrances and keyholes were not blocked by the stems and other plants (weeds). The optimal configuration included a reel with four bats, peripheral diameter of 700 mm and speed of 50 rpm.

### Platform

A platform with passive fingers produced a modified pod stripper, in which the plants move through the V-shaped slots and are stripped. For stripping, the converging edges of the fingers conduct the plants through the entrance width and keyhole (Fig. 4). Keyhole, a hole at the base between the adjacent fingers, removes the pods from the anchored plant. The entrance width should be designed so that the plant enters the keyhole easily and exits difficulty.

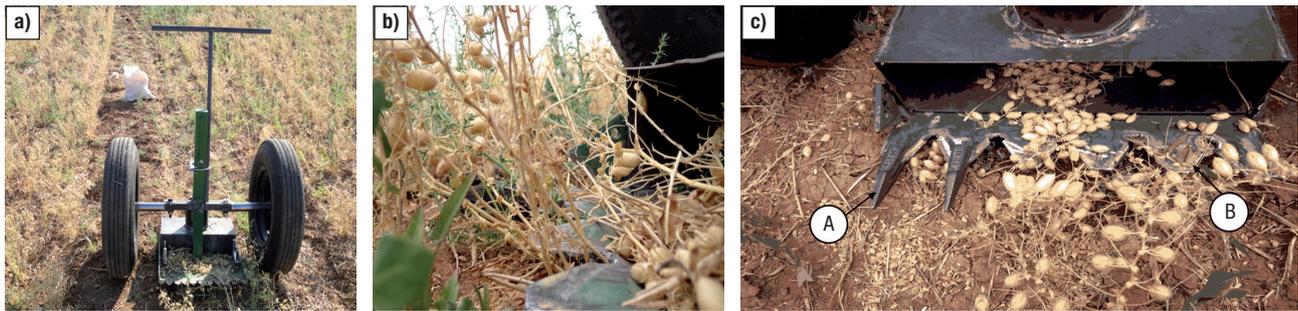


**Figure 4.** General view of the passive finger for chickpea harvesting. D: Keyhole diameter. E: Entrance width. L: Finger length. W: Slot width.

Physical models of the platform with different slot widths, finger length, keyhole diameter and entrance width were fabricated (Table 1). The field experiments used five slot widths of 30, 40, 50, 60 and 70 mm; four finger lengths of 40, 95, 150 and 200 mm; fifteen keyhole diameter and entrance width ranged from 6 to 17 mm for the platform. The width, length and thickness of the platform were 450, 700 and 5 mm, respectively. A simple harvester, with 30 kg weight and 1,000 mm width, was built for testing the functional operators of the platform (Fig. 5a,b). The slot width, finger length, keyhole diameter and entrance width were modified based on shattering losses and pods remaining on anchored plants.

**Table 1.** The dimensions of the different headers fabricated for chickpea harvesting

Headers No.	Slot width (mm)	Finger length (mm)	Entrance width (mm)	Keyhole diameter (mm)
1	70	150	—	—
2	40	200	—	—
3	40	150	—	—
4	72	95	10	16
5	72	95	13	16
6	40	40	6	6
7	58	95	12	13
8	58	95	10	17
9	58	40	12	13
10	58	40	10	17
11	40	40	7	10
12	40	40	14	15
13	40	40	8	11
14	72	95	6	12
15	—	—	13.5	15.5
16	—	—	6.5	9
17	—	—	5.5	13.5
18	—	—	12.5	16



**Figure 5.** The hand-operated carriage (a) to reduce associated cost, testing time and setting difficulties of the modification during field testing of the platform (b). The effect of finger length on the header performance (c); long fingers (A: finger length of 95 mm) produce more losses than short fingers (B: length of 40 mm).

## Experimental area and layout

Field experiments were performed to evaluate and optimize the header, platform and reel. The experiments were conducted on the Saral farm of Kurdistan Agriculture Research Center during the summers of 2008 to 2012 using a very common chickpea variety, Kabuli, on a typical fallow field. Some physical properties of chickpea grain during the harvesting process were measured (Table 2). Furthermore, the average chickpea yield was 300 kg ha<sup>-1</sup> for the rows of 350 mm spacing.

Four header types, fourteen platforms, four reel mechanisms (three, four and six bats), a hand-carriage experimental harvester and two prototype harvesters were fabricated during experiments. As it was not possible to study the effect of all variables simultaneously, the working heights were adjusted at 5 cm, and forward speeds at 3 km h<sup>-1</sup>. The tractor used for testing the prototype was a MF-399 (Iran Tractor Manufacturing Company, Tabriz, Iran).

The total losses of the configurations were measured before and after harvesting. The pods shattering on ground and remaining on anchored plant, except pre-harvest losses, defined as the total losses and calculated from the following equation:

$$l = \frac{W_{pg} + W_{ud}}{W_{dp} + W_{pg} + W_{ud}} \times 100 \quad [5]$$

**Table 2.** Physical properties of chickpea (Kabuli) during harvest

Crop properties	Measured value (average)
Grain weight (g)	0.25
Moisture content (% w.b.)	12.8
Plant height (mm)	224.7
Pod weight (g)	0.38

where  $W_{dp}$ ,  $W_{pg}$  and  $W_{ud}$  are the weight (in kg) of detached pods on the header, detached pods on the ground and remained pods on the plant after harvesting, respectively.

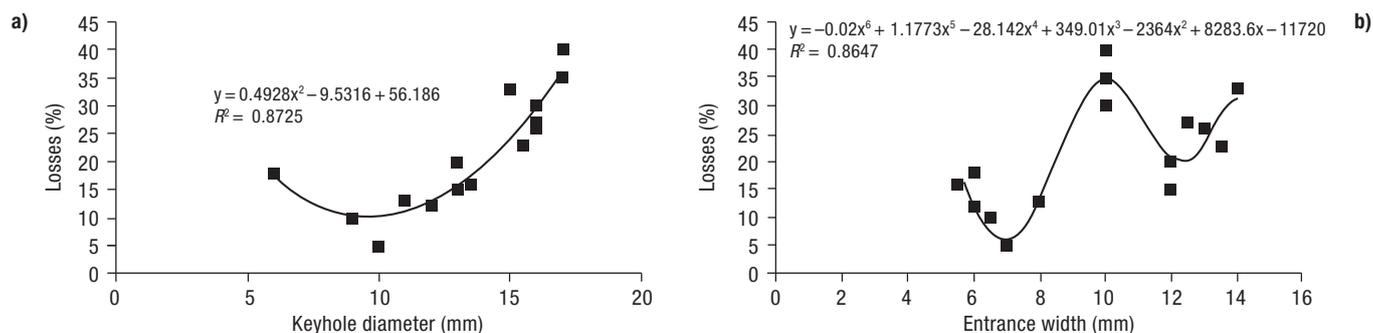
## Statistical analyses

All the experiments were conducted as factorial based on a completely randomized design in three replications. The experimental data were analyzed using a variance analysis to determine the losses based on the mass of pods collected from the ground and those remaining on the plant after harvest. The means of the treatments were compared with Duncan's multiple range tests at a 5% level of significance for the losses. The statistical analyses and design of experiments are not mentioned here and only results are discussed.

## Results and discussion

### Platform design

For the platform design, the results indicated that the 40, 50 and 60 mm slot widths exhibited better performance than the 30 and 70 mm widths with respect to losses. Moreover, better performance, *i.e.* less loss, resulted for short fingers in comparison with long ones (Fig. 5c). The slot width of 40 mm and finger length of 40 mm were optimum for the platform. For long fingers, the stem fractured before the anchored plant comes to the keyhole entrance for stripping. The suitable keyhole diameter for detaching pods was 10 mm (Fig. 6a). In the larger diameters (> 10 mm), pod escape from the keyhole and smaller (< 8 mm), stem pushed back to produce losses.

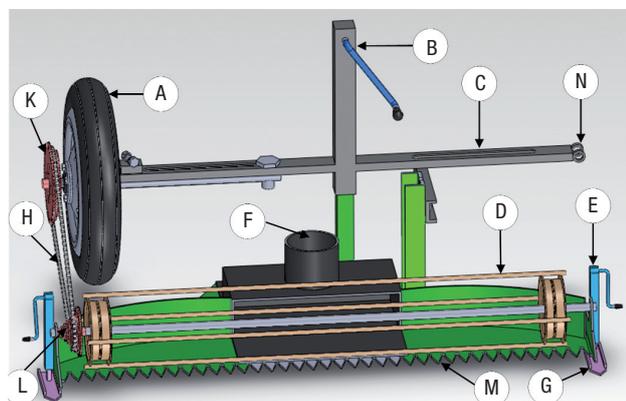


**Figure 6.** The effect of keyhole diameter (a) and entrance width (b) on pod losses.

The data, for pod losses versus entrance width indicated that the optimum value of entrance width was 7 mm whereas larger spacing ( $> 7$  mm) would increase total losses (Fig. 6b). The holding mechanism of keyhole vanished in entrance width of 10 mm which the stems easily exit from keyhole and the losses increased to a maximum of 35%. In large entrance widths ( $> 10$  mm), the keyhole diameter increased accordingly and the losses decreased to 20%, however, which was higher than 6% for 7 mm spacing.

### Header prototype

A modified model was designed using SolidWorks 2011 for the development of the stripper header (Fig. 7). A stripper header was fabricated (Fig. 8), in which the slot width was fixed at 40 mm, finger length at 40 mm, keyhole diameter at 10 mm and entrance width at 6 mm; the reel at angular speed of 50 rpm and peripheral diameter at 700 mm (Table 3). The header weight was 120 kg which can easily be mounted on the



**Figure 7.** Modified stripper header for chickpea harvesting. A: ground wheel. B: adjustable screw. C: frame, D: reel; E: adjustable screw. F: conveyor input. G: shoe. H: chain. K: ground wheel sprocket. L: reel sprocket. M: platform. N: hitch point.

tractor-mounted frame. The header arrangement, which is on-top for transport, rotates to the offset position for harvesting.

By testing the prototype harvester the efficiency of the stripper header was approved for chickpea harvesting (Fig. 9). The floating header, which adapt with ground unevenness, reduced pods remained on anchored plant *i.e.* losses. The light weight and optimum size of the header produced good maneuverability in field experiments. The new header exhibited acceptable working quality regards to the mass of pods collected from the ground and those remaining on the plant after harvest.

For a forward speed of  $3 \text{ km h}^{-1}$  and a 1.4 m working width, the overall work rate of the harvester in fallow fields was  $0.42 \text{ ha h}^{-1}$  (overall throughput of  $0.14 \text{ t h}^{-1}$  pods) whereas for manual harvesting eight labour-day were needed in one hectare.



**Figure 8.** The tractor-mounted experimental harvester for chickpeas.

**Table 3.** Key variables of machine design

Variable	Default value	Range
<i>Platform</i>		
Finger length (mm)	40	40-200
Slot width (mm)	40	40-72
Keyhole diameter (mm)	100	60-170
Entrance width (mm)	60	60-140
<i>Reel</i>		
Speed (rpm)	50	0-113
Diameter (rpm)	700	200 and 700
Number of bats (dimensionless)	4	3-4
<i>Header</i>		
Speed (km h <sup>-1</sup> )	3	3-5
Width (mm)	1,400	400-1,400
Distance between soil and platform (mm)	50	50-150

In conclusion, the field evaluation result confirms the good performance of the modified stripper header for chickpea harvesting. The prototype could be an option to expand profitable plantations with saving cost and time. Future research needs to be focused on the losses reduction for the commercialization of the new method, *i.e.* the reel should be power take-off (p.t.o.) powered.

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**Figure 9.** Harvesting experiments in a field.

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