

Estimation of sesame mechanical harvesting losses in the mechanized rainfed areas of Eastern Sudan

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ABSTRACT

Sesame (*Sesamum indicum* L.) plays an essential role in Sudan economy, but its actual yield is low. Harvesting losses were considered as one factor which contributes to this low yield. The objectives of this research were to analyze and quantify sesame harvesting losses, and to estimate their economic values in the mechanized rainfed areas of Eastern Sudan. Four sesame cutter binders were tested, namely; BCS-I, BCS-II, Warta-2 and New life (a cutting and windrowing machine). The first two machines were self-propelled, the others were tractor operated. The study was conducted for three consecutive seasons, 2012 to 2014. Three types of loss were determined which were; pre-harvesting, machine (cutting and binding) and total losses. The collected data included; plant density, number of capsules per plant, number of fallen capsules before the introduction of machines and number of uncut and unbound capsules. The results showed that the overall average pre-harvesting loss was 0.6%. Cutting loss was 1%, 0.5%, 1.7% and 0.5% for BCS-I, BCS-II, Warta-2 and New life, respectively. Binding loss was between 2.8% for BCS-I and 3.3% for Warta-2, with an overall average of 3.1%. The average percent of machine and total harvesting losses were 3.2% and 3.8%, respectively. The estimated quantity of pre-harvest, machine and total losses were 1.32, 7.04 and 8.4 kg/ha, respectively. The results inferred that when half of the sesame area in Gedarif State is harvested by the tested machines, the estimated annual loss was 975 tons, which amounts to a total loss value of US\$ 1.5 million, with an average US\$ 10.1 loss value per hectare. The results concluded that the position of cutter bar with respect to the driver and the mechanism that prepare bundles for binding besides the knotting system are the machine features which affected mechanical harvesting losses of sesame crop.

INTRODUCTION

Sesame (*Sesamum indicum L.*) plays an essential role in Sudan's economy with regard to both local consumption and export. It is mainly grown under rainfed conditions in the sand dunes and in the central clay plains. Recently, it had been grown in very small scattered patches under irrigation. The total cropped area by sesame was 2.7 million hectares in season 2012/2013; which gave a total production of 0.56 million tons (C. B. S., 2013). Gedarif rainfed area, in the central clay plains, represents one of the most important areas for sesame production. Farmers in Gedarif State have long experience in cultivating sesame crop; however, crop yield is low compared to the potential. The average sesame yield in Gedarif State during the period from 1970 to 2012 was around 260 kg/ha (MFC, 2013); however, the potential yield in research farms was 477 kg/ha (Ali, 2014). To bridge this yield gap it is necessary to study and analyze the factors that affect the yield. Harvesting losses are considered among the factors contributing to the lower yields in farmers' fields.

Sesame harvesting represents a real problem in the mechanized rainfed areas of the Sudan. This problem originated from the uneven maturity of the crop plant; whereby the lower capsules mature earlier compared to the top ones. Moreover, the time from maturity to harvest is very short and any delays from the optimum harvest date cause capsules over drying and seeds loss. These growth habits coupled with the scarcity of hand labor during the critical harvesting period and their high cost are the major constrains of the horizontal area expansion of sesame (Mahmoud, 1994).

However, several experiments were carried out in Sim Sim National Center for the development of rainfed agriculture Eastern Sudan to solve sesame harvesting problems. These studies were focused on finding the best machine or method. As a result mechanical cutting and binding of sesame crop was recommended (Elghali and Dawelbeit, 1992). Recently, Dahab and Mohamed (2007) found that the use of the cutter binder for sesame harvesting is more economical compared to manual harvesting.

Three distinguished types of sesame harvesting losses were recognized; which were pre-harvest, machine and processing losses. Machine loss could be divided into cutting and binding losses. The processing loss includes; threshing, cleaning and bagging. Sesame harvesting loss results in the reduction of production and profits.

Abdoun (1976) mentioned that the ultimate solution for sesame harvesting in Sudan cannot be considered successful unless harvesting losses are reduced to the minimum. To reduce mechanical harvesting loss it is necessary to study the types of losses and understand their causes.

One of the purposes of evaluating a harvesting machine is to determine the performance characteristics of its functional components (Srivastava, *et al.*, 2006). Losses determination is one of the essential tests to evaluate the functional components of harvesting machines. However, the functional components of harvesting machines vary in design according to crop type and its geometry, targeted product and machine-crop interactions.

Recently, many types of cutter binders have been used by farmers in the mechanized rainfed areas in Eastern Sudan. These cutter binders varied in their types of power source and design features. The objectives of this research work were to quantify and analyse sesame harvesting losses for the currently used sesame cutter binders in the rainfed areas of Eastern Sudan and to estimate the economic value of the machines losses.

MATERIALS AND METHODS

A field survey of the sesame cutter binders was conducted in central and northern parts of the mechanized rainfed areas of Gedarif State, for three consecutive seasons (2012, 2013 and 2014). Seven to ten farms were visited each season. Farm size was about 210 hectares or more.

The normal practices for sesame production in the studied areas involve preparing the soil by the wide level disk (WLD) and sowing the crop in broadcasting pattern by the same machine. The sowing date starts during the second week of July and extends up to early August. The crop is ready for harvest in 90 days from emergence; i. e., when the leaves turn yellow and start to drop while most of the capsules are still green. Harvesting normally carried out in the mid of October and extends till early November. The crop is cut and tied either by machines or manually. The tied bundles are stacked in the field and left for 15 to 20 days for natural drying. The others harvesting operations such as seeds separation, cleaning and bagging are usually carried out manually. Table 1 shows the long term average of some weather data during harvesting period.

Description of the selected sesame cutter binders:

Four sesame harvesting machines were studied, two of them were self propelled and the other two were tractor operated. Detailed descriptions of these machines were as follow:

1. **BCS-I:** A self propelled cutter binder with four-piston diesel engine of 26.5 kw (35.51 hp) power, carried on four wheels, having width of cut of 4.1 m, and with a three-sections cutter bar which can work independently; each section has a knotting mechanism. It was made in Italy.
2. **BCS-II:** A self propelled cutter binder with a single-piston diesel engine of 7.6 kw (10.2 hp) power. It has three wheels, two in front and one in the rear. Its width of cut is 1.3 m with a single knotting mechanism. It was made in India.
3. **Warta-2:** A trailed machine on two wheels and attached to the right side at the rear of the tractor, operated by the power take off (PTO) shaft, and has 2.1 m width of cut. The cut plants move through one horizontal canvas and two vertical canvases to the knotting mechanism, which throws tied bundles to the left side of the tractor. It was made in Poland.
4. **New life:** A mounted machine in the front of tractor and operated by the PTO shaft. Its width of cut is 2.3 m. It windrows the cut sesame crop to the right hand side without binding. It was made in India.

Both BCS machines handle the sesame crop vertically for binding. They have a flexible field work pattern either round and round from the outer borders of the field or through head lands. Whereas Wata-2 and New life machines have round and round work pattern from the outer borders of the field with clock wise direction and counter clock wise direction, respectively.

Data collection and analysis

The collected data from the selected farms included plant density, number of capsules per plants as well as uncut and untied capsules, numbers of fallen capsules per square meter. Other data which may affect harvesting losses were also collected such as plant height, height of first capsule and cutting height.

Thirty random samples of these parameters were measured from each farm. The collected data was arranged in a randomized complete block design with three replications, each replicate covered ten samples. Combined analysis of the three seasons was applied (Gomez and Gomez, 1984) by using M-stat-C software version 2.10. Moreover, secondary data was obtained from the Ministry of Agriculture, Forestry and Irrigation and from the crop market in Gedarif State. The secondary data included the annually cultivated areas (ha) by sesame, crop value (SDG/kg) and exchange rate (SDG/ US\$).

Losses determination

Pre-harvesting, machine and total harvesting losses were determined. Due to the small size and shattering of sesame seed (Davila-Cardenas 1976; Khider 1997), the adopted method to calculate these losses was based on the number of capsules. Thus the three types of losses were determined as follows:

Pre-harvesting loss

Pre-harvesting loss occurs from fallen capsules before introduction of the cutter binder. It happens by the movement of people, birds and animals in the field or naturally by wind and over drying. It was determined according to equations 1 and 2 as follows:

$$PHL (\%) = N \times 100 / TNC \dots\dots\dots (1)$$

$$TNC = PP \times NCPP \dots\dots\dots (2)$$

where:

PHL = Pre-harvesting loss (%).

N = Number of fallen capsules before introduction of machine per square meter.

TNC = Total number of capsules per square meter.

PP = Plant population per square meter.

NCPP = Number of capsules per plant

Machine loss

This loss is occurs due to the introduction of the machine in the field. It can be divided into cutting and binding losses.

Cutting loss can be defined as the ratio of uncut capsules due to the use of machine to the total number of capsules. The number of uncut capsules was determined by counting the capsules per square meter for both uncut

plants and when the cutting height was above the height of the first capsule. Cutting loss was determined by equation 3 as follows:

$$C (\%) = UC \times 100 / TNC \dots\dots\dots (3)$$

where:

C = Cutting loss (%).

UC = Uncut capsules per square meter.

Binding loss can be defined as the ratio of the number of cut but untied capsules per square meter due to machine use to the total number of capsules per square meter. It was determined by equation 4 as follows:

$$BL (\%) = (NUTC - N) \times 100 / TNC \dots\dots\dots (4)$$

where:

BL (%) = Binding loss.

NUTC = Number of untied capsules per square meter.

Machine loss was calculated by the summation of cutting and binding losses. The total harvesting loss was obtained by the summation of pre-harvesting loss and machine loss.

Yield determination

One hundred capsules of sesame crop were collected randomly from each field where the sesame cutter binders were used. The capsules were naturally dried and the average seed weight (kg) of each capsule was computed. The sesame yield (kg/ha) was determined by using the total number of capsules per square meter and the capsule seed weight.

RESULTS AND DISCUSSION

The results showed that the overall average plant density per square meter, plant height, number of capsules per plant and height of first capsule for the three seasons were 29 plants, 101 cm, 44 capsules and 44 cm, respectively as shown in Table 2. These values of crop parameters are considered suitable for mechanical harvesting of sesame. Authors' field experience indicated that the success of mechanical harvesting of sesame is directly proportional to plant height, height of first capsule and minimal branches. The variation in these parameters from farm to another is a normal phenomenon; however, they may affect harvesting losses.

Results of pre-harvesting losses percent for the studied cutter binders in the three seasons and their combined analyses were shown in Table 3.

The farms in which the Warta-2 and BCS-II were used gave the highest (0.8%) and the lowest (0.4%) values of pre-harvesting losses, respectively. The overall average value of pre-harvesting loss was 0.6%. No previous records about pre-harvesting losses are available to judge and evaluate this average loss, but it could be taken as a reasonable value under the weather and farm conditions in rainfed areas.

The results showed that there were significant differences between the cutter binders in cutting loss in the three seasons and combined analysis (Table 4). Warta-2 gave the significantly (0.001%) highest cutting loss (1.7%), whereas BCS-II as well as New life gave the lowest cutting losses (0.5%). This variation in cutting loss percent may be due to the position of the machine's cutter bar with respect to the driver, whereby the front position is better for controlling the machine and hence a better performance. In this regard, Kepner, *et al.* (1978) mentioned that self-propelled machines like harvesters provide more flexibility and better maneuverability, better visibility and control by the operator.

On the other hand, the hitch system of the machine with the power source may affect cutting loss; since it is easy to control mounted implements compared to trailed ones. This illustrates why Warta-2 gave the highest cutting loss. The average cutting losses were 1.1%, 1.2% and 0.4% for seasons 2012, 2013 and 2014, respectively. The overall cutting loss was 0.9%. The cutting loss of the studied machines is within the reasonable level, since the cutting mechanisms of all binders were working efficiently and their cutting height was below the height of the first capsules. Cutting loss may happen due to branched and prone crop plants and the employment of unskilled drivers.

The results of binding loss for the studied sesame cutter binders during the three seasons are shown in Table 5. No significant differences between the BCS machines and Warta-2 in binding losses. The overall value of binding loss was 3.2%. Binding loss was almost three folds compared to cutting loss. The causes of binding loss include; jamming in the knotting system, and the mechanism that prepares the bundle for binding, uneven distribution of plant density and variability in plant height. In the case of BCS binders the shorter plants and branches when cut pass under the knotting twine and consequently resulting in more binding loss. In the case of Warta-2, binding loss occurs due to the movement of the cut plants through the canvasses.

Table 6 shows the result of the total machine loss for the studied cutter binders in the three seasons. Warta-2 resulted in significantly (0.001%) highest total machine loss (4.9%); whereas BCS machines gave the same machine losses (3.8%). The overall machine loss was 3.2%, which is equivalent to 7.04 kg/ha. The New life machine resulted in the lowest total loss (0.5%), this is because no binding loss is valid for this machine. Machine loss can be reduced via the correct setting and adjustment of the machines; adoption of proper agricultural practices and manual collection of uncut and unbound sesame plants.

The results showed that the average total sesame harvesting losses during seasons 2012, 2013 and 2014 were 3.6%, 4.0% and 3.9%, respectively (Table 7). Warta-2 resulted in the significantly highest total harvesting losses in the first two seasons and their combined analyses. However, Dahab and Mohamed (2007) found that the total average harvesting losses for Warta- 2 cutter binder was above 8%.

The overall average sesame harvesting loss was 3.8%; when multiplied by the overall average yield (220 kg/ha), it was equivalent to 8.4 kg/ha. As the recommended seed rate of sesame crop was 3.2 kg/ha (Anonymous, 2002); this amount of loss represents 2 to 3 folds of the recommended seed rate. In addition to this total loss, other losses are expected, which were not quantified in this study, such as threshing, cleaning and bagging losses.

The economic analysis of sesame harvesting losses by machines is shown in Table 8. The results showed that the BCS-I and Warta-2 obtained the same machine losses value (12.1 US\$/ha). The BCS-II and New life obtained the highest and lowest loss values, respectively.

For results implication, according to records of the Ministry of Agriculture, Forestry and Irrigation in Gedarif State, the average area under sesame production in the last ten years (2003 to 2012) was 300 thousand hectares. If half of this area is assumed to be mechanically harvested by these cutter binders, the estimated total mechanical loss is about 975 tons, and the equivalent total cash loss amounted to about US\$ 1.5 million. This indicated that each hectare harvested with the use of a sesame cutter binder lost about US \$10.1.

CONCLUSION

The sesame crop parameters, field conditions and cutter binder design affected harvesting loss. The overall average pre-harvesting loss was 0.6%. Machines cutting, binding and total losses were 0.9%, 3.1% and 3.2%, respectively. The overall average total harvesting loss was 3.2%. Position of the cutter bar with respect to the driver, hitching system to the power source and the delivery system of cut plants to the knotting mechanism are the machine features which contribute to sesame harvesting losses. The total mechanical harvesting losses from the studied machines cost farmers dearly in lost income. The estimated total machine loss was about 975 tons, which amounted to about US\$ 1.5 million annually with an average of US\$ 10.1 loss value per hectare.

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Estimation of sesame harvesting of losses

Table 1. Long term average of some climatological parameters during harvesting period

Parameters / Months	Sep.	Oct.	Nov.	Dec.
Rain (mm)	89.6	26.5	1.1	0.0
Rainy days when rainfall \geq 1.0 mm	7.0	2.8	0.2	0.0
Relative humidity (%)	66	50	33	34
Wind speed (km/h)	8	6	7	7
Mean dry temperature (C°)	28.3	29.9	29.8	27.5
Bright sunshine duration (h)	8.5	8.8	9.3	9.5

Source: Sudan Metrological Authority, Gedarif Station Climatological Normals from 1981 to 2010.

Table 2. Average crop parameters for different machine seasons 2012, 2013 and 2014

Machines	Plant density (plant/m ²)	Plant height (cm)	Number of capsules/plant	Height of first capsule (cm)
BCS-I	28 b	105 b	39 bc	44 b
BCS-II	25 b	111 a	51 a	48 a
Warta-2	20 c	90 d	42 b	38 c
New life	41 a	99 c	35 c	45 a
Average	29	101	44	44
± SE	0.92***	1.47***	2.03***	1.14**
C.V. (%)	9.64	4.44	14.54	7.96

, * = significant at 0.01% and 0.001%, respectively

Table 3. Pre-harvesting loss (%) for seasons 2012 to 2014

Machines	Season 2012	Season 2013	Season 2014	Average
BCS-I	0.5 bc	0.6	1.0	0.7
BCS-II	0.2 c	0.5	0.5	0.4
Warta-2	1.4 a	0.6	0.5	0.8
New life	0.7 b	0.4	0.4	0.5
Average	0.7	0.5	0.6	0.6
± SE	0.14**	0.10ns	0.18 ns	0.82*
C.V. (%)	34.26	32.33	49.92	39.81

*, ** = significant at 0.05% and 0.01%, respectively, ns = not significant

Table 4. Cutting loss (%) for the tested cutter binders, seasons 2012 to 2014

Machines	Season 2012	Season 2013	Season 2014	Average
BCS-I	0.9 b	1.6 ab	0.5 abc	1.0 b
BCS-II	0.4 c	0.9 b	0.3 c	0.5 c
Warta-2	2.7 a	2.1 a	0.2 c	1.7 a
New life	0.2 c	0.4 c	0.8 a	0.5 c
Average	1.1	1.2	0.4	0.9
± SE	0.16 ***	0.64 *	0.12 *	0.11 ***
C.V. (%)	26.38	36.35	46.11	35.93

*, *** = significant at 0.05% and 0.001%, respectively

Table 5. Binding loss (%) for some cutter binders, seasons 2012 to 2014

Machines	Season 2012	Season 2013	Season 2014	Average
BCS-I	2.7	2.6	3.0 b	2.8
BCS-II	1.5	2.5	5.5 a	3.2
Warta-2	3.2	3.7	2.9 b	3.3
New life	N/A	N/A	N/A	N/A
Average	2.5	2.9	3.8	3.1
± SE	0.38 ns	0.49 ns	0.18***	0.22 ns
C.V. (%)	26.86	28.74	8.04	21.04

*** = significant at 0.001, ns = not significant, N/A = not applicable

Table 6. Total machine loss (%) for the cutter binders, seasons 2012 to 2014

Machines	Season 2012	Season 2013	Season 2014	Average
BCS-I	3.6 b	4.2 b	3.5 b	3.8 b
BCS-II	1.9 c	3.4 b	5.8 a	3.7 b
Warta-2	5.9 a	5.8 a	3.1 b	4.9 a
New life	0.2 d	0.4 c	0.8 c	0.5 c
Average	2.9	3.5	3.3	3.2
± SE	0.23***	0.50**	0.22***	0.20***
C.V. (%)	14.06	25.12	11.46	18.63

, * = significant at 0.01% and 0.001%, respectively

Estimation of sesame harvesting of losses

Table 7. Total harvesting loss for cutter binders, seasons 2012 to 2014

Machines	Season 2012	Season 2013	Season 2014	Average
BCS-I	4.1 b	4.7 b	4.5 b	4.4 b
BCS-II	2.1 c	3.9 b	6.2 a	4.1 b
Warta-2	7.4 a	6.4 a	3.5 c	5.8 a
New life	0.9 c	0.8 c	1.2 d	1.0 c
Average	3.6	4.0	3.9	3.8
± SE	0.39***	0.51**	0.34***	0.24***
C.V. (%)	18.51	22.18	12.29	18.96

** , *** = significant at 0.01% and 0.001%, respectively

Table 8. Economics of mechanical sesame harvesting loss

Machines	Machine loss (%)	Yield (kg/ha)	Loss (kg/ha)	Loss value (US\$/ha)*
BCS-I	3.8	206	7.8	12.1
BCS-II	3.7	243	9.0	13.9
Warta-2	4.9	160	7.8	12.1
New life	0.5	271	1.4	2.1
Average	3.2	220	6.5	10.1

* Source: crop market records; the average crop value for the three seasons (2012 to 2014) was 12 SDG/ Kg; and exchange rate was 7.8 SDG/US\$

تقدير فواقد الحصاد الآلي للمسمم في مناطق الزراعة الآلية المطرية في شرق السودان

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الخلاصة

محصول السمسم يلعب دور مهم في الاقتصاد السوداني، إلا أن إنتاجيته ضعيفة. فواقد الحصاد تعتبر من العوامل المساهمة في ضعف الإنتاجية. الهدف من هذه الدراسة هو تحليل وتقدير فواقد حصاد السمسم عند استخدام آلات القطع والحزم بالإضافة لتحديد القيمة النقدية لهذة الفواقد في مناطق الزراعة الآلية المطرية في شرق السودان. اختبرت أربع من آلات القطع والحزم تحديداً، Warta-2 BCS-II, BCS-I, و New life . الآلاتان الأوائل ذاتية الحركة والآخرتان بوساطة الجرار. اجريت الدراسة خلال ثلاثة مواسم متتالية، 2012 إلى 2014م. تم تحديد ثلاثة أنواع من الفواقد هي فاقد قبل الحصاد، فاقد الآلة (فاقدي القطع والحزم) والفاقد الكلي. البيانات التي جمعت شملت الكثافة النباتية، عدد الكبسولات في النبات، عدد الكبسولات الساقطة قبل الحصاد، عدد الكبسولات غير المقطوعة وعدد الكبسولات غير المحزومة. أشارت النتائج إلى أن المتوسط العام لفاقد قبل الحصاد كان 0.6%. وكان متوسط فاقد القطع 1%، 0.5%، و 1.7% لكل من آلات BCS-I، BCS-II، و Warta-2، و New life على التوالي. وجد أن متوسط فاقد الحزم يتراوح بين 2.8% للقاطعة الحازمة BCS-I و 3.3% للقاطعة الحازمة Warta-2 ومتوسط فاقد الحزم بلغ 3.1%. وجد أن المتوسط العام لفواقد الآلة و فاقد الحصاد الكلي كان 3.2% و 3.8% على التوالي. وجد أن متوسط الكمية المحسوبة لفاقد قبل الحصاد، فاقد الآلة والفاقد الكلي كانت 1.32%، و 7.04 و 8.4 كجم/هكتار، على التوالي. قدر الفاقد الكلي لحصاد السمسم عند استخدام الآلات قيد الدراسة لحصاد نصف مساحة ولاية القضارف المزروعة بمحصول السمسم بحوالي 975 طن في العام وهو ما يكلف حوالي 1.5 مليون دولار أمريكي بمتوسط تكلفة فاقد تقدر بحوالي 10.1 دولار/الهكتار. خلصت النتائج إلى أن موقع جهاز القطع بالنسبة للسائق ومنظومة توصيل نباتات السمسم المقطوعة لجهاز الحزم بالإضافة لجهاز الحزم من خصائص الآلة الأساسية التي أثرت في فواقد الحصاد الآلي لمحصول السمسم.