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Investigation of insect population density, species composition and associated losses in chickpea seeds stored on farms in Ethiopia

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A R T I C L E I N F O

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A B S T R A C T

This survey aimed to investigate the extent of insect infestations, associated losses, and insect species abundance in farm-stored chickpea seeds across five chickpea growing districts in Ethiopia. Despite being the largest producer, consumer, and exporter of chickpea in Africa, insect pest infestations have caused significant losses to Ethiopia's chickpea industry. Results showed that *Callosobruchus chinensis* (L.) was the most prevalent insect species, followed by *Sitophilus oryzae* (L.) and *Tribolium confusum* (J. du Val). The insect pests infested both local and improved chickpea varieties, and traditional containers and polypropylene bags were used for storage. The percentage of insect-damaged seed ranged from 4.61% to 14.48%, while the seed weight loss ranging from 1.13% to 4.55%. The range of seed germination percentages was from 65% to 88%, with a mean rate of 71%. These losses significantly affect the market value of the crop as grain and its use as seed, affecting farmers' income and food security. Therefore, it is crucial to develop effective solutions to prevent the loss of farm-stored chickpea in Ethiopia.

1. Introduction

Chickpea (*Cicer arietinum* L.), a significant legume, sustains over one million households and with an annual average yields of 0.47 million tons over an area of 258,486.29 ha [1]. Ethiopia is the leading producer, consumer, and exporter of chickpea in Africa, and is among the top ten producers in the world [2]. Chickpeas are a popular crop for smallholder farmers in Ethiopia, who often grow them at the end of the main rainy season using residual soil moisture. This approach allows farmers to cultivate chickpeas as a second crop, which provides them with an additional source of income and protein. Moreover, chickpeas are ecologically friendly and can be grown

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in areas suffering from soil nutrient depletion.

In Ethiopia, chickpeas are a popular food crop and are used in a variety of dishes such as snacks, curries, mixes, and other culinary creations. While both *desi* and *kabuli* types of chickpeas are produced in Ethiopia, there has been a recent increase in the country's chickpea production, largely due to the replacement of old cultivars (*desi type*) with improved varieties (*kabuli type*) [2].

Due to its environmental benefits, chickpea is widely integrated into the farming system in Ethiopia and cultivated in various locations with depleted soil nutrients. The crop is extensively grown in different parts of the country, with Amhara, Oromia, the Southern Nations, Nationalities, and People's Region (SNNPR), and Tigray being particularly suitable for its cultivation [3]. Together, the Amhara and Oromia areas produce 93% of Ethiopia's total chickpea output, compared to 3.5% and 3%, respectively, from SNNPR and Tigray [4].

Despite the government's interest in expanding chickpea production for export and its potential for improving the livelihoods of rural communities, the crop's productivity is currently below its potential due to several biotic and abiotic stresses [5]. The most significant biotic constraint affecting chickpea productivity is insect pests, which cause substantial reductions in both crop yield and quality in the field (pre-harvest) or in storage (post-harvest) [6].

Significant post-harvest losses of chickpea seeds that have been attributed to storage insect pests such *C. chinensis*, *C. maculatus* (F.), *C. analis* (*F.)*, *Acanthoscelides obtectus* (Say), and *Bruchus incarnates* (B.) were reported so far [7]. Similarly, studies on chickpea seeds held in poor storage conditions revealed a substantial invasion of post-harvest insect pests [8]. Out of the over 100 species of arthropods that have been associated with grains over the years, only a few dozen are considered to be significantly important in this case [9]. However, some species that have been classified as minor may become major species in certain storage conditions.

In Ethiopia, the most prevalent category of storage pests are beetles (Coleoptera), which include major pests such as *C. chinensis*, *S. zeamais* (M.), *S. oryzae*, *A. obtectus, Zabrotes subfasciatus* (B.), *Tribolium* spp., *Carpophilus* spp. (S.), and *Cryptolestes* spp.(S.) [9,10]. The presence of *C. chinensis* in chickpea crops was resulted in a significant losses, with up to 50% in Ethiopia [11] and 28% in Eritrea [12]. Similarly, a weight loss ranging from 36.9 to 51.9% was reported due to *C. chinensis* in Ethiopia [8]. When bruchids damage chickpea grains, they become unsuitable for planting due to poor germination and for consumption as food or feed due to spoilage, bad odor, and toxin production, resulting in additional losses [12]. Certain pests, mentioned previously, initiate their infestation during the field stage before harvest and eventually spread in the storage area where their populations expand rapidly [9,13].

Chickpea is a vital crop in Ethiopia, providing income and nutrition for smallholder farmers and is also a major export commodity. However, storage pests are causing substantial damage and losses, negatively affecting farmers' livelihoods and food security. Ethiopian farmers traditionally store their chickpea grain in storage facilities that are prone to quality and quantity losses. There are limitations in post-harvest protection studies of chickpea in Ethiopia to manage significant crop losses. Therefore, the current study aims to assess the population density, species composition, infestation levels, and losses in quantity and quality of stored chickpea in Ethiopia's major growing regions. This study can provide valuable insights into developing pest management strategies that can be applied to other crops, leading to sustainable and resilient agricultural practices.

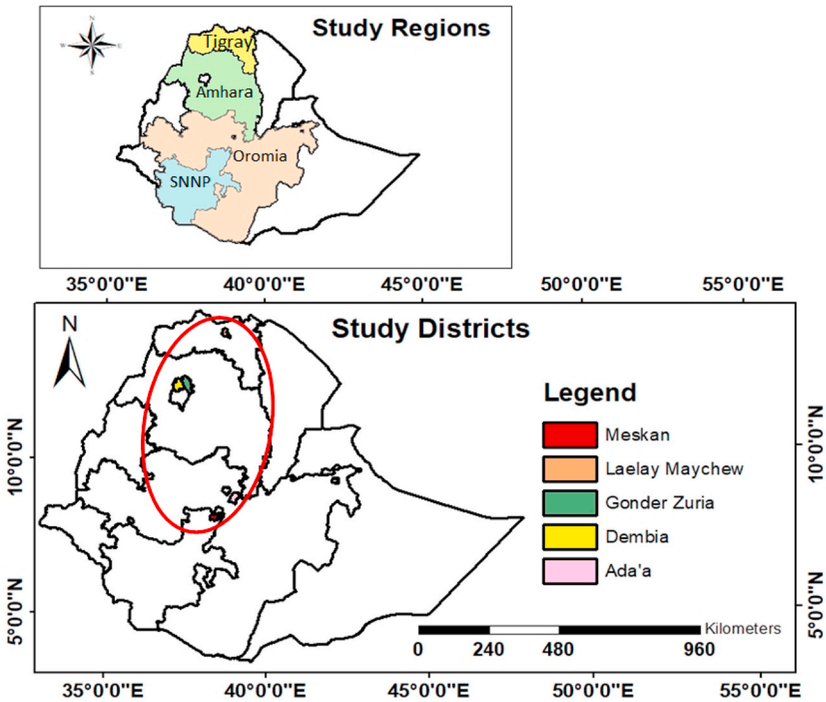


Fig. 1. Map of Ethiopia showing selected study districts for chickpeas storage pest assessment in Tigray, Amhara, Oromia and SNNP regions.

2. Materials methods

2.1. Description of the study areas

The survey included five important chickpea-growing districts located in four regional states of Ethiopia, namely Oromia, Tigray, Amhara, and the Southern Nations, Nationalities, and Peoples (SNNP) Regions. The districts included Dembia, Gondar Zurya, Ada'a, Laelay Maychew, and Meskan (Fig. 1).

2.2. Sampling procedures

To ensure a representative sample, a multi-stage sampling procedure was utilized to select farm households for the survey. The selection of districts within the targeted regions was based on their chickpea production status. Purposive sampling was used to select 12 villages/peasant associations, with four from Dembia, four from Gondar Zurya, two from Ada'a, and one each from Meskan and Laelay Maychew. A total of 290 farm households were selected randomly, with 104 from Dembia, 99 from Gondar Zurya, 30 from Meskan and Ada'a each, and 27 from Laelay Maychew.

Sampling began with the already-existing grains or seeds. A household served as the sample unit. Those 290 farm households were selected by walking through the population and selecting every third household for investigation. The following household was taken into consideration if any of the family's adult members were absent. Seed samples weighing 1 kg were collected from each storage facility of the selected farm households. The sampling was done using a compartmentalized sampling spear, considering samples from the top, middle, and bottom of the storage structure since insect dispersion in storage structures could not be uniform.

2.3. Data collection

During the 2017/18 cropping season, after a period of nine months of storage, a survey was carried out to collect various data related to seed age, storage method, household gender, pesticide usage, and biophysical factors such as intra-granular temperature, seed moisture content, and relative humidity. Additionally, information regarding the household gender, chickpea storage duration/age, farm households' experiences with chickpea storage methods, chickpea variety used, and insect pest control methods applied by farm households during the storage period were obtained through face-to-face interviews using a questionnaire. Biophysical data was collected using the USAID Feed the Future Innovation Lab for the Reduction of Post-Harvest Losses (PHL-IL) moisture meter [14]. The occurrence and extent of infestation of insect pests in the stored chickpea seed were determined by applying incubation and inspection methods to the sampled seeds.

2.3.1. Inter-granular temperature, moisture content and relative humidity

The USAID Feed the Future Innovation Lab for the Reduction of Post-Harvest Loss (PHL-IL) moisture meter was used to monitor inter-granular temperature, seed moisture, and relative humidity [14]. The moisture meter was placed and let to stabilize for 2–4 min before recording the equilibrium inter-granular temperature (^{o}C), equilibrium moisture content (%wb), and equilibrium relative humidity from the meter display. Three different readings [15], were taken from each sample unit, and the mean value for each of the measuring parameters was calculated.

2.3.2. Insect population density and species identification

Each collected seed sample from all districts were brought to the entomology laboratory at Dry land Crop and Horticultural Science Department of Mekelle University, Ethiopia. Total number of insects in 1 kg of sample were counted and morphologically identified to the species level. First, the number of live and dead adult species was counted by sieving the 1-kg sample through Supertek Scientific standard test sieves (Addison, Illinois, USA) with mesh sizes of 2 mm and 0.425 mm, which were held over a bottom pan. Afterwards, the seeds were placed in plastic jars that had mesh covers, allowing gas exchange with the atmosphere while preventing insects from getting in. Before counting the first offspring (F_1), the plastic jars were incubated for six weeks, which is deemed long enough to allow the insect pests to grow. The initial live adult count and the F_1 offspring were combined and treated as the total number of live insects in this experiment. On the same day, insect counts were established for each sample unit. By using taxonomic and morphological insect identification keys presented in Refs. [16,17], the collected insects were recognized to genus and species level under stereomicroscope. Unidentified species were retained in vials and sent to Department of Grain Science and Industry at Kansas State University, Manhattan, Kansas, USA for further identification by Dr. Bhadriraju Subramanyam (University Distinguished Professor).

2.3.3. Seed damage and weight loss

Sub-samples of 100 g seed were taken from the one kg of samples following the quartering and conning techniques. Damaged and undamaged seeds were separated, counted and weighed individually using the INDOSAW Seed Counter (Osaw Industrial Products Pvt. Ltd., Salarheri, and Haryana, India) and sensitive balance, respectively. Based on the holes formed by boring insects, insect-damaged seeds were visually detected. Mechanically damage seeds were considered for dockage. Percent seed damage was calculated using the following equation [14]:

$$Seed\ damage(\%) = \frac{Number\ of\ damaged\ grain}{Total\ number\ of\ used} \times 100$$

Percent seed weight loss due to insect damage was calculated by the count and weigh method [18] using the following formula: $Seed\ weight\ loss\ (\%) = \frac{(Wu\times Nd)-(Wd\times Nu)}{Wu\times(Nd+Nu)}\times 100$; Where: Wu = weight of undamaged seeds, Nd = number of damaged seeds, Wd = weight of damaged seeds and Nu = number of undamaged seeds

2.3.4. Seed germination percentage

Seed germination was tested using 100 randomly picked seeds from each replicate storage unit by using blotter method [19]. Plastic Petri dishes lined with filter paper were used to hold the seeds. These dishes were then placed in a germination room equipped with fluorescent lights that operated on a 12-h cycle of light and darkness, and kept at a temperature of 25 °C [20]. Every day, distilled water was poured to the plate to keep the filter paper from drying out. After one week, the percentage of seeds that were germinated was determined as follows.

$$Seed\ ger\ mination(\%) = \frac{No.ger\ minated}{Total\ no.ofsample\ seed}\times 100$$

2.3.5. Seed dockage

The seed samples of 1 kg were used to determine dockage produced. Each sample was passed through a 12-mesh sieve for separation of the seeds and dockage. The dockage passed was weighed and recorded in gram or milligram.

2.4. Statistical analysis

Statistical analysis was performed using R software version 4.2.2 on the qualitative and quantitative data that were gathered through checklists and measurements on samples. For nominal parameters, cross-tabulations were created, and descriptive statistics were computed to provide an overview of information on the chickpea seed varieties used, storage procedures, household gender, and insect occurrence. Using a two-sided Fisher's exact test [21], the association between nominal parameters was evaluated. To find variations between samples from the five study districts, one-way analysis of variance was applied to measurement variables. On samples from each district that were chosen at random, nonparametric conclusions were made. Multiple mean comparisons were made using the Kruskal-Wallis non parametric test for Significant Difference. Pearson correlation was conducted to assess the association between measurement and count factors for chickpea types (local "Desi" type and improved "Kabuli" type), storage methods (polypropylene bag and gota), and household gender using the Welch two-sample *t*-test.

The study calculated the species richness (S) of stored chickpea insects using Margalef's index [22], while Shannone-Wiener Index [23] was used to calculate species diversity (H′). Simpson's Index [24] was employed to determine species dominance (J), and evenness was evaluated using Pielou's Index [25].

3. Results

3.1. Insect species composition and population density

Twelve species of stored chickpea insect pests were identified in this investigation and are shown in Table 1. *Callosobruchus chinensis* was the most prevalent insect species, accounting for roughly 92.21% of the entire insect population. It was followed by *Sitophilus oryzae* and *Tribolium confusum*, which were abundant to different degrees (6.02% and 0.42%, respectively). However, the abundance of the other nine species together is only about 1.35%. In general, this survey result shows that the Azuki bean weevil (*C. chinensis*) (92.21%), Cereal weevil (6.14%) (*S. oryzae, S. zeamais, and S. granarius*), and Flour beetle, (0.55%) (*T. confusum and T. castaneum*), were the most abundant insect species detected in the total 290 samples (Table 2) collected from the five major chickpea producing districts in Ethiopia.

In the infested samples of *C. chinensis*, the total population density count was 49264 insects (92.21%) with an average count of 169.89 (min/max = 0/8406) insects per kg of the sample seed (Table 2). Out of the total 290 samples, only 97 (33.45%) had *Sitophilus*

Table 1
List of insect pest species compositions identified in stored chickpea.

Order	Family	Common name	Insect species	Pest type
Coleoptera	Bruchida	Azuki bean beetle	*Callosobruchus chinensis*	Primary
	Curculionidae	Rice weevil	*Sitophilus oryzae*	Primary
		Maize weevil	*Sitophilus zeamais*	Primary
		Granary weevil	*Sitophilus granarius*	Primary
	Tenebrionidae	Confused flour beetle	*Tribolium confusum*	Secondary
		Red flour beetle	*Tribolium castaneum*	Secondary
		Darkling beetles	*Mesostena picea*	Secondary
	Dermestidae	Black carpet beetle	*Attagenus* spp.	Secondary
		Carpet beetle	*Dermestidae* spp. *(larva)*	Secondary
	Carabidae	Ground beetle	*Carabidae* spp.	Secondary
	Nitidulidae	Yucca Beetle	*Carpophilus* sp.	Secondary
	Elateridea	Wireworms	*Limonlus* spp,	Secondary

Table 2
Population density and species composition of insect pests in stored chickpea sample collected from five districts (N = 290).

Insect spp.	Mean population density	Minimum population density	Maximum population density	Total Population density		Sample with insect (%)	Sample with no insect (%)
				count	%		
*C.chinensis_*	169.89 ± 50.40	0	8406	49264	92.21	44.14	55.86
Sitophilus_spp.	11.32 ± 2.98	0	450	3282	6.14	33.45	66.55
Tribolium_spp.	1.02 ± 0.18	0	30	296	0.55	18.62	81.38
Other_spp.	2.02 ± 0.35	0	53	587	1.10	26.55	73.45
Total insect	184.24 ± 51.48	0	8424	53429	100	54.14	45.86

spp. present, with a total insect population count of 3282 (6.14%) and an average count of 11.32 (min/max = 0/450) insects per kg of the sample seed (Table 2). The third most prevalent stored chickpea insect species, *Tribolium* spp., was found in 54 out of the total 290 samples, with a total population density of 296 (0.55%) insects and an average count of 1.02 (min/max = 0/30) insects per kg (Table 2). Of the total samples collected (N = 290), 157 (54.14%) were positive for stored chickpea insect pests, with a total population density of 53429 insects and an average count of 184.24 (min/max = 0/8424) insects per kg, while 133 (45.86%) samples were found to be free of insects during the sampling period (Table 2).

3.2. Abundance and diversity of stored chickpea seed insects

The majority of the districts investigated in this study were found to harbor three of the dominant species of chickpea insects (Table 3). As showed in Table 3, the most prevalent species in terms of abundance was *C. chinensis*, with Laelay Maychew recording the highest abundance, followed by Dembia, Gondar Zurya, Meskan, and Ada'a. The frequency distribution of Sitophilus spp. (*S. oryzae, S. zeamais, and S. granarius*) was highest in Dembia, followed by Gondar Zurya, Meskan, Laelay Maychew, and Ada'a, in that order. In a similar vein, *Tribolium* spp. (*T. confusum/T. castaneum*) was found to be abundant in Gondar Zurya, followed by Dembia, Laelay Maychew, Ada'a, and Meskan, respectively.

Table 4 provides details on the diversity of chickpea stored insects in various districts in Ethiopia, based on different diversity indices. The results reveal significant variations in the diversity and abundance of chickpea stored insects among the studied districts. Laelay Maychew district showed the highest diversity and evenness of species, whereas Ada district had the lowest insect evenness. The Shannon-Wiener diversity index ranged from 0.596 in Gondar Zurya to 0.934 in Laelay Maychew, indicating that Laelay Maychew had the highest species diversity of chickpea insects, while Gondar Zurya had the lowest. The richness values indicated that Ada had the highest species richness (4.45), followed by Meskan (1.98) and Gondar Zurya (2.28), while Laelay Maychew had the lowest richness (1.71). The evenness values, which show the relative abundance of different species in each district, indicated that Laelay Maychew had the highest evenness value (1.73), followed by Meskan (1.33) and Gondar Zurya (0.72), whereas Ada had the lowest evenness value (0.47). The Simpson's index values ranged from 0.02 in Laelay Maychew to 0.26 in Gondar Zurya.

3.3. Storage material, chickpea varieties and C. chinensis distribution

The majority of farmers in the study regions used conventional containers as their main method of storing chickpea seeds, although there were notable variations ($P < 0.001$) in the types of storage structures employed. Polypropylene (PP) bags were used by all households sampled in Ada'a and Meskan districts, while the usage was 46.2% in Dembia, 3.7% in Laelay Maycheaw, and 19.2% in Gondar Zurya (Table 5), indicating a significant difference in storage material preference among the districts. Across all the study districts, two traditional storage structures were identified - Polypropylene (PP) bags (44.14%) and gota (55.86%) (Table 5, Fig. 2 A).

Table 5 presented a significant variation ($P < 0.001$) in the chickpea types collected from all the studied districts. All the samples collected from Ada'a (100%) were of improved *kabuli* chickpea varieties, as well as 59.3% of the samples from Laelay Maychew, 50% from Meskan, 32.3% from Gondar Zurya, and 9.6% from Dembia. Among the collected samples (N = 290), the majority (64.5%) belonged to the local *desi* type chickpea seed varieties, with 50% of which were from Dembia, followed by Gondar Zurya, Meskan, and Laelay Maychew, accounting for 36%, 8%, and 6% of the samples, respectively (Fig. 2B). A significance variation in *C. chinensis*

Table 3
Total insect distribution of each species in five chickpea growing districts in Ethiopia.

Study district	Total Insect abundance of each species				
	C.chinensis	Sitophilus_spp	Tribolium_spp.	Other_spp.	Total insect
Ada'a	327	3	13	13	356
Dembia	14512	1771	86	170	16539
Gondar Zurya	10411	1417	150	238	12216
Laelay Maychew	16299	15	43	119	16476
Meskan	7715	76	4	47	7842
Total	49264	3282	296	587	53429

Table 4
Measures of diversity indices for chickpea stored insects in the study disricts

Study district	Total Insect abundance of each species			
	Species richness (S)	Shannone Weiner diversity (H′)	Pielou's Evenness (J′).	Simpson index of dominance (D).
Ada'a	4.45	0.70	0.47	0.15
Dembia	2.17	0.65	0.84	0.22
Gondar Zurya	2.28	0.60	0.72	0.26
Laelay Maychew	1.71	0.93	1.73	0.02
Meskan	1.98	0.91	1.33	0.03

Table 5
Frequency distribution of storage materials and chickpea varieties across selected chickpea growing districts in Ethiopia.

Study District	Samples from PP bags (%)	Samples from Gota (%)	Samples of an improved kabul variety (%)	Samples of a local desi variety (%)
Ada'a	100^{a}	0^{d}	100^{a}	0^{d}
Dembia	46.2^{b}	53.8^{c}	9.6^{d}	90.4^{a}
Laelay Maychew	3.7^{d}	96.3^{a}	59.3^{b}	40.7^{c}
Gondar Zurya	19.2^{c}	80.8^{b}	32.3^{c}	67.3^{b}
Meskan	100^{a}	0^{d}	50^{bc}	50_{bc}
P value	<0.001	<0.001	<0.001	<0.001

[a]Means followed by different letters are significantly different (P < 0.05).

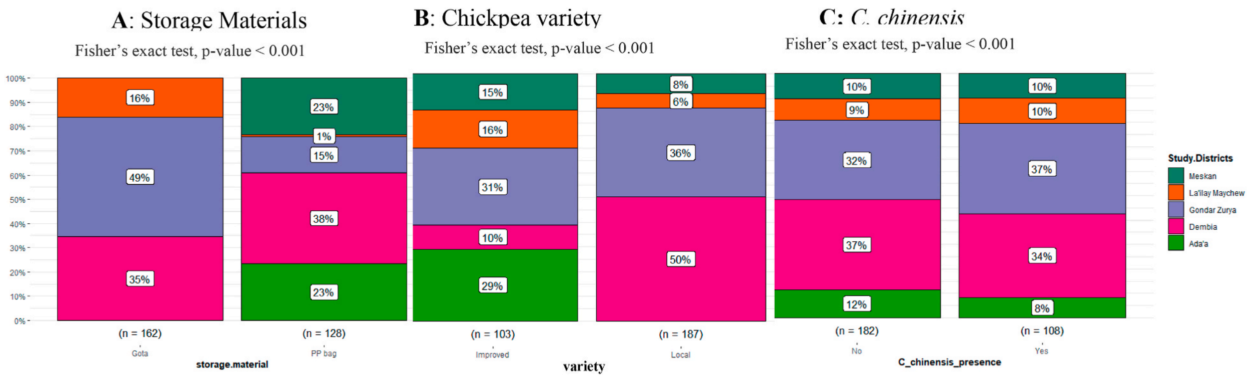


Fig. 2. Frequency distribution of storage materials (A), chickpea varieties (B) and C. *chinensis* distribution (C) across chickpea growing districts in Ethiopia.

infestation was also recorded among samples across the study districts (Fig. 2C).

Table 6 revealed a significant difference ($P = 0.04$) in the distribution of the overall insect population among the districts. Out of all the samples (N = 290) analyzed, *C. chinensis*, which is the predominant stored chickpea insect species, was present in 108 (37.2%) samples (Fig. 2). The highest infestation rate of *C. chinensis* was noted in Gondar Zurya (37%) followed by Dembia (34%) among the positive samples, indicating significant differences between the districts (Fig. 2). The remaining three districts, namely Meskan, Laelay Maychew, and Ada'a, were accountable for 10%, 10%, and 8% of the 108 infested survey samples, respectively.

Table 6
Frequency of percentage of samples with filed count, F_1 count, and total insect count across chickpea growing districts in Ethiopia.

Study District	Samples with parents before incubation (%)	Samples with F_1 progenies after incubation (%)	Samples with both parent & progeny insects (%)
Ada'a	33.3	30.0	33.3^{a}
Dembia	65.4	33.7	52.9^{ab}
Laelay Maychew	51.9	51.9	51.9^{ab}
Gondar Zurya	73.7	46.5	63.6b
Meskan	40.0	50	50.0^{ab}
P value	0.392	0.110	0.04

[a] Means followed by different letters are significantly different (P < 0.05).

3.4. Bio-physical characteristics of seed samples

Based on the findings, there were noteworthy distinctions identified among the research districts in terms of the inter-granular temperature ($P < 0.001$), seed moisture ($P < 0.001$), and relative humidity ($P < 0.001$) of the stored chickpea sample seeds (Table 7). The results provided in Table 7 reveal that Gondar Zurya district recorded the highest values for all biophysical parameters, trailed by Dembia and Laelay Maychew districts, whereas Ada'a and Meskan districts exhibited the lowest values.

3.5. Seed damage and weight loss

Table 8 revealed significant differences ($P < 0.001$ and $P = 0.04$, respectively) among the chickpea samples in all districts concerning insect-damaged seed and seed-related weight loss. Across the studied locations (N = 290), insect-damaged seeds ranged from 4.61% in Ada'a to 14.48% in the Gondar Zurya district, with a mean of 12.57% (min/max = 0/71.6%). There was a significant difference in weight loss observed between districts, with a range of 1.13% in Ada'a to 4.55% in Laelay Maychew. The weight loss in Gonder Zurya (3.82%) was statistically similar to that of Laelay Maychew. Overall, approximately 3.25% (min/max = 0/36%) of the seed weight in the tested locations was lost.

The study revealed that the extent of seed weight loss varied based on the type of chickpea varieties used. Table 9 showed a significant difference in the percentage of weight loss between local *desi* type and improved *kabuli* type chickpea varieties (t = −2.22, $P = 0.03$, df = 196). The mean seed weight loss was 3.72 ± 0.33% (N = 187) for local varieties, while the improved types had a mean seed weight loss of 2.4 ± 10.49% (N = 103) with a 95% confidence interval of (−2.481, −0.145).

Furthermore, the storage methods utilized in each district showed a significant difference in the percentage of seed damage (t = 2.77, $P = 0.006$, df = 222) (Table 7). Among the traditional materials used to store chickpea seeds in all districts, pp bags (N = 128) had the lowest mean percentage of seed damage (10.8 ± 0.90%), while gota (N = 162) had the highest mean percentage of seed damage (14.00 ± 0.76%) with a 95% confidence interval of (0.94, 5.56). The seed weight loss in chickpea stored in pp bags was found to be lower (2.75 ± 0.42%) compared to that in gota bags (3.65 ± 0.42%), although the difference was not statistically significant ($P = 0.11$) (Table 9). In addition, there was no significant difference in seed weight loss (t = 1.3, $P = 0.20$, df = 46) and seed damage ($P = 0.25$) (Table 7) between households where the chickpea was grown by females or males.

3.6. Seed germination, seed dockage and total insect count

In this study, significant variations were observed in the percentage of seed germination ($P < 0.001$), dockage ($P = 0.047$), and overall mean insect density (count/kg) among the regions where chickpeas were grown (Table 10).

The study found that the overall mean seed germination rate was 71% (range 23%–100%) across the 290 samples, with significant variation among the study districts. The lowest germination rate was observed in Gondar Zurya (65%), while the highest was in Ada'a (88%) (Table 10). Samples that had been stored with insect infestations had a lower mean seed germination rate (57.7 ± 0.91%) than those without infestations (86.7 ± 0.93%), and this difference was statistically significant (t = 22.38, P < 0.001, df = 284).

A significant difference was also found in the mean seed germination percentage between the two types of chickpea varieties (improved *kabuli* type and local *desi* type) grown across all study districts (t = 4.45, P < 0.001, df = 195) (Table 11). The improved k*abuli* type chickpea seeds had a higher seed germination rate of 77.4% (N = 103) than the local *desi* type chickpea seeds (N = 187), which exhibited a germination rate of 67.5%.

The study also revealed that samples from Laelay Maychew, Dembia, and Maksegnit had higher percentages of dockage compared to samples from Ada'a, which had the lowest percentage of dockage (Table 11). The two types of chickpea used in the investigation showed a significant difference in the mean percentage of dockage (t = −2.70, p < 0.001, df = 237). The improved chickpea variety in the samples (N = 103) had the lowest percentage of dockage, ranging from 0.08% to 0.25%, while the local chickpea varieties used in the research districts had a dockage percentage ranging from 0.52% to 0.7%.

3.7. Interrelationships between biophysical characteristics, insect population density, seed physical characteristics and insect damage variables

The correlation matrix depicted in Fig. 3 indicated that there were significant association between the different parameters

Table 7
Mean (±SE) of stored chickpea seed inter-granular temperature, moisture and relative humidity in different chickpea growing districts in Ethiopia.

Study district	Sample size (No.)	Temperature (^{0}C)	Moisture (%)	Relative humidity (%)
Laelay Maychew	27	$24.31^{ab} \pm 0.65$	$10.30^{ab} \pm 0.48$	$52.11^{ab} \pm 2.18$
Ada'a	30	$21.39^{c} \pm 0.67$	$8.72^{c} \pm 0.39$	$43.99^{c} \pm 2.10$
Gondar Zurya	99	$24.85^{a} \pm 0.23$	$10.74^{a} \pm 0.15$	$54.39^{a} \pm 0.75$
Dembia	104	$24.30^{a} \pm 0.18$	$10.61^{a} \pm 0.13$	$53.52^{a} \pm 0.59$
Meskan	30	$23.54^{b} \pm 0.59$	$9.71^{b} \pm 0.43$	$49.58^{b} \pm 2.05$
P value		P < 0.001	P < 0.001	P < 0.001

[a] Means followed by different letters are significantly different (P < 0.05).

Table 8
Means (±SE) seed damage, and seed weight loss of chickpea samples collected from different chickpea growing districts of Ethiopia.

Study District	Seed damage (%)	Seed weight loss (%)
Ada'a	4.61^{b} ± 1.16	1.13^{b} ± 0.32
Dembia	13.40^{a}±0.85	3.19^{ab} ± 0.41
Laelay-Maychew	14.37^{a}±3.31	4.55a±1.79
Gondar Zurya	14.48^{a}±0.79	3.82^{ab} ± 0.33
Meskan	9.73^{ab} ± 2.02	2.52^{ab} ± 1.12
P value	<0.001	0.04

[a] Means followed by different letters are significantly different ($P < 0.05$).

Table 9
Comparison of Means (±SE) seed damage, and seed weight loss along with chickpea varieties, storage structures and householder gender in the study districts.

Parameters	Seed damage (%)	Seed weight loss (%)
Chickpea varieties		
improved	9.8 ± 1.0	2.41 ± 0.49
local	14.11 ± 0.70	3.72 ± 0.33
t-value	−3.55	−2.22
P value	<0.001	0.03
storage structure		
PP bag	10.8 ± 0.90	2.75 ± 0.42
Gota	14.00 ± 0.76	3.650.37
t-value	2.77	1.61
P value	0.006	0.11
Household Gender		
Female	14.6 ± 1.9	4.20 ± 0.78
Male	12.27 ± 0.61	3.11 ± 0.30
t-value	1.18	1.30
P value	0.25	0.20

Table 10
Means (±SE) percentage of seed germination, dockage and total insect density in chickpea samples collected from different chickpea growing districts of Ethiopia.

Study District	Seed germination (%)	Weight of Dockage (%)	stored Chickpea insect (counts/kg)
Ada'a	88.03^{a}±3.27	0.04^{b} ± 0.01	11.87^{c}±4.99
Dembia	68.51^{c}±1.44	0.52^{a}±0.09	159.0^{b} ± 72.1
Laelay Maychew	73.85^{bc}±4.18	0.55^{a}±0.28	610^{a}±361
Gondar Zurya	65.25^{c}±1.61	0.48^{a}±0.07	123.4^{b} ± 41.9
Meskan	79.00^{b} ± 3.76	0.24^{ab} ± 0.16	261^{ab} ± 2.43
p value	<0.001	0.047	0.036

[a] Means followed by different letters are significantly different ($P < 0.05$).

Table 11
Comparison of Means (±SE) seed germination, and seed dockage along with chickpea varieties, storage structures and householder gender in the study districts.

Parameters	Seed germination (%)	Seed dockage (%)
Chickpea varieties		
improved	77.4 ± 1.8	0.25 ± 0.08
local	67.5 ± 1.2	0.54 ± 0.07
t-value	4.45	−2.7
p value	<0.001	0.007
storage structure		
PP bag	75.2 ± 1.7	0.38 ± 0.08
Gota	67.7 ± 1.3	0.46 ± 0.07
t-value	−3.51	0.76
p value	0.001	0.45

investigated in this study. Across all five districts, a strong and significant association ($P < 0.001$) was observed between all the parameters. The correlation between intra-granular temperature and seed moisture content ($r = 0.97$), relative humidity ($r = 0.97$), seed damage ($r = 0.8$), and seed weight loss ($r = 0.7$) was found to be highly significant ($P < 0.001$) (Fig. 3). Additionally, a robust positive correlation was observed between the total insect population density and seed weight loss ($r = 0.9$), seed damage ($r = 0.8$), seed dockage ($r = 0.8$), and seed moisture content ($r = 0.5$). Furthermore, a strong negative correlation was observed between the total insect population density and the percentage of seed germination ($r = -0.43$). Similarly, a significant negative association was found between the percentage of germinated seeds and all biophysical traits, including seed weight loss ($r = -0.8$), seed damage ($r = -0.9$), and dockage ($r = -0.64$).

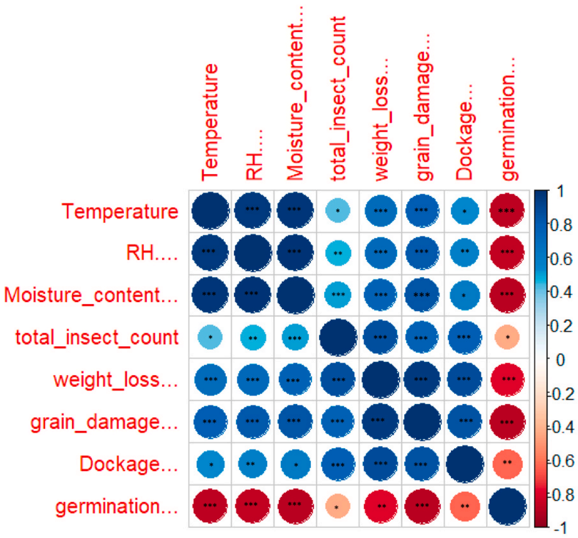
4. Discussion

Chickpeas are grown in Ethiopia for multiple purposes such as food, feed, earning money, and foreign exchange profits. However, the country's chickpea production is currently falling short of its potential due to various biotic and abiotic factors. One major cause of significant grain loss in chickpeas is attributed to insect pests during storage [7]. To mitigate the risk of losses in terms of quality and quantity during storage, it is essential to have a comprehensive understanding of the dynamics of storage insect pests, their impact, and the prevailing environmental conditions during storage. Therefore, future farm-storage systems should be supported by this knowledge.

The present investigation aimed to analyze the prevalence of stored insect pests in 290 chickpea samples collected from the five major chickpea-growing regions in Ethiopia. The study identified 12 arthropod species from the collected chickpea seeds, all of which belonged to the Coleoptera order. The Coleoptera order was further classified into seven families, with three species each in the Curculionidae and Tenebrionidae families, two species in the Dermestidae family, and one species each in the Bruchida, Carabidae, Nitidulidae, and Elateridae families.

The three most dominant insect species found in all five chickpea-growing districts were the Azuki bean beetle (*C. chinensis*), rice weevil (*S. oryzae*), and confused flour beetle (*T. confusum*), accounting for approximately 98.65% of the total insect population density. Our study found that *C. chinensis* was the most significant and widespread pest of stored chickpeas in Ethiopia, which is consistent with the findings reported so far [9,10,13,26–28]. The rice weevil, also known as *Sitophilus oryzae*, is a well-known pest of rice, maize, cotton, nuts, and other stored cereals [29]. It has also been reported in samples collected from stored chickpeas in Bangladesh [30] and pulses [27,31]. *Tribolium confusum,* a secondary pest that feeds on previously contaminated grains, is known to target cereals, cereal products, groundnuts, coffee, cocoa, dried fruits, and occasionally pulses [27,29]. Similarly, *C. chinensis*, *T. castaneum Trogoderma granarium* (E.), *Rhizopertha dominica* (F.), and *S. oryzae* were reported in stored chickpea in India [32]. To confirm that *S. oryzae* and *T. confusum* were pests of stored chickpea seeds rather than contaminants, we incubated the sieved samples and kept them for six weeks. The presence of *S. oryzae* and *T. confusum* F1 progeny in the tested seeds further demonstrates that these insects are pests of stored chickpeas, even though they may have appeared as pests of other crops. Among the remaining nine species, wireworms (*L. californicus*) have been found to damage chickpea crops by consuming seedlings or sprouting chickpea seeds [33]. In general, *S. oryzae* and *T. confusum* have not been documented from stored chickpea grains in Ethiopia, making this study a pioneer in reporting these two significant pests, and the other species, in farm-stored chickpea seeds in Ethiopia.

The study further found significant variation in the abundance of chickpea insects across the different districts, with *C. chinensis*,



*Significance codes: < 0.001 '***' 0.01 '**' 0.05 '*' not significant at 0.05 level of confidence ''*

Fig. 3. Pearson correlation matrix among biophysical, insect and seed damage variables.

Sitophilus spp., and *Tribolium* spp. being the most prevalent species. The highest abundance of *C. chinensis* was recorded in Laelay Maychew, while the highest frequency distribution of *Sitophilus* spp. was found in Dembia, and the highest abundance of *Tribolium* spp. was observed in Gondar Zurya. The variation in insect abundance among the districts may be attributed to differences in the climatic conditions, such as temperature, humidity, and storage methods, which can influence insect growth and reproduction.

These results confirm earlier research showing that *C. chinensis* is a significant pest of chickpeas, both in Ethiopia as a whole and the Amhara region in particular [34]. The distribution of storage insects is influenced by temperature and the type of grain, reflecting their ecological adaptation [35]. The prevalence of a high stored chickpea insect population and frequency of distribution in Gondar Zurya and Dembia of the Amhara region could be associated with the storage system used. Most of the farmers from these two districts stored their chickpea in gota, which was reported to be easily accessible to stored insects [36]. It is important to note that the high abundance of insect pests can have significant economic implications, as it can lead to reduced yield and quality of chickpea crops.

The study found significant variations in the diversity of chickpea stored insects among the studied districts, with Laelay Maychew having the highest species diversity and evenness of species, while Gondar Zurya had the lowest. The observed in differences in biophysical factors, storage conditions, and the genetic makeup of chickpea varieties grown in the different districts could explain this variation [37–39]. The identification of areas with high insect diversity could help in developing targeted control strategies, while information on the dominant species in each district could aid in selecting appropriate control measures. The results also showed that Ada'a had the highest species richness, followed by Meskan, suggesting that these districts have a greater variety of different chickpea stored insect species compared to other districts. The presence of diverse ecological niches, habitat heterogeneity, and higher levels of gene flow [40] and connectivity with other areas could explain this finding.

Districts with relatively high evenness values, such as Laelay Maychew, Meskan, and Gondar Zurya, indicated that the abundance of different chickpea insect species was relatively evenly distributed within these districts. This could be due to the presence of diverse ecological niches and habitat heterogeneity, allowing different insect species to coexist and thrive [40]. On the other hand, Ada had the lowest evenness value, suggesting that one or a few dominant insect species were present in this district, while others were less abundant. The Simpson's index values also varied among the districts, with the lowest value in Laelay Maychew indicating more even distribution of species diversity and the highest value in Gondar Zurya suggesting domination by a few species. These findings have implications for the management of chickpea stored insects in different districts and highlight the need for tailored control strategies that take into account the specific insect communities present in each area.

Farmers in different regions of Ethiopia use different methods to store chickpea seeds. In the Ada'a and Meskan districts, all farmers used polypropylene (PP) bags. In the Amhara and Tigray regions, most farmers used a traditional earthen pot called *gota*, while a smaller percentage used PP bags. The popularity of PP bags in some regions is due to their convenience for transporting and selling the seeds, as well as their effectiveness in checking for insects and removing grains for consumption [35,41]. Our study's findings on how farmers store chickpea seeds are consistent with an earlier study conducted in Ethiopia, which found that farmers typically use traditional containers such as *gotas* and various types of bags (jute or PP) [42]. Past research has also shown that Ethiopian farmers rely on a range of storage structures, including gotera, kefo, clay jars, gourds, wooden boxes, metal drums, and subterranean pits for storing their crops [9,13].

The majority of the 290 chickpea samples collected in this study were of the *desi* type, with most sourced from the Amhara region. However, all samples from the Ada'a region consisted of improved *kabuli* type chickpea varieties, which may be due to the promotion of new technologies by the Debre Zeit Agricultural Research Center and the higher concentration of farmers' seed producer associations in the Oromia region [43]. The use of improved *kabuli* type chickpea by farmers in Debre Zeitt Zurya in Oromia may be due to the promotion of new technologies by the Debre Zeit Agricultural Research Center and the higher concentration of farmers' seed producer associations in the Oromia region, where 13 out of 20 legal associations are located [44]. On the other hand, the prevalence of local desi varieties across all study districts may be attributed to various factors, such as insufficient knowledge, limited market demand, worries about plant theft for green pods, inadequate access to superior chickpea varieties, or the unavailability of improved variety seeds [43]. This source indicates that in Ethiopia, there is a common problem of theft and pilferage of large-seeded chickpeas, as they are often consumed while still in their green pod stage. This fear of theft may lead to farmers being reluctant to plant the Kabuli type large-seeded chickpeas.

The local *desi*-type chickpea seed variety was found to have more infestation by *C. chinensis* than the improved *kabali*-type varieties. This finding contradicts previous laboratory studies, which indicated that improved varieties were more susceptible to infestation [45]. The larger seed size of improved varieties has been suggested as a possible cause for increased infestation [45]. Similarly, on-station investigations also found that the *kabuli* type chickpea varieties, which have smooth seed coats, were more infested by *Callosobruchus* spp [46–48]. Genetic studies have shown that rough seed surfaces are dominant over smooth seed surfaces, and this trait can be easily transferred to the *kabuli* type through breeding [49]. Therefore, encouraging farmers to use storage pest resistance resources could be an effective and environmentally friendly method to control storage losses.

This research found significant differences in biophysical characteristics among the study districts. The increase in inter-granular temperature and seed moisture in Gondar Zurya and Dembia districts may be due to environmental factors and high insect populations within the storage containers. Previous studies have suggested that insects thrive in seed storage temperatures and increasing the intra-granular temperature can support insect growth [50]. Additionally, the temperature of the external environment and the heat generated by grain respiration and insects present in storage can affect the inter-granular temperature of stored seeds [50,51].

Maintaining safe moisture levels is essential for the proper storage of chickpea seeds. In this study, the collected samples had an average moisture content of 10% across all study districts during the sampling period, which is within the safe storage range for chickpea seeds (<14%) [14,52]. The lower average moisture content observed in this study may be due to the storage age of the seeds (nine months), which caused them to dry out over time. However, the variation in moisture content among the study districts may be attributed to differences in intra-granular temperature, relative humidity, and insect populations. Therefore, the increase in moisture content observed in samples from Gondar Zurya and Dembia may be due to the release of vapor [35] from high insect populations and relatively higher relative humidity in those districts.

According to the study, the average insect-damaged seed was 12.57%, and the mean seed weight loss across the sampled areas was approximately 3.25%. These values are lower than those reported in previous studies, where the average damage and weight loss were 27.5% and 8.2%, respectively, in chickpea stored for six to seven months in Ethiopia [53]. Variations in seed weight loss and damage were observed among chickpea varieties and storage materials. The local varieties showed higher average seed weight loss and damage compared to the improved variety. Seeds stored in pp bags, which have a tighter woven polypropylene structure, exhibited less weight loss and damage compared to those stored in the conventional storage structure, gota, which provides easy access for stored insects [36]. Therefore, there is a need to develop and expand new storage technologies to benefit chickpea farmers in Ethiopia.

Moreover, a significant correlation was found between the number of *C. chinensis* and the proportion of insect-damaged seed in this study. As the severity of seed damage increases, there is a direct impact on seed germination, leading to a significant decrease in seed germination rates. Damaged seeds also experience nutrient loss during the early stages of germination, hindering their ability to develop into healthy seedlings [54].

5. Conclusions

The study identified 12 insect pest species that have significant impacts on stored chickpeas, with *C. chinensis, S. oryzae, and T. confusum* being the most common pests in the five major chickpea-growing districts. These pests cause both quantitative and qualitative damage to chickpea seeds, with *C. chinensis* and *S. oryzae* being primary pests and *T. confusum* being a secondary pest. The study also found that traditional storage containers like PP bags and Gota were susceptible to pest activity, highlighting the need for effective management strategies to control insect pests in the study areas. The damage caused by these pests can result in nutrient loss during germination, underscoring the importance of implementing proper storage practices to minimize insect damage and ensure the availability of high-quality seeds for farmers. However, the study's single sampling approach may not provide a comprehensive understanding of insect dynamics in the entire chickpea post-harvest system. As such, future studies should be conducted to investigate insect dynamics in farm stores and warehouse conditions, using repeated sampling.

6. Future perspective

Research should continue to focus on developing and expanding storage technologies that can protect chickpea seeds from insect infestations and minimize seed damage and weight loss. Additionally, efforts should be made to increase awareness among farmers about the importance of proper seed storage practices to ensure that they are equipped with the knowledge and tools they need to protect their crops and maximize their yields.

Author contribution statement

Muez Berhe: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Bhadriraju Subramanyam; Girma Demissie; Mekasha Chichaybelu; Fetien Abay Abera: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Rizana Mahroof: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Jagger Harvey: Conceived and designed the experiments.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e17826.

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