Postharvest Handling Practices and on Farm Estimation of Losses of Sesame (*Sesamum indicum* L.) Seeds: The case of two Wollega Zones in Ethiopia

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Abstract: Sesame is an important crop for the Ethiopian economy. However, poor post-harvest handling is a major problem that hampers exporting sufficient volume and quality of the crop. This study was aimed at identifying major causes and critical loss points during postharvest handling practices from maturity of the crop to before storage time. The study was conducted using FAO's 4S [screening of relevant data, surveying, sampling (load tracking) and synthesis] approach mainly addressing the assessment and load tracking approaches. The assessment study was conducted in East and Horro Guduru Wollega Zones of Oromia region. Two districts from each Zones and three kebeles from each district were purposively selected and totally 382 sesame producers were interviewed. For load tracking approach to generate objective data, small (<5 hectares), medium (5-10 hectares) and larger (>10 hectares) size farms were selected and estimated losses determined at each postharvest activity. The estimated losses at each postharvest activity were determined in parallel with estimating losses under farmers' practice. The survey result revealed that the majority of the farmers (55%) use capsule or pod color to determine the right time of harvesting and 90% of them believed that shattering is the major cause of loss during harvest. About 95% of the producers conducted field drying without using plastic or canvases, 90% of them did not use wrapping materials during bundle transport to threshing sites. The results from load tracking indicated that field drying (7.1%), pre-harvest shattering (4.7%), threshing/winnowing (3.5%) and bundle carrying/ transport (1.6%) were major points of loss. The results revealed aggregate loss of 17% only between maturity and storage (excluding storage losses). In conclusion, late harvest, over drying (long duration of field drying), poor transport mechanisms of the bundles to threshing site, incomplete threshing, and poor winnowing were found to be the major causal factors for high post-harvest loss (PHL) of sesame. Field drying, pre-harvest shattering and threshing activities have been identified as critical loss points, which need technical intervention to tackle the poor postharvest handling practices and minimize the losses.

Keywords: Bundle carrying; Field drying; Load tracking; Postharvest loss; Shattering

1. Introduction

Sesame (*Sesamum indicum* L.) is one of the cultivated plants in the world and a highly prized oil crop (Oplinger *et al*., 1990). Ethiopia is among the top 10 producers of the crop (FAOSTAT, 2020) and the major crop to generate hard currency for the country (Taffesse *et al*., 2011). The crop mainly produced for the international market that closes to 95% of the total volume for export and engaging more than 736,000 households in the production and marketing of the crop (CSA, 2018). According to the National Bank of Ethiopia, the export value of sesame was estimated at around 600 million US dollars between 2013 and 2014 (SBN, 2016).

However, the contribution that the crop could make to the growth of the economy of the country is constrained by low productivity and further aggravated by high post-harvest losses at different stages of harvesting activities (MoA, 2015). Shattering loss due to delay of harvesting and during harvesting, field drying of bundles, less care during field transportation, threshing, and winnowing are the major on-farm or immediate causes for high loss of sesame seeds. The estimated postharvest losses of sesame are high in Ethiopia since sesame varieties in the country are shattering types. The scale of losses also varies with the size of farms depending upon the level of technologies and handling practices farmers apply (Abay and Berhe, 2014). A survey works conducted in northern Ethiopia estimated an average sesame postharvest loss

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of 24% (Gebretsadik *et al*., 2016). Furthermore, a load tracking study conducted in northwestern Ethiopia indicated a 13% loss of sesame along the supply chain (field drying, pre-harvest shattering, transportation and re-bagging) (SBN, 2014). In general, the total average grain loss in Ethiopia is estimated to range from 30 to 50% (Befikadu, 2018; MoA, 2018).

The value chain analysis as well as economic efficiency of sesame were studied extensively by different authors (Aysheshm *et al*., 2007; Abebe, 2016; Wana *et al*., 2016; Kedir, 2017; Mekuria *et al*., 2018; Gebremedhin *et al*., 2019). Furthermore, the majority of postharvest loss estimates are from assessment studies except one load tracking result (SBN, 2014). This indicates a huge variability in data from different sources, which creates problems to conduct intervention works by policy makers and other stakeholders. In addition to this, the hot spots or critical loss points (CLP) for the loss is not yet well identified under Ethiopian condition. Spotting the CLP in major on farm postharvest activities are important to make the relevant intervention activities. Accordingly, the scope of this study was delimited to estimate losses and identify CLP of on farm postharvest activities (between crop maturities before harvesting to threshing/ winnowing, excluding storage). Limited research has been conducted to elucidate sesame losses with load tracking methods by using appropriate sampling techniques mainly focusing on farm postharvest practices. Therefore, this study was aimed at determining major causes and extent of sesame losses along selected on farm postharvest activities in major production districts of Wollega Zones of Oromia Regional State.

2. Materials and Methods

2.1. Description of the Study Areas

The study was carried out in Hababo Guduru, Abe Dongoro, Sasiga and Guto Gida districts (Figure 1) in selected zones. The districts were selected based upon their production potential and other features as indicated in Table 1.

Table 1. Description of the study areas.

No	Location	Latitude	Longitude	Altitude (m.a.s.l)	Mean rainfall (mm)
1	Hababo Guduru	09°41' N	37°32' E	1750	1248
2	Abe Dongoro	09°29' N	36°49' E	1925	1752
3	Sasiga	09°09' N	36°29' E	1730	1000
4	Guto Gida	09°09' N	36°44' E	1900	1800

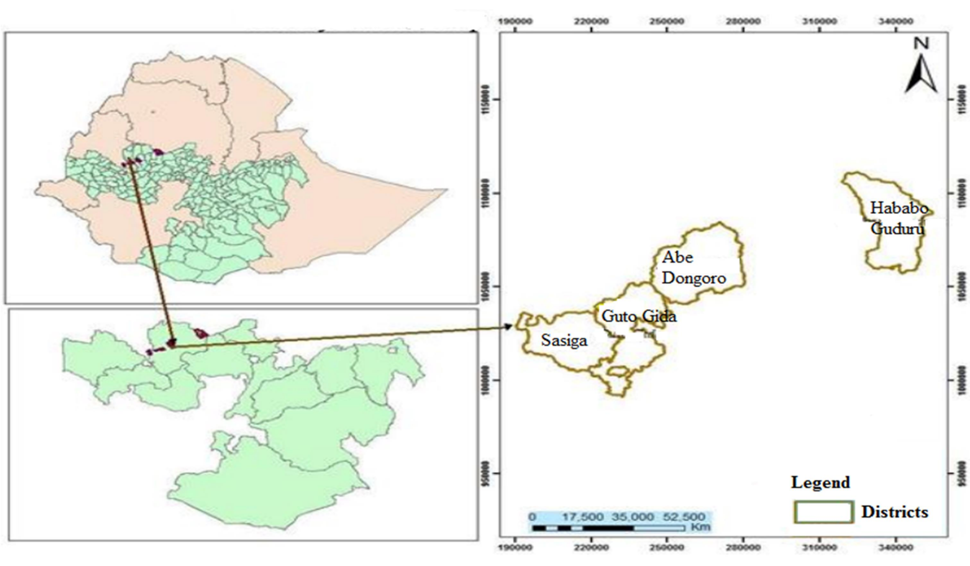

Figure 1. Map showing selected sesame producing districts in East and Horro Guduru Wollega Zones, Ethiopia.

2.2. Sampling and Data Collection

2.2.1. Study approach and sample size

To conduct this study, FAO (2016) 4S [screening of relevant data, surveying, sampling (load tracking) and synthesis] approach was followed. The screening mainly focused on literature review work and desk review of secondary data as input for the surveying and sampling (load tracking) works. After screening relevant information, to assess production and postharvest handling practices, a survey was conducted in selected two districts zones (East and Horro Guduru) of Wollega. From each zone, two districts (Sasiga and Guto Gida districts) were from East Wollega zone and the other two districts (Hababo Guduru and Abe Dongoro) from Horro Guduru Wollega were included in the study. The districts were purposively selected based on their potential for sesame production. Three kebeles from each district were also intentionally selected as per their production potential and totally, 382 sesame producers were randomly selected using the method of Yamane (1967) as described in Eq. 1:

$$n = \frac{N}{1+N(e)^2} \quad \text{(Eq. 1)}$$

where, n is the sample size, N is the population size (8531), and e is the level of precision at 95% confidence interval (e = 0.05).

Data were collected using pre-tested semi-structured questionnaires through individual interviews. The scope of the load tracking study was delimited from major production practices to threshing and winnowing of the seeds since the storage part was independently addressed in subsequent work. The questionnaires contained topics related to socio-economic characteristics of respondents, major production and postharvest practices before the storage and marketing of sesame.

2.2.2. Load tracking method to determine cause and extent of losses

Load tracking (LT) is a method that is used to measure specific losses at a given value chain step (FAO, 2016). Three farms were randomly selected based on the size of farms; small (<5 hectares), medium (5-10 hectares) and larger (>10 hectares) as per the classification of district agriculture and natural resource management offices. 20 m x 20 m quadrats were randomly located from each selected farm. The losses due to pre-harvest and harvest shattering, field drying, bundle transportation, threshing, and winnowing were measured from 400 m^2 areas, and calculated in terms of percentage loss from the potential harvest. The losses were calculated based on the average yield of sesame in the sampled area, which was 0.4 tons ha^{-1}. The average yield (0.4 ton ha^{-1}) obtained by the survey result, was also triangulated to confirm the actual yields by measuring on the field. Potential harvest in this regard was defined as the sum of net yield plus losses determined at different stages as indicated above. Total loss was calculated by adding losses at each postharvest activity and expressed in terms of percentage. The specific procedures to determine losses along the supply chain are indicated below.

a. Pre-harvest and harvest loss

Loss due to capsules shattering before and during harvesting, was determined using selected quadrants. Figure 2 shows the stage of maturity at harvest and harvested sesame plants using hand sickles. To estimate the extent of losses on the field due to harvesting, five 1 m x1 m quadrants were selected from four corners and at the center of the 20 m x 20 m quadrants. Sesame harvesting was conducted when the color of the leaves are changed from green to yellow (before complete drying). However, some of the plants dried irregularly and started opening their pods due to different factors. So, to quantify the extent of losses before and after harvesting, the number of dried pods and opened pods in the 1 m^2 quadrant was identified and counted before starting harvesting. The average number of seeds per pod was determined and the average 1000 seed weight was measured using seed counter (Model: PFEUFFER GMBH, Germany). Once the sesame pods are dried and started opening their pods, the seeds shattered easily before and at harvesting. The opening of the pods and over-drying is an indication of loss. Finally, the measured pre-harvest and harvesting losses were added in the calculation of total potential harvest.

Figure 2. Harvesting stages and manual harvesting of sesame to estimate shattering loss during harvesting.

b. Determination of field drying loss

After harvesting, stacking was done by keeping the bundles of the sesame plants vertically as shown in Figure 3b. To monitor losses during field drying, the bundles were stacked on polypropylene sheet for 15 days (practice at the study sites) along with the practice of producer. Sesame seeds that shattered on the sheets were measured and used to determine loss during field drying of bundles as indicated in Figure 3a.

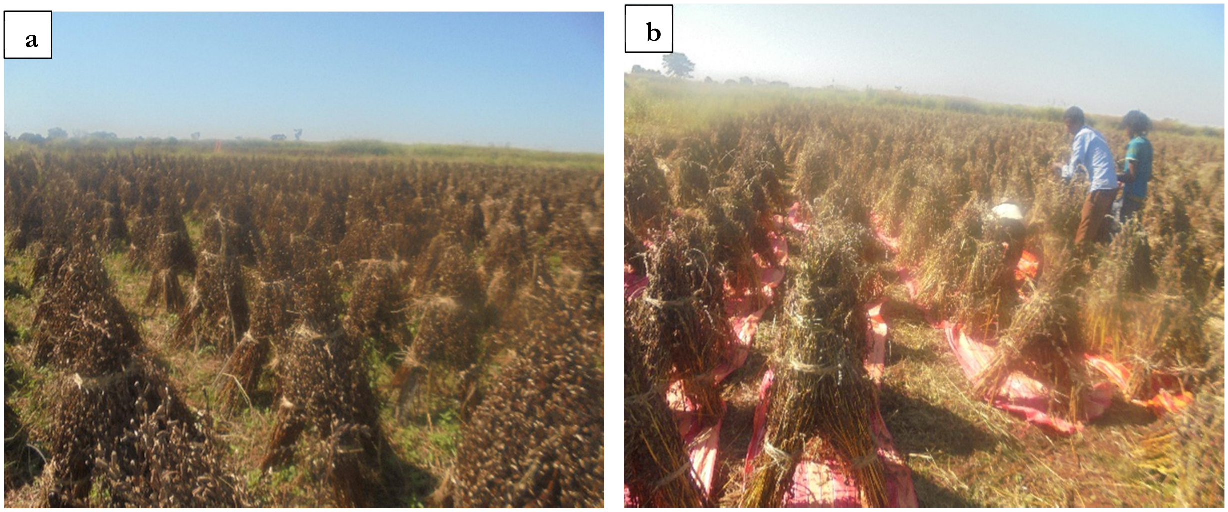

Figure 3. Sesame bundle drying on bare land without using polypropylene sheets (a) and putting on polypropylene sheets (b) to estimate field drying loss.

c. Loss estimation during transportation of bundles to threshing field

Shattering loss due to transportation was determined by carrying the bundles on the polypropylene sheet as indicated in Figure 4 in parallel with traditional practice without the use of wrapping materials. The seeds that shattered on polypropylene sheet were measured and considered as equivalent quantitative loss during transportation of the bundles.

Figure 4. Bundle transport/ carrying on polypropylene sheets from field drying to threshing place for load tracking method to estimate shattering loss during transportation/carrying.

d. Estimation of loss during threshing and winnowing

Threshing was done manually following the producers' practices by threshing the bundles either on canvas or plastic sheet with a stick. To estimate losses associated with threshing and winnowing, the same practice was applied with maximum care on large size canvas as compared to with canvas or plastic sheets used in traditional practices as indicated in Figure 5. Seeds that scattered beyond the expanse of producers' canvas as well as those retained in the plant (in the capsules) were carefully collected and weighed to estimate the loss at this stage. The total yield was obtained by adding the weights of seeds threshed on the canvas with those that got scattered around the canvas as well as those that were retained in the capsule of the plant. This was used to estimate potential yield. Both potential harvest and extent of postharvest losses were converted to a hectare basis.

Figure 5. Sesame threshing on stretched canvas by beating with stick.

2.3. Statistical Data Analysis

Descriptive statistics using SPSS Version 20 was used to analyze the survey data. One-way Analysis of Variance (ANOVA) was conducted using SAS Version 9.3 software program (SAS, 2014) to estimate extent of losses and determine critical loss points from load tracking data. Mean comparisons were computed for identifying treatment differences at the P-value of < 0.05 using the least significance difference (LSD) test.

3. Results and Discussion

3.1. Assessment of Production Status and Postharvest Handling Practices

3.1.1. Demographic and socio-economic characteristics of the respondents

About 94% of the respondents were male, with an average household family size of five. Sesame was produced by 98% of the respondents as a cash crop. More than 88% of the respondents were either illiterate or had attended only primary school education. Only 6% of the respondents completed secondary school education. Lower level of literacy might be associated with a low level of adaptation of technologies in pre and postharvest activities to produce more and reduce losses. In the study area, sesame production is dominated by the active age group (18-49 years old) (67.8%), and only 32.2% of the respondents were above 49 years of age (Table 2). It implies production and handling of the crop are handled by active but less experienced and resource-limited age group which might contribute to the low level of productivity of the crop.

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Table 2. Demographic and socio-economic characteristics of the respondents during assessment study.

Variable	(N = 382)	%
Sex		
Male	359	94.1
Female	23	5.9
Means of livelihood		
Crop production	374	97.8
Casual labor, self-employment/ Small business	4	1.1
Charcoal making and other	4	1.1
Family size in the household		
1-3	112	29.3
4-6	164	43.0
>6	106	27.8
Education level		
No formal education	181	47.4
Not completed primary school	157	41.1
Completed primary school (1 to 8 grades)	21	5.6
Completed secondary school (9 to 12 grades)	23	5.9
Age the respondents		
18 - 29 years	52	13.7
30 - 49 years	207	54.1
> 49 years	123	32.2

3.1.2. Production and productivity status of sesame

The average yield of sesame obtained by the respondents was 0.40 tons ha^{-1} (Table 3). This yield of sesame in the sampled area was low as compared to the average national yields of the crop in the country, which were 0.79 tons ha^{-1}in 2016 and 0.69 tons ha^{-1} in 2017 (CSA, 2018). These average yields of sesame in Ethiopia are similar to the average yield of the crop obtained in Uganda which is 0.64 tons ha^{-1}, but far lower than those obtained in the United Republic of Tanzania (1.07 tons ha^{-1}), Nigeria (1.10 tons ha^{-1}) and China (1.40 tons ha^{-1}) (FAOSTAT, 2019). Lack of improved cultivars, weak seed supply system, and low use of agricultural inputs may be the major factors for low productivity (Gelalcha, 2009). Unimproved production technology, weeds, insect pests and diseases, climate change impacts, domestic and global market fluctuations and little research and expert knowledge and skill, are additional challenges (Girmay, 2018).

For instance, more than 94.4% of the respondents use local sesame varieties for production (Table 3). A few farmers (5.6%) use improved varieties from agricultural research centers (4.8%). More than 91% of the respondents believed that delay in sowing influenced postharvest loss of sesame. Khan *et al.* (2009) also indicated that the highest economic loss of about 24.6% could be due to a delay in sowing of sesame in Bangladesh.

Table 3. Types of sesame variety used, sowing time, and yield of sesame obtained.

Variable	(N = 382)	%
Variety used by farmers		
Number of respondents used local variety	361	94.4
Number of respondents used improved varieties	21	5.6
Source of improved variety		
Research Center	18	4.8
Delayed sowing time has effect on PHL?		
Yes	349	91.5
No	33	8.5
Sesame yield (ton ha^{-1}) obtained by respondents		
<0.20 ton	21	5.5
0.30 ton	81	21.2
0.40 ton	147	38.5
0.50 ton	95	24.9
> 0.60 ton	38	9.9

3.1.3. Harvesting practices, estimated losses and cause factors

Sesame harvesting starts in late September and lasts until December yearly based upon the type of variety, sowing time, and weather conditions during growth. Most of the respondents (64%) indicated that October and November (Table 4) are the two main months to accomplish harvesting. The maturity of sesame seeds depends on the weather condition and types of variety which varies from 90 - 120 days (Terefe *et al*., 2012; Ayana, 2015). Respondents commonly do not count days after planting. They rather use pod color change from green to yellow (55%) or senescence or drying of leaves and pods (45%) to start harvesting. Consistent with these facts, Tunde-Akintunde *et al.* (2012) reported that harvesting commonly is done when 50% of the pods turn yellow. Change in the color of the pods on the plant to brown, change in the color of the stem to yellow, and fall (senescence) of the leaves are different maturity indices used in different areas (Hegde, 2012; Tunde-Akintunde *et al*., 2012).

Table 4. Harvesting practices of farmers, their expectation of losses and factors affecting PHL (Post-Harvest Loss) at harvesting stages.

Variable [a]	(N = 382)	%
Harvesting time		
September to October	27	7.0
October to November	245	64.1
November to December	110	28.9
Maturity indices		
When pods color turn from green to yellow	211	55.2
When leaves and capsules dry completely	171	44.8
Harvesting mechanism		
Manual	382	100.0
Machine	0	0
Who involve in harvesting		
Male family members	64	16.7
Female family members	18	4.8
Both male & female family	280	73.3
Hired (laborer)	20	5.2
The expectation of PHL at harvesting by respondents?		
Yes	330	86.3
No	52	13.7
Estimate of PHL by respondents at harvesting out of the potential harvest		
Half of the harvested seed	33	8.5
One-third (1/3rd)	35	9.3
One-fourth (1/4th)	48	12.6
< One-fifth (1/5th)	257	67.4
Main factors of PHL by respondents during harvesting		
Shattering due to late harvest	344	90.0
Insects	28	7.4
Birds	3	0.7
Other (Specify)	7	1.9
Suggested mechanism to minimize PHL during harvesting		
Harvesting at a time of maturity	366	95.9
Protecting from insect damage	13	3.3
Protecting from rodent damage	3	0.8

Note: [a] *PHL = Post-harvest loss.*

Because of the high shattering nature of the pods, globally 99% of sesame harvesting is still done manually. In many parts of the world, knives, scythes, and cutters are used to harvest sesame, which are highly labor-intensive (Kumar and Kalita, 2017), and also critically aggravate shattering losses. The same is true in Ethiopia and harvesting is entirely done manually using a sickle and no any mechanical harvesting device was mentioned by respondents during this study. Thus, in this study, harvesting was done manually (100%) mainly using family and hired labor of both gender groups (73.3%).

The majority of the respondents (86%) were aware of the presence of postharvest loss at the time of harvesting. More than 67% of the respondents estimated that up to 20% of sesame grain was lost during harvesting out of the total potential harvest. Shattering (90%) is the major avenue of loss during harvesting. The degree to which shattering occurs depends on the type of sesame variety grown as well as time and method of harvesting. For example, some sesame varieties contain both matured and immature seeds and, at or before harvesting, early capsules dry, open, and shed seeds during harvesting time (Islam *et al*., 2016). Knowing the optimum harvesting time is also important to minimize harvesting losses. Delayed harvesting causes an adverse effect on the sesame seed yield (Tirkey, 2011). The method of harvesting (Hodges, 2013) and the skill of the harvester also affect the level of shattering losses (Boxall, 1998). As a loss reduction strategy, more than 95% of the respondents indicated that knowledge of the optimum maturity stage is a key factor in minimizing pre-harvesting and harvesting shattering losses.

3.1.4. Field drying practices and factors for losses

Immediately after harvesting, the bundles are stacked on the field for a certain period of time to allow drying. Field drying is one of the main practices, which enhances shattering losses due to pod opening. This study showed that more than 95% of the respondents conducted field drying on bare land without using any plastic sheet or canvas to cover the ground under the stacked bundles. Only 4.4% of the respondents in the study area practiced the use of polyethylene or laminated woven polypropylene sheet to collect shattered seeds during field drying. Almost 85% of the respondents agreed that bundles on the field dried thoroughly between 15-20 days after harvesting (Table 5). More than 71% of the respondents used the pod opening to determine sufficiency of field drying. About 20-30% losses of sesame seeds were estimated by the majority of the respondents (86%) which may be due to shattering during field drying. Almost 85% of the respondents indicated that over drying and untimely rain and wind were the major loss factors during field drying (Table 5). Abay and Berhe (2014) also reported that human and animal contacts with bundles as well as insect and rodent damages are additional causes of loss in sesame production.

Table 5. Traditional field drying practice and estimated percentage of losses during field drying of sesame bundles.

Variable [a]	(N = 382)	%
Place of drying		
Dry sesame bundles on the field	365	95.5
Dry the bundles of sesame on plastic sheets or cements	17	4.4
Duration of field drying		
10 days	33	8.5
15 days	198	51.9
20 days	127	33.3
> 20 days	24	6.3
Parameters to determine field drying		
The opening of capsules/pods	273	71.5
Seed scattering	8	2.2
The color of leaves and stalks	70	25.9
The rattling sound of seed	1	0.4
Estimated PHL by respondents at field drying		
Half of the grain	48	12.6
One-third of the grain	59	15.6
One-fourth of the grain	79	20.7
One-fifth of the grain	195	51.1
Major causes of loss during field drying		
Over drying (long duration for drying of the bundles)	192	50.4
Rainfall and wind	133	34.8
Rodents and animals (domestic and wild) contacts	51	13.4
Insects pests (locust/ grasshoppers)	6	1.5

Note: [a] *PHL = Post-harvest loss.*

3.1.5. Bundle transport and threshing practices

Field drying is followed by bundle transportation, threshing, and winnowing. All these activities are done manually. Almost 96% of the respondents indicated that they did not wrap the bundles when carrying to the threshing site (Table 6). This could exacerbate shattering loss particularly when there the bundles have to be transported to a long distance for threshing. Thus, as the distance gets far apart, it may increase the losses with the movement of bundles with the workers (SBN, 2014).

Table 6. Bundle transport to threshing site, threshing methods, estimated loss and associated loss enhancing factors.

Variable [a]	(N = 382)	%
Method of bundles transportation		
Wrapping the bundle with plastic sheets / walking on plastic sheets/ canvas while transporting	15	3.9
Carrying bundle alone without wrapping and walking on plastic/ woven sheets/ canvas	367	96.1
Method of threshing		
Manual	382	100
Estimates of PHL by respondents at the threshing		
Half of the grain	30	7.8
One-third of the grain	37	9.6
One-fourth of the grain	52	13.7
One-fifth of the grain	263	68.9
PHL Factors during threshing and winnowing		
Incomplete threshing	113	29.6
Seed left in the straw/chaff during cleaning/winnowing	200	52.4
Losses due to quality defects (immature, soil, etc.)	69	18.1

Note: [a] *PHL = Post-harvest loss.*

Threshing (separation of seeds from the pods) is done manually (100%) by tapping the bundles with a small stick on a starched plastic sheet (Table 6). More than 69% of the respondents estimated a 20% loss of grains during threshing and winnowing. Incomplete threshing and inefficient winnowing are the two major factors indicated by most of the respondents (>70%). Boxall (1986) also revealed that losses during threshing might arise because of incomplete threshing i.e. grains remain on the straw, scattering as spillage during the operation.

3.1.6. Storage practices and associated loss factors

Grain storage is another major post-harvest practice in the sesame supply chain. As indicated in Table 7, more than 92% of the respondents use woven polypropylene bag to transport and store sesame. Studies showed that the use of polypropylene bag for grain storage is less effective in loss prevention as compared to hermetic storage materials of the metal silo, PICS bag and GrainPro Bags (Baributsa *et al.*, 2017; Abass *et al.*, 2018; Walker *et al.*, 2018). Tefera *et al.* (2011) also indicated that traditional storage practices could not guarantee protection against major storage pests.

Only 48.5% of the respondents indicated to have a separate sesame storage place. However, the remaining respondents said they store sesame also with other crops. Separate storage places are required to keep the safety of grains from insect pests and other quality causing defects. Men are responsible family members to select and prepare storage places (92% of respondents). More than 90% of the respondents indicated that human labor and donkey are the two major means of transportation of sesame from the threshing field to place of storage. The majority of the respondents (75.6%) indicated that they would clean storage places before storing sesame, but only few of them use pesticides for protections against pest damages. Considering storage time, the majority of them (90%) responded that they could store the seeds only for a maximum of three months because of mold growth (51%) and storage insect pests (66%) (Table 7). Consistent with the results of this study, Manandhar *et al.* (2018) also showed that storage losses mainly due to damage by insect and mold (mycotoxins) are the highest among the post-harvest storage losses of grains in developing countries.

Table 7. Storage materials used, methods, and practices of storage of sesame grain.

Variable	(N = 382)	%
Type of storage structures used		
Gotera/ Gombisa	13	3.3
Polypropylene bags	354	92.6
GrainPro/ PICS bag	16	4.1
Storage place		
Dedicated Storage only for sesame	185	48.5
Common storage with other crops	197	51.5
Gender role in storage place preparation		
Men	352	92.2
Women	20	5.2
Both	10	2.6
Transportation means to the storage place		
Human labor	82	21.5
Donkey	260	68.1
Vehicle	40	10.4
Cleaning practice		
Cleaning of storage places before storage	289	75.6
No practice of cleaning	93	24.4
Chemical treatment of grains before storage		
Yes	93	24.4
No	289	75.6
Duration of storage		
<1 month	197	51.5
1-3 month	151	39.6
4-6 month	23	5.9
>7 month	11	3
Growth of mould experience during storage		
Yes	195	51.1
No	187	48.9
Experience of insect pests damage during storage		
Yes	252	65.9
No	130	34.1

3.1.7. Marketing systems and major marketing problems

Almost all (99%) of the respondents produced sesame to generate income (Table 8). Since sesame price is highly volatile and mainly determined by the international market price, most of the respondents indicated that they sell the produce immediately after harvest. According to the respondents, 70% of them sell the yield immediately after harvest or after temporary storage (1-3 months), only 13% of respondents hold for some time until better prices are offered (Table 8). Gebremedhin *et al.* (2019) also revealed that sesame farmers in Humera district (Northern Ethiopia) sell the produce immediately after harvest when the price is the lowest. Price instability, lack of awareness, absence of appropriate storage materials, lack of infrastructure, the exploitive influence of middlemen and limited access to market linkage and information are market problems indicated by respondents. For example, as indicated in Table 8, only 54.4% of the respondents have partial market information. Most producers sell their produce when prices are 30% lower, and generally are not well informed on domestic, regional, and international prices (Coates *et al.*, 2011).

Almost equal proportions of the respondents indicated that low-quality grain supply (25.9%), the role of middlemen in the supply chain (29.3%), and lack of market information and price instability (33.3%) are the major sesame market problems they face. In Ethiopia, the constraints for sesame value chain development are related to market access (local, regional, international) and market orientation, available resources, and physical infrastructures and institutions (Kedir, 2017).

Table 8. Purpose of sesame production, marketing system, price and associated problems.

Variables	(N = 382)	%
Purposes of sesame production		
Market	379	99.3
Consumption/ processing	3	0.7
The decision to make sell		
Immediately after threshing	270	70.7
When good price available	51	13.3
When a family problem happens	58	15.2
Other (Specify)	3	0.7
Place of marketing		
Local market	299	78.1
Ethiopian Commodity Exchange (EXC)	10	2.6
Respondents' cooperative	74	19.3
Estimated USD per 100 Kg		
40-60 USD	72	18.9
61-80 USD	35	9.3
81-100 USD	82	21.5
101-120 USD	154	40.4
121-140 USD	34	8.9
>141 USD	4	1.1
Access for market information		
Yes	208	54.4
No	174	45.6
Major marketing problems		
Low-quality seed	99	25.9
Limited participation of Respondents' Cooperative Unions in marketing	33	8.5
Transportation	11	3.0
The problem of actors in the sesame value chain	112	29.3
Limited market information and price instability	127	33.3

The local market is the preferred destination for most of the respondents (78%) and only 19.3% of the respondents had a chance and experience to sell to farmers cooperatives. Only 2.6% of the respondents sold their produce to the Ethiopian Commodity Exchange (ECX). The presence of a farmers' cooperative is also important to attain maximum quality for export and exclude middleman's roles in the value chain. The market linkage of sesame producers in the study areas with ECX is also weak. However, strengthening the linkage is important because ECX is an organized marketplace, where buyers and sellers come together to trade - assured of quality, quantity, payment, and delivery with a better market price to producers.

When the price of the 100 kg sesame is considered, almost 60% of the respondents had the experience to sell for between 80–120 USD in the local market. On average, the price of sesame in the study area is 30–36 Ethiopian Birr (ETB) kg^{-1} (1–1.24 USD kg^{-1}). According to FAO (2015), the price of sesame increased from 6.8 ETB kg^{-1} in 2005 to 24 ETB kg^{-1} in 2012. Based on the ECX selling price, the average price for the 2013-2014 is 40 ETB kg^{-1} (SBN, 2014). The price may exceed 40 ETB kg^{-1} in some parts of the country based on the type/ or quality of seed. FAO (2015) revealed that the price of sesame in Ethiopia varies according to quality; the golden sesame fetches a higher price than the white one.

3.1.8. Agro-processing and supporting institutions

In the study area, all respondents (100%) indicated that there is no sesame processing and value addition practice (Table 9). This indicates that, it is raw sesame that is supplied entirely to the central market with no value addition. The participation of local and international investors in sesame processing is limited. It is because, sesame value addition targeting high-value export markets is capital and technology-intensive and needs the support of the government. Therefore, sesame value addition should be encouraged because it is advantageous to increase the country's foreign currency earning. Diversification of sesame products through value addition with acceptable quality certification can improve its competitiveness.

Table 9. Agro-processing and supporting institutions associated with sesame production and supply.

Variables	(N = 382)	%
Availability of sesame processing industry		
Yes	-	-
No	382	100
Value addition experience		
Yes	-	-
No	382	100
Awareness about the availability of financial institutes to support production or value addition		
Yes	287	75.2
No	95	24.8
Experience to get credit for the sesame production/value addition		
Yes	236	61.9
No	146	38.1
Government support in relation to PHM of sesame		
Yes	190	49.6
No	192	50.4

3.2. Load Tracking (the extent and causes) to assess Losses along the Sesame Supply Chain

The results of losses at selected sesame post-harvest handling practices were determined using a load tracking method to validate the survey results. Table 10 presents the load tracking results (extents and causes) along the supply chain for three different farm sizes (small (<5 ha), medium (5-10 ha), and large size (>10 ha)). As indicated in the Table 10, a significant ($P < 0.05$) loss was observed among three farm sizes when pre-harvest and harvesting stage was considered. As the farm size increased, the extent of loss also increased due to pre-harvest and harvesting factors. As farm size increases, the labor force to harvest at optimum maturity time may not be available and it is also difficult to control the hostile attitudes of harvesters.

Table 10. Mean (mean ± SD) showing the extent of loss and cause factors along the supply chain of sesame in Wollega Zones, Ethiopia.

Loss factors	Losses in ton ha^{-1} at different farm sizes			Overall loss	
	Small farm (<5 ha)	Medium (5-10 ha)	Larger scale (>10 ha)	ton ha^{-1}	%
Pre-harvest & harvest	0.014 ± 3.5^{d-f}	0.018 ± 5.3^{c-e}	0.025 ± 3.5^{bc}	0.019	4.7
Field drying	0.023 ± 7.1^{b-d}	0.028 ± 5.3^{ab}	0.035 ± 6.1^{a}	0.028	7.1
Bundle carrying/ transport	0.005 ± 1.8^{f}	0.006 ± 0.7^{f}	0.007 ± 1.1^{f}	0.006	1.6
Threshing & winnowing	0.011± 3.1^{ef}	0.014 ± 3.4^{d-f}	0.017 ± 4.2^{c-e}	0.014	3.6
Total loss	0.052	0.065	0.085	0.067	16.9

Note: *Means with the same letter(s) are not significantly different at a = 0.05 level of significance according to least significance test.*

The results showed that the extent of pre-harvest and harvesting related losses is 4.7% (Table 10). It is the second highest loss in our study next to the loss of in-field drying. Sesame Business Network (SBN) in northern Ethiopia also reported a 3.25% loss due to pre-harvest shattering (SBN, 2014). Similarly, Muyinza *et al.* (2017) reported about 2% loss for sunflower seed was reported at the stage of harvesting. The total seed losses of oilseed rape during harvesting ranged from 3 to 7.6% of the yield (Zhu *et al*., 2012). During harvesting up to 23.6% losses of camelina seed were found due to pod shattering (Sintim *et al*., 2016).

Sometimes sesame matures irregularly due to the use of mixed varieties, disease pressure, and climate conditions that could contribute to shattering loss of early maturing pods. Large losses occur before or during the harvesting operations, if not performed at adequate crop maturity and moisture content (Kumar and Kalita, 2017). For example, according to Langham and Wiemers (2002), up to 50% of sesame seeds were lost due to shattering before harvesting. The degree to which shattering occurs depends on the variety, stage of maturity, and extent of handling at different postharvest activities (Hodges, 2013). Crop harvesting at optimum physiological maturity obtained higher seed yield and better qualitative characteristics of the oil as reported by Tirkey (2011).

Knowledge of optimum maturity and indication for maturity or harvesting time of sesame seeds is important to control pre-harvest shattering losses. However, some of the respondents in this study had started harvesting when the plants were above optimum maturity. This delay would lead to a considerable seed loss due to capsule shattering. Consistent with this suggestion, Ogutcen *et al.* (2018) revealed that shattering was one of the major limiting factors in the yield of oil crops when the harvest was delayed (Zhu *et al.*, 2012; Ogutcen *et al.*, 2018).

As indicated in the previous section of this survey work, the respondents dried the stacked or bundles of sesame seeds on the field without putting plastic/woven sheets/canvas or other clean materials on the ground for a period of 10–20 days. The same result was observed during field drying even if there was no significant difference between medium and large size farms. However, a significant difference in loss was observed among small and large farms during field drying. No significant ($P > 0.05$) difference in a loss was observed among three farm sizes during the transportation of bundles from the field to the threshing site. However, threshing and winnowing loss from a large-sized farm is the highest, followed by medium and small farm sizes.

When selected postharvest activities in each farm size were compared as indicated in Table 10, a significant difference was observed with the greatest extent of loss during field drying, followed by pre-harvest and harvesting stage, threshing and winnowing and transportation to the threshing field. Consistent with the results of this study, the results of a study conducted by Sesame Business Network (SBN) in Amhara and Tigray Regional States of Ethiopia revealed that the highest loss (5.54%) occurred during field drying (SBN, 2014). However, the loss reported by SBN is low as compared to the loss observed in this study during field drying. This may be attributed to the differences in location, variety, handling practices, and maturity stages among the locations. According to Zhu *et al.* (2012), rapeseed losses during drying were significantly higher than during harvesting.

A research finding on different crops including sesame in central and northern Tanzania showed a 15% field loss (Abass *et al.*, 2014) and a 5% loss of sunflower about drying (Muyinza *et al.*, 2017). The extent of losses during field drying was determined based on the type of different factors. Based on the results of our survey report, the main cause of sesame losses during field drying was due to prolonged drying of the bundle on the field. The length of time needed for the field drying of ears and grains depends considerably on weather and atmospheric conditions. The capsules open at the top when over dry, which causes seed shattering at the slightest touch. During field drying, once the bundle dries, the seed shatter promptly especially if there are high rainfall and strong winds. It was also identified that some of the losses were due to damage of the bundle by rodents, insects, and other animals in the field, which may exacerbate the rate of seed shattering.

The preparation of the drying place for the bundles is important. Based on the results of this study, the respondents did not use polypropylene plastic sheets or other materials during the field drying. More than 95% of the respondents dried the stacked bundles on bare land without using plastic/ woven sheet/ canvas under the bundle to collect shattered seeds. Appropriate bundle placement was recommended as an important sesame postharvest operation to reduce losses during field drying (Neekhara, 2009; SBN, 2014; SBN, 2018). Immediately after harvesting, vertical positioning of the bundles of sesame on polypropylene plastic sheets is good to minimize seed losses. Singh *et al.* (2006) also recommended that the bundles of harvested sesame should be dried on the threshing floor by tying them vertically for 5–7 days. Swathing (wrapping harvested plants into bundles) before completion of drying combined with the use of desiccant sprays prevents the splitting of the valves upon maturity, and can reduce shattering (Summers *et al.*, 2003).

In this study, a relatively low average loss was measured during transportation of bundles of sesame (Table 10). The loss was high at large farms as compared to small farms due to the long distance between drying and threshing site and wrong handling practices. In Ethiopia, according to SBN (2014), about 1.85% of sesame losses were reported due to bundle transport to threshing sites. This percentage of loss is consistent with the results of this study. The lower the distance between field drying and threshing sites, the better the strategy is to reduce the loss, in addition to wrapping and caring bundles in canvas or plastic sheets.

Losses during threshing and winnowing of bundles are the higher loss next to the pre-harvest and harvesting stage. The estimated average loss of 3.5% is mainly caused by scattering of seeds and less efficient threshing. The survey results also confirmed that the main cause for threshing loss was due to trapping of seeds in the straw/chaff during cleaning/winnowing (inefficient winnowing), and incomplete threshing. If the harvest is threshed before it is dry enough, the operation most probably is incomplete. Unfortunately, we could not find literature data on threshing loss of sesame to compare with our results. However, estimated losses for cereal grains during threshing were about 6% in Ethiopia, 6.5% in Madagascar and 2.5–3.5% in Zimbabwe (Hodges and Maritime, 2012), 0.86–2.27% for rice (Nath *et al.*, 2016). Furthermore, according to FAO (2017), estimated threshing losses in Ethiopia were 0.6–4.75% (maize), 2.5–3% (wheat), 2–9.15 (sorghum), and 0.2–5.2% for common bean.

Good management practices during threshing are crucial in minimizing sesame loss. Threshing should be conducted carefully by avoiding incomplete threshing and quality defects. During cleaning or winnowing, the seed should be separated carefully without leaving it in the chaff/ straw. In terms of identifying and prioritizing the critical loss steps, our finding in the load tracking agrees with the survey outputs. However, the extent of losses estimated during the assessment study was more exaggerated compared to our data in the load tracking step.

3.3. Estimation of Sesame Loss in terms of Economic Value

In our study, the results of the load track showed that about 0.068 tons ha^{-1} or 67.5 kg ha^{-1} (~17%) of sesame is lost before storage. According to the production data obtained from the agricultural bureau office of East and Horro Guduru Wollega zones of Oromia regional state, the average land covered by sesame for the last five years (2014–2018) is 42,753.6 ha (Table 11). Out of the total production, on average, about 2,885.87 tons of sesame seed is lost per year only in the specified Zones. When it is converted into a monetary value, this loss is estimated at 3,289,889.5 USD per year. This money value was calculated based on the survey results of 2017-2018 which indicated that the average selling price of 1 kg of sesame seed is 33 ETB (1.14 USD) in the study area. It was shown that the loss of sesame along the supply chain may have a huge impact on the respondents' income as well as the economy of the country.

Post-harvest losses in grains can lead to a significant economic loss to the food supply chain actors and the nation at large (FAO, 2017). The purpose of converting this quantitative loss in terms of economic value is to estimate the price lost at farm levels before reaching even storage places of farmers. It may be a better way to tell the amount of loss in terms of monetary value rather than telling in terms of quantity or physical loss to create awareness and mitigation strategies to reduce loss.

4. Conclusions

Results of this study indicated that, there was an agreement between assessment and load tracking studies in terms of identifying critical loss points of sesame during on farm postharvest activities. From the load tacking study, a 17% seed loss was estimated during on farm postharvest activities, and field drying, pre-harvest shattering and threshing/winnowing were identified as critical loss points. A 17% on farm loss due to poor post-harvest on farm activities will have a significant economic impact when it is added upon losses in other parts of the value chain (storage, transportation and processing). Policy makers and other stakeholders in the value chain should consider the identified critical loss points as an entry point to implement loss reduction strategies. A 17% loss reduction due to good on farm post-harvest activities will result in the same volume of supply of the crop to local and international markets. In order to have a general picture of the loss impact at country level, it is also recommended to have reliable data of losses during storage as well as processing.

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