ASSESSMENT OF FARMERS' CHICKPEA (C*ICER ARIETINUM* L.) SEED PROCESSING AND STORAGE PRACTICES IN CENTRAL ETHIOPIA

Abebe Sori [1*], Zewdie Bishaw [2], Mashilla Dejene [3], Karta Kaske Kalsa [1]

[1] Ethiopian Biodiversity Institute, P.O. Box 30726, Addis Ababa, Ethiopia

[2] International Center for Agricultural Research in the Dry Areas, Addis Ababa, Ethiopia

[3] Haramaya University, P.O. Box138, Dire Dawa, Ethiopia

ABSTRACT: Smallholder chickpea producers should implement effective and efficient post-harvest seed handling practices to guarantee that their seeds are high quality, competitive in domestic and international markets. However, there is limited information on current post-harvest handling practices applied by chickpea farmers in central Ethiopia. Therefore, this study assessed chickpea seed processing, storage, and management practices through a field survey across five major chickpea-growing districts, using multi-stage and purposive sampling to engage 203 farmers. Results revealed that core processing operations threshing, cleaning, drying, and moisture testing were entirely guided by traditional knowledge. The majority of farmers (79.3%) used fumigant chemical treatments to protect stored seed from insect pests and diseases. More than 90% stored seed in polypropylene or reused fertilizer bags, with or without inner plastic lining. Farmers identified key storage challenges as vulnerability to fluctuating weather conditions and both qualitative and quantitative seed losses caused by insect pests and rodents. Regarding management practices, 86.7% of farmers stored grain and seed separately after processing, while 74.4% cleaned storage facilities before loading newly produced seed. Nearly all farmers relied on visual observation for seed and storage inspection. These findings highlight that continued dependence on traditional practices is insufficient to address existing gaps in seed quality and quantity. Adopting improved, evidence based post-harvest handling methods is essential for smallholder chickpea producers to remain competitive in both domestic and international markets. Hence, farmers should adopt improved seed processing, storage technologies, and extension support to enhance chickpea seed quality and market competitiveness.

Keywords: Drying and trashing, farmers' survey, quality loss, seed cleaning, seed inspection

*Corresponding author: abebe.sori@ebi.gov.et

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is an important food legume globally, recognized as the third-largest pulse crop with a cultivated area of 14.14 million hectares and a production of 15.94 million tons (FAO, 2021). In Sub-Saharan African (SSA) countries, chickpeas have shown an increase in land area allocated and production since 1961 (Fikre *et al.*, 2020a). Specifically, the land area cultivated with chickpeas expanded from 188,000 hectares in 1961 to 380,395 hectares in 2018, while production increased remarkably from 123,600 tons to 637,681 tons during the same period (FAO, 2020). Chickpea has strategic relevance for the agricultural sector transformation and improving food and nutrition security, soil health, economic returns, and income stability for SSA (Gaur *et al*., 2018; Fikre *et al.*, 2020a). Additionally, chickpea is a vital protein and minerals source for millions in developing countries (Gaur et al., 2010). Hence, chickpea contributes to the improvement of the livelihoods of many farmers and food security (ICARDA, 2019; Haileyesus and Mekuriaw, 2021; Bishaw *et al*., 2022).

Chickpea cultivation spans over 50 countries (Jukanti *et al*., 2012), with Ethiopia being among the six largest producers globally and the leading producer, consumer, and exporter of chickpeas in Africa (FAO, 2021; Chichayebelu *et al*., 2021). Chickpea accounts for more than 14% of Ethiopia's legume production, with the production of 0.46 million tons on an estimated land area of 0.22 million hectares during the main cropping season (CSA, 2021). This demonstrates that chickpea is the third-largest food legume in volume of production and land area allocated in the country (CSA, 2021; Chichayebelu *et al.*,2021). In addition, chickpea has become the third-most important exported legume crop, generating about US$61 million annually (ICARDA, 2019). Moreover, chickpea is part of the integrated crop-livestock farming systems based on the experience and resources of the farmers (Mekuanint *et al.*,2018).

This shows that chickpea has become the source of livelihood for many farmers in the country (Ferede *et al.*,2018; ICARDA, 2019).

Although chickpea has substantial economic, nutritional, and agronomic benefits, the national chickpea productivity remains relatively low, with an average yield of about 2 t ha^{-1} (CSA, 2021), which is considerably lower than the potential grain yield of about 4 t ha^{-1} under improved management conditions (Eshete et al., 2015). Seed quality is recognized as one of the major constraints limiting chickpea production and productivity in Ethiopia (Fikre and Bekele, 2020b). Crop productivity can be substantially improved through the use of high-quality seed of improved varieties combined with appropriate agronomic practices (Abebaw et al., 2023). High-quality seed plays a critical role in ensuring better crop establishment, improved yield performance, and resilience to pests, diseases, and drought stresses (FAO and ICRISAT, 2015). However, farmers' seed processing, handling, and management practices often influence the quality of seed used for subsequent planting.

Seed processing operations and management practices are essential components of high-quality seed production (Delouche, 2021; Sinha *et al.,* 2023). However, seed processing is a technical operation that requires skilled, knowledgeable, and experienced personel, as well as appropriate equipment (FAO, 2018). As a result, farmers in developing countries could face a common challenge during seed processing operations and management practices (Delouche, 2021). Seed frequently deteriorates in the field during harvesting or drying, resulting in low-quality seed being stored (Saeed *et al*., 2020). In developing countries, it is a common practice to heap threshed crops in the field for several days to allow adequate drying (Bam *et al*., 2007). This may not provide a guarantee to attain optimum seed moisture, particularly during the rainy season.

In developing countries, smallholder farmers use traditional seed storage methods, which are often inefficient in protecting stored seeds from pests, moisture damage, and other storage-related losses during extended storage periods (Endashaw and Hiruy, 2021). Such inadequate storage practices may lead to deterioration in seed quality, reduced germination capacity, and significant post-harvest losses. However, there is limited information regarding chickpea farmers seed processing, storage and seed management practices in the central Ethiopia. Therefore, understanding the existing knowledge, experience, and practices of smallholder farmers regarding chickpea seed post-harvest and storage management practices is essential for improving seed quality and ensuring the availability of viable seed for planting. Hence, this study was undertaken to assess current chickpea seed processing, storage, and seed management practices among smallholder farmers in central Ethiopia.

MATERIALS AND METHODS

Description of the study areas

The chickpea on-farm storage study was conducted in five districts drawn from three administrative zones: Two districts from East Shewa Zone (Ada'a and Lume), two districts from West Shewa Zone (Dandi and Ejersa Lafo), and one district from North Shewa Zone (Minjar-Shenkora) (Figure 1). The study districts are geographically located between 7°53′21.84″N and 9°59′21.84″N latitude and 38°00′47.52″E and 39°31′38.64″E longitude, with altitudes ranging from 1,699 meters above sea level (m a.s.l.) in Minjar-Shenkora district to 2,263 m.a.s.l., 102 in Lume district. According to the agro-ecological zone (AEZ) classification developed by the Ministry of Agriculture and Rural Development (MoARD, 2005), Dandi and Ejersa Lafo districts fall within the tepid to cool moist mid-highland (M2) agro-ecological zone, while Ada'a and Lume districts are categorized under the tepid to cool sub-moist mid-highland (SM2) zone. In contrast, Minjar-Shenkora District is classified under the hot to warm sub-moist lowland (SM1) agro-ecological zone.

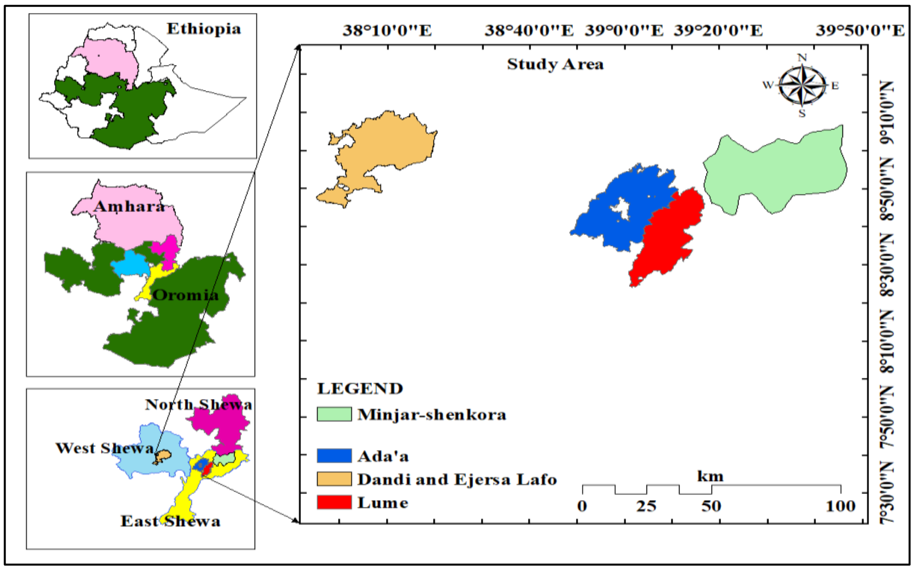

Figure 1.Map of Ethiopia showing the chickpea field survey zones and districts in 2021/2022 crop season

Sampling Procedures and Sample Size

A four-stage and purposive sampling techniques was employed, involving zones, districts, *kebeles*, and chickpea farmers as sampling units. In the first stage, major chickpea-producing zones in central Ethiopia were purposively identified based on their production potential and relevance to the study objectives. During the second and third stages, five districts from the three zones and four *kebeles* from each district were selected, respectively. The selection of districts and *kebeles* was carried out purposively in consultation with agricultural experts and local extension agents, based on their suitability for chickpea production. In the fourth stage, a total of 203 chickpea farmers were selected from 20 *kebeles* using a simple random sampling technique. Primary data was collected through face-to-face interviews using a carefully designed and pre-tested structured questionnaire. The enumerators and the researcher conducted interviews in the farmers' local languages (Afan Oromo and Amharic) to ensure understanding and accuracy. All responses were then recorded and translated into English for data processing and analysis.

Data collection

Primary and secondary data were collected. Primary data came from chickpea growers via household surveys. This data included information on household characteristics (gender, age, education, family size, oxen and land ownership, and chickpea farming experience), and socio-economic factors (labor source, off-farm income, access to credit and extension services, and farmer's Association membership). Additionally, the study examined chickpea farmers' knowledge and experience regarding current seed processing and storage practices in central Ethiopia.

Data Analysis

The survey data were carefully cleaned, coded, and checked for accuracy and completeness prior to analysis. The cleaned data were entered into the Statistical Package for the Social Sciences (SPSS), version 25 (IBM SPSS Statistics) for further analysis. Data coding and entry procedures were standardized to minimize errors and ensure data consistency. Both descriptive and inferential statistical methods were employed for data analysis. Descriptive statistics, including frequencies, percentages, and means, were used to summarize and describe the key characteristics of the sampled households and study variables. In addition, inferential statistical techniques were applied to examine differences among districts. Specifically, one-way analysis of variance (ANOVA) was used to test for statistically significant differences in continuous variables, while the Chi-square (χ^2) test was employed to assess differences among categorical variables across districts. All statistical tests were conducted at level of significance of $p \leq 0.05$.

RESULTS

Farmer Household Characteristics

A summary of descriptive statistics and results of statistical significance tests for both categorical and continuous variables are presented in Tables 1, 2, and 3. The results of the Chi-square (χ^2) test indicated that there was no statistically significant difference in the gender of household heads across districts ($\chi^2 = 8.15$; $p > 0.05$). However, the educational status of household heads varied significantly among districts ($\chi^2 = 39.98$; $p = 0.005$). Out of the 203 households (HHs) surveyed, male-headed households accounted for 93.6%, indicating a strong dominance of male household heads in the study areas (Table 1). Approximately one-quarter (24.9%) of the household heads were illiterate, while the majority (75.1%) were literate at different levels, including informal education (19.0%) and formal education (elementary school and above). This suggests a relatively moderate level of literacy among chickpea-producing households, which may influence the adoption of improved agricultural practices.

Table 1. Chickpea farmers' gender and educational levels

Variable		Sex of HH (%)		Education level of HH (%)					
District	N	MHH	FHH	Illite Rate	Inform Edu.	Elementary	Junior School	High School	College and above
Dandi	41	85.4	14.6	31.7	7.3	29.3	17.1	12.2	2.4
E. Lafo	43	95.4	4.7	20.9	11.6	30.2	25.6	7.0	4.7
Ada'a	35	91.4	8.6	14.7	20.6	26.5	14.7	23.5	0.0
Lume	43	95.4	4.7	25.6	18.6	39.5	4.7	11.6	0.0
M/Shenkora	41	100.0	0.0	31.7	36.6	24.4	0.0	4.9	2.4
Total	203	93.6	6.4	24.9	19.0	30.0	12.4	11.8	1.9
F/x^2- value		8.15^a (4) ^{ns}				39.98^a (20) **			

**, ns = values are significant at 1% and non-significant at 5% level of significance, respectively. [a] Chi-square value (X^2) is from two-way cross-tabulation (number in the parentheses are degree of freedom). Abbreviations: HH = Household (head); MHH = Male household head; FHH = Female household head.

The result of the analysis of variance (ANOVA) revealed that there are statistically significant age differences ($F_{(4, 198)} = 3.40$; $p = 0.01$) and active family size ($F_{(4, 198)} = 3.80$; $p = 0.005$) among the HHs across the districts (Table 2). However, there was no significant difference ($F_{(4, 198)} = 2.16$; $p = 0.075$) in the farmers' experiences in growing chickpea across the five districts (Table 1b). The ages of the household heads ranged from 24 to 78 years, with an average of 46.6±0.9 years, while the mean active family size was 4.7 ± 0.2 members, ranging from 3.6 ± 0.3 in Minjar-Shenkora to 5.4±0.4 members in Ejersa Lafo districts (Table 2). Moreover, the average household head experience in growing chickpea was around 24.0 ± 0.9 years (Table 2).

Table 2. Chickpea farmers' age, active family labor and experience in chickpea production

District	N	Age	Active family size	Experience of HH
Dandi	41	45.7±1.5	5.0±0.4	25.0±1.8
Ejersa Lafo	43	50.9±1.8	5.4±0.4	28.0±1.9
Ada'a	35	46.9±2.2	4.5±0.3	20.8±2.1
Lume	43	47.5±1.9	4.7±0.3	23.5±1.7
Minjar-Shenkora	41	41.7±1.8	3.6±0.3	22.0±2.0
Mean/Total	203	46.6±0.9	4.7±0.2	24.0±0.9
Df(error)		198	198	198
F. values		3.40**	3.80**	2.16^{ns}
P-values		p=0.01	p=0.005	p=0.075

Source: Our survey, 2022.

*, ** values are significant at 5% and 1%, respectively. ns = non-significant ($p > 0.05$); HH= household head. The variables mentioned in Table 2 were analyzed using one-way ANOVA.

The one-way ANOVA results further indicated statistically significant differences among districts in the number of oxen owned ($F (4, 198) = 11.50$; $p < 0.01$), land area allocated for chickpea production ($F (4, 198) = 2.86$; $p = 0.025$), and grain yield (kg ha^{-1}) during the 2021/2022 main cropping season ($F (4, 198) = 13.61$; $p < 0.01$) (Table 3). On average, households owned 3.1 ± 0.1 oxen, with the lowest ownership recorded in Minjar-Shenkora District (2.3 ± 0.2) and the highest in Ada'a District (4.4 ± 0.4). Similarly, the mean land area allocated to chickpea production was 0.66 ± 0.04 ha, varying from 0.49 ± 0.01 ha in Dandi and Minjar-Shenkora districts to 0.84 ± 0.1 ha in Ejersa Lafo District.

The average chickpea grain yield across the study districts was 1449.92 ± 94.00 kg ha^{-1}, which is lower than the national average yield of 2018 kg ha^{-1} (CSA, 2021). This indicates a yield gap in the study areas, potentially attributable to differences in management practices, input use, and agro-ecological conditions. Among the districts, Lume recorded the highest yield (2460.65 ± 154.60 kg ha^{-1}), whereas Minjar-Shenkora recorded the lowest yield (651.12 ± 87.50 kg ha^{-1}). Furthermore, the observed yields in the present study are lower than those reported by Ashu et al. (2023) for central and southern Ethiopia, suggesting potential constraints in productivity that warrant further investigation.

Table 3. Chickpea farmers' oxen ownership, land allocation, and grain yield in the study districts

Districts	N	Oxen (head)	Land area (ha)	Grain yield (kg/ha)
Dandi	41	2.4±0.2	0.49±0.1	1313.50±295.41
Ejersa Lafo	43	3.0±0.2	0.84±0.1	1115.14±171.12
Ada'a	35	4.4±0.4	0.76±0.2	1715.00±165.23
Lume	43	3.7±0.2	0.76±0.1	2460.65±154.60
Minjar-Shenkora	41	2.3±0.2	0.49±0.0	651.12±87.50
Total/mean	203	3.1±0.1	0.66±0.04	1449.92±94.00
Df (error)		198	198	198
F-values		11.50**	2.86*	13.61**

Source: Own survey data (2022). *, ** values are significant at 5 and 1% levels of significance, respectively.

The results of the chi-square tests (X^2-value ranged from 3.17 to 8.64; P = 0.05) showed that there were no significant differences (*p* > 0.05) among the HHs of the five districts in their responses to the categorical variables (Table 4). When considering farmers' involvement in off-farm and on-farm activities, about 44.3% of farmers engaged in off-farm activities, whereas 55.7% of them were engaged in on-farm activities (Table 4). Family members provided roughly 63.5% of the labor that chickpea farmers needed, while about 36.5% of HHs hired labor to support their families (Table 4). Considering credit service access, about 42.4% of HHs in the study areas accessed credit services from various micro-financial intuitions (Table 4). However**,** the majority (57.6%) of farmers in the study areas did not get access to credit services.

Table 4. Chickpea farmers' socio-economic characteristics by categorical variables in the studied districts

Variables	Districts							
	Dandi	Ejersa Lafo	Ada'a	Lume	M/Shenkora	Mean	X^2	Df
Source of labor	*n*=41	43	35	43	41	203	3.17ns	4
Family alone	61.0	55.8	60.0	72.1	68.3	63.5		
Family and hired	39.0	44.2	40.0	27.9	31.7	36.5		
Off-farm income	*n*=41	43	35	43	41	203	7.60ns	4
Yes	58.5	51.2	42.9	32.6	36.6	44.3		
No	41.5	48.8	57.1	67.4	63.4	55.7		
Credit service	*n*=41	43	35	43	41	203	8.64ns	4
Yes	43.9	46.5	51.4	23.3	48.8	42.4		
No	56.1	53.5	48.6	76.7	58.5	57.6		
Extension service	*n*=41	43	35	43	41	203	6.85ns	4
Yes	80.5	86.0	88.6	95.3	95.1	89.2		
No	19.5	14.0	11.4	4.7	4.9	10.8		
Membership (FA)	*n*=41	43	35	43	41	203	4.56ns	4
Yes	78.0	90.7	82.9	79.1	90.2	84.2		
No	22.0	9.3	17.1	20.9	9.8	15.8		

Source: Own survey data (2022). Note*:* ns= values are not significant at 5% by the Chi- square test. Abbreviation: FA = Farmers' Association.

3.2. Chickpea Seed Processing

3.2.1.Drying and threshing

The survey results indicated that smallholder farmers employed a range of traditional techniques for chickpea drying and threshing operations in central Ethiopia during the 2021/2022 cropping season (Table 5). More than one-quarter of the respondents applied combined sun-drying methods, including piling harvested crops in the field followed by spreading on the threshing floor, or piling near the threshing floor and subsequently spreading on the threshing floor (Figure 2). These results suggest that farmers rely on multiple sequential drying practices rather than a single method to ensure adequate drying prior to threshing. Similarly, the majority (87.2%) of smallholder chickpea farmers reported that threshing was carried out by trampling the harvested crop using draft animals, primarily oxen, while a smaller proportion (12.8%) used a combination of animal trampling and beating with sticks (Table 5). This indicates a heavy reliance on traditional threshing techniques, which may have implications for seed quality and post-harvest quantitative losses.

Figure 2. Chickpea drying by spreading on an unplastered threshing floor. Photograph taken during the field survey (Abebe Sori, 2022).

Table 5. Chickpea drying and threshing practices among farmers in the study districts

1.What technique(s) did you apply to dry chickpea before threshing?(n=203)	Frequency	%
Natural, (complete sun dry before harvesting)	1	0.5
Sundry by piling harvested crop in the field	6	3.0
Sundry by piling harvested crop near threshing floor	28	13.8
Sundry by spreading harvested crop on threshing floor	17	8.4
Natural, and sun drying by piling in the field	2	1.0

Sundry by piling in the field and near threshing floor	2	1.0
Sundry by piling in the field and spreading on threshing floor	52	25.6
Sundry by piling near threshing floor and spreading on threshing floor	53	26.1
Natural, sundry by piling in the field, and spreading on threshing floor	4	2.0
Sundry by piling in the field, near threshing floor and spreading on threshing floor	33	16.3
Natural, sundry by piling near threshing floor, and spreading on threshing floor	4	2.0
2. How did you thresh the chickpea after harvest (n=203)	Frequency	%
Trampling with animals (usually oxen)	177	87.2
Trampling with animal and biting with stick	26	12.8

Source: Own field survey (2022)

Note: Natural practice indicated where chickpea crop is allowed to sundry completely before harvesting.

Seed cleaning and moisture tests

In the study districts, about 56.2% of farmers cleaned seeds by winnowing under natural wind, followed by manual cleaning and handpicking of the inert materials in central Ethiopia. However, about 42.4% of farmers cleaned chickpea seeds using winnowing under natural wind and manual cleaning using sieves and other locally made tools (Table 6). Furthermore, farmers were asked if they measured seed moisture content before harvesting and storage. Accordingly, the majority (86.2%) of farmers assessed the seed moisture content before harvesting and storage using a combination of visual examination and teeth biting (53.7%), whereas about 36.0% of farmers assessed moisture content with visual examination alone.

Table 6. Chickpea seed cleaning and moisture assessment practices among farmers

1. How did you clean seed after threshing? (n=203)	Frequency	Percent
a. Winnowing under natural wind	3	1.5
b. Winnowing and manual cleaning	86	42.4
c. Winnowing, manual cleaning and hand-picking inert materials	114	56.2
2. Did you measure seed moisture content? (n=203)		
a. Yes	175	86.2
b. No	28	13.8

3. How did you know whether the seed is dry enough to store? (n=175)		
a. Biting with teeth	18	10.3
b. Visual observation	63	36.0
c. Both biting with teeth and visual observation	94	53.7
4. After cleaning, did you manage separately grain for Consumption and seed for planting? (n =203)		
a. Yes	176	86.7
b. No	27	13.3
5. Did you clean chickpea seed before storing? (n=176)		
a. Yes	146	83.0
b. No	30	17.0
6. How did you clean the seed? (n=146)		
a. Winnowing alone	4	2.7
b. Hand picking the inert matters alone	2	1.4
c. Winnowing, hand pick the inert matters and manual cleaning	98	67.1
d. Winnowing and manual cleaning	23	15.8
e. Hand picking the inert matters, and manual cleaning	19	13.0

Source: Own field survey (2022).

Note. In all cases, winnowing was performed under naturally blowing wind.

Seed Storage Practices and associated challenges

Chickpea seed storage practices

Table 7 presents the current on-farm chickpea seed storage practices among smallholder farmers in central Ethiopia during the 2021/2022 cropping season. The survey results indicate that farmers employ a range of traditional storage techniques, largely depending on the availability, accessibility, and perceived effectiveness of storage materials. The findings reveal that nearly all farmers rely on traditional storage containers, primarily polypropylene (PP) bags (57.1%), either used alone or in combination with re-used fertilizer bags with or without inner plastic linings. Only a negligible proportion of farmers (0.5%) reported using hermetic storage technologies such as Purdue Improved Crop Storage (PICS) bags, indicating extremely low adoption of improved storage technologies in the study areas (Table 7). This suggests a significant technological gap in post-harvest seed management practices.

Table 7. Current on-farm chickpea seed storage practices by farmers in the central high lands of Ethiopia during the 2021/2022 main cropping season

1. What type of storage containers do you employ? (n=203)	Frequency	Percent
a. Polypropylene bags (PP bags)	116	57.1
b. PP bag and fertilizer bag without inner plastic	25	12.3
c. Fertilizer bag without inner plastic	18	8.9
d. PP bag and re-used fertilizer bag with inner plastic	11	5.4
e. Fertilizer with inner plastic	8	3.9
f. PP bags, fertilizer bag and *dogogo*	4	2.0
g. PP, fertilizer bags w/out inner plastic, and ZeroFly® bag	20	9.9
h. Hermetic bags (e.g. PICS bag)	1	0.5
2. Do you currently utilize hermetic bags for chickpea seed storage? (n= 203)		
a. Yes	1	0.5
b. No	202	99.5
3. What was/ were you concerns with current seed storage(n=203)		
a. Insect pest and rodents	119	58.6
b. Insect pests, rodents and birds	57	28.1
i. Rodents	11	5.4
j. Insect pest	9	4.4
k. Insects, rodents and mold	3	1.5
l. No challenge	4	2.0

Source: Own field survey data (2022).

Challenges of on-farm chickpea seed storage

Seed quality and quantity losses

During the 2021/2022 field survey, farmers were asked to identify the major constraints associated with their current seed storage systems (Table 8). The results indicated that the primary challenges were storage insect pests and rodents, as reported by 58.6% of respondents. In addition, 28.1% of farmers identified a combination of insect pests, rodents, and birds as key storage problems, while a smaller proportion reported issues related to rodents alone (5.4%) or insect pests alone (4.4%). These findings highlight that biological seed storage agents are the dominant constraints affecting seed quality, quantity and storage performance.

Table 8. Farmers' challenges associated with current seed storage practices in central Ethiopia

What was/ were you concerns with current seed storage (n=203)	Frequency	Percent
m. Insect pest and rodents	119	58.6
n. Insect pests, rodents and birds	57	28.1
o. Rodents	11	5.4
p. Insect pest	9	4.4
q. Insects, rodents and mold	3	1.5
r. No challenge	4	2.0

Source: own field survey data (2022)

Capability to withstand fast changing weather condition

In this study, farmers were asked for their perceptions of the effectiveness of existing storage methods and their willingness to adopt improved technologies (Table 9). The results revealed that 78.3% of farmers believed that their current storage systems are not resilient to fluctuating environmental conditions, such as temperature and humidity variations. This perception reflects limitations in the protective capacity of traditional storage materials. Subsequently, farmers were asked about their demand for improved seed storage technologies. The findings show that an overwhelming majority (99.0%) expressed willingness to adopt improved storage methods, indicating a strong demand for technological interventions in seed storage. Further, farmers identified the specific reasons for preferring improved storage technologies, with the most frequently cited being protection against insect pests (30.0%), followed by combined benefits such as insect pest protection and seed longevity (22.2%), and insect pest protection and durability (17.7%). Other reasons included durability alone (16.3%) and durability combined with seed longevity (11.8%), while only a small proportion (2.0%) indicated seed longevity alone as the primary reason (Table 9). These results suggest that farmers prioritize protection against storage pests as the key driver for adopting improved storage technologies.

Table 9. Farmers' perceptions of current seed storage systems and demand for improved technologies during the 2021/2022 cropping season

1.Can your current seed storage methods withstand ever-changing weather conditions? (n=203)	Frequency	%
a. Yes	44	21.7
b. No	159	78.3
2. Do you need improvement of current seed storage systems? (n=203)		%
a. Yes	201	99.0
b. No	2.0	1.0
3. Why do you need improved seed storage? (n=203)		
a. Insect pest protection	61	30.0
b. Insect pest protection and seed longevity	45	22.2
c. Insect pest protection and durability	36	17.7
d. Durability alone	33	16.3
e. Durability and seed longevity	24	11.8
f. Seed longevity alone	4.0	2.0

Source: Own field survey data (2022).

Farmers' Seed and Storage Management Practices

Separate seed and grain storage

Farmers were asked to describe how they manage chickpea seed and grain after threshing and cleaning operations (Table 10). The results indicate that farmers differentiate seed from grain based on physical characteristics, whereby larger, denser, and well-filled seeds are selected for planting, while lighter, shriveled, and immature seeds often separated during winnowing are designated for consumption or sale. This traditional selection method reflects farmers' indigenous knowledge of seed quality attributes. Accordingly, the majority of farmers (80.3%) reported storing seed and grain separately after processing, while 19.7% did not practice such separation (Table 10). This suggests that most farmers recognize the importance of maintaining seed quality through segregation from consumable grain. Furthermore, farmers were asked to indicate the locations used for seed storage. The results show that chickpea seed was primarily stored indoors using various arrangements within the household (Appendix A).

The largest proportion of farmers (43.4%) stored seeds within the living house but in a separate room, often together with grain and seeds of other crops, while 37.9% used separate storage spaces that still contained both grain and seed of different crops (Table 10). This storage practices indicate a potential vulnerability in the farmers' seed management, which could influence seed quality.

Table 10. Chickpea farmers’ seed management and storage location practices in central Ethiopia during the 2021/2022 cropping season

1. Do you store seed and grain separately? (n=203)	Frequency	Percent
a. No	40	19.7
b. Yes	163	80.3
2. Where do you store your seed? (n=203)		
a. In living room with grain and seed of other crops	31	15.3
b. In separate seed store with seed of other crops	7	3.4
c. In separate store but with grain and seed of other crops	77	37.9
d. In living house but in separate room with grain and seed of other crops	88	43.4

Source: Own field survey data (2022).

Seed inspection practices

Seed inspection was identified as one of the keys on-farm storage management practices among chickpea farmers. The results indicated that nearly all farmers (98.5%) reported inspecting their stored seed, demonstrating a high level of awareness regarding the importance of monitoring seed condition during storage (Table 11). Among those who practiced seed inspection, the frequency of inspection varied considerably. About 45.8% of farmers inspected their stored seed on a monthly basis, while 30.5% conducted inspections weekly, and 9.4% performed inspections every two weeks. Only a small proportion of farmers carried out inspections either daily or at longer intervals (beyond one month). This variation suggests differences in farmers’ management intensity and perceived storage risks. In terms of inspection methods, farmers relied predominantly on indigenous techniques, including visual observation alone (26.6%) or in combination with manual methods such as inserting the hand into the storage container to assess seed condition (34.0%). Other sensory-based methods, such as listening to sound or smelling the seed, were used less frequently (Table 11). These findings indicate a reliance on experiential and sensory-based assessment methods rather than standardized or instrument-based stored seed inspection practices in the study areas.

Table 11. Chickpea seed storage inspection practices among the farmers in central Ethiopia

1. Do you inspect storage? (n=203)	Frequency	Percent
a. Yes	200	98.5
b. No	3	1.5
2. How often do you inspect your seed storage? (n=200)		
a. On daily basis	6	3.0
b. Weekly	62	30.5
c. Bi-weekly	19	9.4
d. Every three weeks	3	1.5
e. Monthly	93	45.8
f. Bi-monthly	11	5.4
g. Every 3 up to 5 months	4	3.0
3. How do you inspect your stored seed? (n=200)		
a. Visual observation alone	54	26.6
b. Insert hand and visual observation	69	34.0
c. All except smell methods	31	15.3
d. Listen to sound and visual observation	14	6.9
e. Smell and visual observation	4	2.0
f. All except listen the sound	2	1.0
g. Listen sound alone	7	3.4
h. All methods	22	10.8

Source: Own field survey data (2022)

Storage management practice

Farmers' seed storage management practices are presented in Table 12. The results showed that farmers employ several management strategies to maintain the quality of stored chickpea seed. Approximately 74.4% of respondents reported cleaning their storage facilities prior to loading newly harvested seed, which is a critical practice for reducing contamination and pest infestation risks. However, only 43.1% of farmers reported repairing or maintaining storage containers, while the majority (56.9%) did not practice storage repair and maintenance (Table

12). This may be attributed to the widespread use of single-use woven polypropylene (PP) bags, which are often difficult to repair once damaged. The limited practice of storage maintenance may contribute to increased vulnerability of stored seed to pest infestation and physical damage.

Table 12. Farmers' storage management practices in central Ethiopia

1.Do you clean the store before loading them with newly harvested seed?(n=203)	Freq.	%
a. Yes	151	74.4
b. No	52	25.6
2. Do you practice seed storage container repair and maintenance? (n=203**)**		
a. Yes	88	43.1
b. No	115	56.9

Source: Own survey results (2022).

DISCUSSION

Household characteristics

The characteristics of chickpea-growing households in five districts of central Ethiopia were assessed during the 2021/2022 main cropping season to understand production and seed management practices. The results revealed that gender composition and farming experience were relatively uniform across districts, whereas age, education level, and family size exhibited notable variation, suggesting heterogeneity in human capital among farming households. Regarding household headship, male-headed households dominated the sample (93.6%), which is consistent with previous findings in Ethiopia, where male-headed households accounted for approximately 93% of respondents (Haileyesus and Mekuriaw, 2021). This pattern reflects prevailing socio-cultural norms influencing land ownership, decision-making, and access to agricultural resources. In terms of education, about 25% of household heads were illiterate, while the remainder had either informal or formal education. This level of illiteracy is comparable to earlier studies in the central highlands of Ethiopia, which reported about 21% illiteracy among household heads (Mekuria et al., 2020). Educational status is a critical determinant of technology adoption, particularly for improved seed and storage practices. This need efforts to improve educational access to rural areas to reduce illiteracy rates over time.

The mean age of household heads (46.6 years) indicated that most farmers fall within the economically active age group, which is favorable for labor-intensive agricultural operations such as chickpea production. This finding aligns with Asfaw et al. (2012), who reported similar average ages (46–46.8 years) in major chickpea-growing areas. Likewise, the average farming experience of about 24 years suggests substantial accumulated indigenous knowledge, which can positively influence management decisions, although it may also reinforce reliance on traditional practices. The average active family size (five persons) implies adequate household labor availability, consistent with findings by Asfaw et al. (2010). Family labor constituted the primary workforce, supplemented by hired labor during peak agricultural periods, confirming earlier reports (Bishaw et al., 2010). Labor availability is particularly important for timely operations such as harvesting, threshing, and seed processing.

Regarding resource ownership, oxen were the primary source of draft power, with households owning an average of three oxen, underscoring their critical role in land preparation and overall crop production systems. The average land allocation for chickpea (0.66 ha) is consistent with findings by Mulat et al. (2023). However, the average grain yield (1449.9 kg ha^{-1}) was substantially lower than the national average (2018 kg ha^{-1}; CSA, 2021) and significantly lower than yields reported in other regions (Ashu et al., 2023). This yield gap suggests the presence of production and post-harvest constraints, including sub-optimal seed quality and storage practices, as identified in earlier sections of this study.

Chickpea seed processing practices

Seed processing plays a critical role in maintaining seed quality, encompassing operations such as drying, threshing, cleaning, treatment, and storage. Effective processing is essential to ensure physical, physiological, and sanitary seed quality, which directly influences germination, vigor, and field performance (van Gastel et al., 2007; Sudhakar et al., 2020). The findings of this study indicated that farmers rely predominantly on traditional, labor-intensive seed processing methods, which are often influenced by environmental conditions and resource availability. While these practices demonstrate adaptability, they may not consistently meet recommended standards for high-quality seed production, particularly under variable climatic conditions.

Drying and threshing practices

Farmers employed multiple traditional sun-drying methods, often in combination, to reduce seed moisture content to acceptable levels before storage. The absence of standardized drying techniques reflects dependence on ambient weather conditions, which can delay drying and expose seeds to risks such as re-wetting and fungal contamination. This variability increases the likelihood of pre-storage seed deterioration. Empirical evidence suggests that reducing seed moisture content to safe levels is essential for prolonging seed longevity (Vernooy et al., 2022). Failure to achieve optimal moisture levels prior to storage is a major factor contributing to seed quality decline, particularly in tropical environments.

Threshing practices were predominantly based on animal trampling, consistent with findings from other regions (Tinsley, 2014). However, this method has several limitations, including, mechanical damage to seed, contamination with soil, inert matter, and other crop seeds and increased exposure to pests and pathogens**.** Additionally, threshing on unplastered or poorly prepared surfaces further exacerbates contamination risks. Delayed threshing due to labor or weather constraints also contributes to quality deterioration. These findings are consistent with Sudhakar et al. (2020), who reported that inappropriate threshing practices lead to increased seed damage and reduced quality.

Seed cleaning practices

Shortly after the threshing was finished, chickpea farmers carried out traditional seed-cleaning operations. To maximize the physical seed quality, inert matter (such as plant parts, damaged seed, dust, soil, stone particles, etc.) must be removed from the threshed seed, along with other crop seeds, weed seeds, immature seeds, etc. Our study results showed that most farmers applied seed-cleaning operations that involved different stages using traditional homemade tools. Initially, winnowing under natural wind is carried out to remove major impurities (dust, lightweight straws, other light materials, etc.) using traditional tools like *menshe/Manshi/Qorbi*, *layeda/lameda/Darba* (Appendix B). Further seed cleaning is accomplished, which includes hand-picking larger-sized inert matter and manual cleaning using traditional tools such as *wonfit/gingilcha* (sieve), *safed/Safedi/Gundo* (Appendix B) to remove small-sized inert matter, immature/shriveled, damaged/broken seed, etc. In addition, seed cleaning may be applied before planting if the physical condition of the seed is believed to be unsatisfactory. Similarly, Bishaw *et al*. (2010) investigated that wheat seed cleaning involved two-stage operations, in which the threshed wheat grain is separated from the rough straw first and followed by further seed cleaning from fine straw, inert materials, shriveled and broken seeds using homemade tools. Chichayebelu (2014) reported that farmers' only method of cleaning chickpea grain was winnowing under the naturally blowing wind. This could mean that for chickpea seed and grain, farmers use different management practices.

According to Gaur *et al.* (2010) and Sudhakar *et al.* (2020), the threshed seeds must be cleaned to remove contaminants such as plant parts, soil particles, stones, weed seeds, other crop seeds, and shriveled, broken/damaged seeds. Thus, a maximum percentage of other varieties or crop seeds, weed seeds, and other inert matters present in the seed lot need to be considered as vital components of physical seed quality. This study confirms that chickpea farmers employ traditional and time-consuming practices for chickpea seed cleaning using locally made inefficient tools. Reliance on manual and traditional tools could limits the ability to meet formal seed quality standards, particularly regarding removal of inert matter, elimination of diseased or damaged seeds, and uniformity of seed size and weight. Consequently, achieving certified seed quality under such systems remains challenging.

Seed moisture tests

Seed moisture content is a critical determinant of seed storability and longevity. The findings reveal that farmers rely on traditional methods such as visual inspection and teeth-biting to estimate seed moisture content, consistent with earlier studies (Chichayebelu, 2014). While these indigenous methods are accessible and cost-effective, they lack precision, potentially resulting in storage of seeds at unsafe moisture levels. This limitation is primarily due to the lack of access to affordable moisture measurement technologies, as also noted by Akter *et al.* (2018). Improving access to simple moisture testing tools could significantly enhance seed storability.

Chickpea seed storage practices

Chickpea farmers in the central part of Ethiopia could employ on-farm seed storage facilities that evolved in terms of size, form, holding capacity, and the material from which they were fabricated. In our present study, practically all chickpea farmers currently use traditional seed storage containers, including polypropylene bags (PP), fertilizer bags with and without inner plastic, or a combination of these, depending on which bags are easily accessible and secured. PP bags and re-used fertilizer bags were the most widely used storage facilities in Ethiopia (Dessalegn *et al.*,2017). Similarly, several authors also revealed that PP bags were the most common seed storage method in the central highlands of Ethiopia (Hengsdijk and de Boer, 2017; Getaneh *et al*.,2021; Name *et al.*,2021; Hunduma *et al.*,2021).

The reason for this is that these bags could be accessible in the local markets and affordably priced. Name *et al.* (2021) also reported that PP bags were the most popular storage container types in Ethiopia because they are inexpensive and easily accessible in the local markets. Unfortunately, because of mold and insect pests' inadequate protection and unstable storage conditions, the PP bags now in use cannot guarantee the preservation of quality seeds for a longer time. Therefore, spending resources on seed processing operations alone is insufficient to preserve and supply the required quantity and quality of seed. Appropriate seed storage method should be regarded as an integral component of a high-quality seed supply.

In our present study, it was indicated that nearly no respondents use improved storage methods like hermetic bags for chickpea seed storage. This finding agrees with the recent studies by Getaneh *et al*. (2021), Alemu *et al*. (2021), and Hunduma et al. (2021), who indicated that nearly no respondents in the districts under study used improved storage practices. A few farmers in the surveyed areas have already experienced the advantages of hermetic bags. However, chickpea farmers were unable to use the hermetic bags, mainly because they were not aware of the potential benefits of the bags. In general, hermetic bags are relatively new storage technologies for smallholder chickpea farmers in central Ethiopia, so there is a need to test and validate the technology as well as create awareness (Jones and Walsh, 2014). For effective seed production and distribution, storage must preserve quality seed until it reaches end users. Therefore, hermetic bags should be widely promoted and made accessible locally to increase adoption (Kaske *et al.*,2019).

Seed and Storage Management Practice

Seed quality losses can also result from improperly implemented seed and storage management practices (Bishaw *et al.*, 2010). In the study districts, most farmers employed separate seed and grain storage practices. It is impressive to note that most chickpea farmers separate chickpea seed from grain while it is still on the threshing floor. Farmers would categorize a chickpea as a seed if it appeared larger and heavier in weight, whereas the lighter, shriveled, and immature chickpeas that are removed by the wind in the far front area of the threshing floor are considered grain for consumption and/or sale in the market. Alemu *et al*. (2023) and Abebaw *et al*. (2023) reported that about 42.6% of bread wheat farmers separated the seeds soon after threshing and stored the cleaned seeds separately for the forthcoming cropping season. In addition, all farmers used the indoor storage method (their living houses) to minimize the risk of the thief and other uncertainties. It would be safer to preserve seeds inside the house to prevent theft and similar dangers (Thijssen *et al*. 2008). However, chickpea households rarely ever use a separate seed storage house, mostly due to a lack of resources to construct separate seed and grain storage. Only a limited number of chickpea farmers had separate seed storage houses that were entirely owned by the local seed producer unions and cooperatives.

It is vital practice to assess the condition of the seed and storage facilities for timely management of storage insect pests and rodents (WCDI, 2020). Thus, most of the farmers employed seed and storage inspection practices at least once a month, using their traditional experiences. Similarly, most wheat farmers inspect their stored products at least once a month (Chichayebelu, 2014). This result is consistent with the observation of Befikadu (2014), who stated that inspection needs to be done at least once a month during the colder season and every two weeks during the warmer ones. The chickpea farmers commonly preferred a visual observation technique. This finding is in line with the investigation by Chichayebelu (2014), and Tesfaye (2020), who reported that visual inspection was the primary traditional knowledge employed by farmers for inspecting stored products from time immemorial.

Farmers used several seed and storage management practices to ensure that their stored seed lasted for the intended period. Our results indicated that most farmers employed storage containers cleaning activities before loading them with newly produced chickpea seed.

It is important to clean the storage container and the surroundings before loading the new season's harvested seed into storage to prevent early pest infestations in the storage area (Befikadu, 2014). Otherwise, even a small number of moldy seeds and insect-infested seeds from the previous season could contaminate the seed that has just been stored (Haile, 2006). In addition to cleaning storage containers, repairing damaged seed storage containers is also an essential management practice when impairment occurs before storage or at any time during storage. Similarly, according to Kshetri (2010), the majority of farmers repair on-farm seed store management practices. However, most farmers did not regularly repair seed storage containers in central Ethiopia. This is because the majority of chickpea growers store their seeds in one-time-use woven PP bags that cannot be repaired.

CONCLUSION AND RECOMMENDATION

This study demonstrates that chickpea farmers in central Ethiopia predominantly rely on traditional knowledge and practices for seed processing, storage, and storage management. While these practices are locally adapted and resource-efficient, they are insufficient to maintain seed quality under prevailing environmental and production conditions. The widespread use of polypropylene and reused fertilizer bags reflects their accessibility and affordability; however, these storage systems provide inadequate protection against biological agents such as insect pests and rodents, as well as physical factors including temperature and humidity fluctuations. Consequently, significant losses in seed quality and quantity occur during storage. The findings further indicate that inefficiencies across post-harvest operations, including drying, threshing, cleaning, moisture assessment, and storage practices. Although traditional practices remain integral to smallholder farming systems, their continued dominance limits the effectiveness of improved crop varieties, as genetic potential cannot be fully realized without adequate post-harvest management. Therefore, improving productivity in chickpea systems requires a more integrated approach that combines varietal improvement with enhanced seed handling and storage technologies. To address these challenges, the study recommends the promotion of affordable and context-appropriate improved storage technologies, such as hermetic storage systems, alongside strengthened extension services to enhance farmer awareness and technical capacity. Capacity-building interventions should focus on improved seed processing practices and the introduction of simple, low-cost moisture assessment tools. In addition, integrating post-harvest management into existing agricultural development programs and supporting community-based storage solutions could substantially reduce losses. Policy support and institutional collaboration are also essential to facilitate dissemination and adoption of improved or/and new technology. Future research should prioritize evaluating the impacts of improved storage technologies on seed quality and quantity, as well as identifying location-specific constraints and adoption barriers to ensure sustainable interventions.

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Supplementary Materials

Appendix A. Different indoor chickpea seed storage mechanisms in central Ethiopia

A. Seed stored in living room with grain and seed of other crops

B. Seed stored in a separate store together with other crops seed

C. Seed stored in a separate store together with grains and seed of other crops

D. Seed stored in separate room together with grain and seed of other cops

These pictures represent different on-farm chickpea seed storage mechanisms practices in central Ethiopia during the 2021/2022 storage season. Source: Photo by Abebe Sori (March 2022)

Appendix B. Different chickpea seed cleaning homemade traditional tools

E. *Mensh/Manshii/Qorbi*

F. *Layeda/Lameda/Darba*

G. *Wenfit/Gingilcha* (sieve)

H. *Safed/Gundo*

These pictures represent different traditional homemade tools used for chickpea seed cleaning at different stages in the central Ethiopia during the 2021/2022 cropping season.

Source: These Photos are captured by Abebe Sori (March 2022).