Heliyon 9 (2023) e18223

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Farmers' willingness to pay for metal silo cereal storage technology in northeast Ethiopia

Degu Gobezie Teshome [a], Essa Chanie Mussa [b,c], Abebe Birara Dessie [b,*], Tadie Mirie Abate [b], Degarege Yitayih Ayalew [b]

[a] Department of Agribusiness and Value Chain Management, College of Dry Land Agriculture, Samara University, P.O. BOX 132, Samara, Ethiopia
[b] Department of Agricultural Economics, College of Agriculture and Environmental Science, University of Gondar, P.O. BOX 196, Gondar, Ethiopia
[c] Center for Evaluation and Development (C4ED), P.O. BOX 46529, Addis Ababa, Ethiopia

ARTICLE INFO

Keywords:
Contingent valuation method
Postharvest losses
Metal silo
Storage
Willingness to pay

ABSTRACT

In Ethiopia, cereal crops play a significant role in food security and income for most smallholder farmers. In the Gubalafto district, the environment is ideal for growing vital cereal crops such as sorghum, maize, and teff. However, various factors such as weevils, rodents, mold infestation, and lack of suitable storage materials were blamed for a post-harvest loss of cereal at the storage stage in the district. Hence, this research study was intended to identify factors affecting households' willingness to pay for metal silo cereal storage technology and the maximum willingness to pay for the technology. The study used both primary and secondary sources to gather the data. A total of 385 sample households were selected using a systematic random sampling technique. The semi-structural questionnaire was used to collect the primary data during a face-to-face interview, and double-bounded questions were also followed by open-ended questions. Combinations of data analysis methods such as descriptive, inferential statistics, and econometrics models were used. a binary probit regression model was used to identify factors that influenced farmers' willingness to pay for metal silo cereal storage technology. A bivariate probit regression model was also used to estimate the household's willingness to pay for metal silo cereal storage technology. The survey results showed that the majority (71.69%) of the sample households were willing to pay for metal silo cereal storage technology due to the severity of cereal post-harvest loss. Moreover, the binary probit model results revealed that household educational status, total household annual income, market accessibility, and extension service positively and significantly affected the household's willingness to pay decisions. The mean willingness to pay of households in open-ended and double-bounded methods was 4157 Ethiopian birr and 5147 Ethiopian Birr (ETB), respectively. In general, the result of the study revealed that farmers were more willing to adopt metal silo cereal storage technology due to its high-storage quality. Therefore, as a part of the recommendations, there should be great integration among farmers, metal manufacturing factories, local and regional governments to supply and offer metal silos technology for farmers at a reasonable price and time. Moreover, training should be arranged on how to use the metal silo technology to prevent post-harvesting loss during the storage time.

* Corresponding author.
E-mail address: a.birara@yahoo.com (A.B. Dessie).

https://doi.org/10.1016/j.heliyon.2023.e18223
Received 28 November 2022; Received in revised form 10 July 2023; Accepted 12 July 2023
Available online 19 July 2023

1. Introduction

Grains provide the primary source of nutrition for one-third of the world's poorest people in Sub-Saharan Africa and South-East Asia [1]. Cereal crops such as maize, sorghum, and wheat, as well as grain legumes, play an important role in Sub-Saharan Africa's (SSA) food and nutritional security [2]. Around $1 trillion is thought to be lost annually due to postharvest losses globally [3]. From the total global crop production, one-third or 1.3 billion metric tons per year are lost in the food supply chain from agricultural production to the final consumer level [4]. Losses from insect infestation in grain storage alone range from 5% to 30% of the world's total agricultural production [5]. Moreover, poor postharvest management results in 20–30% grain loss in most Sub-Saharan African countries [6].

Cereal crop losses occur primarily during on-farm postharvest storage, processing, and packaging [7]. Similarly, Ethiopian farmers use traditional grain storage methods that are poorly constructed with locally available materials and cannot protect stored grains from abiotic and biotic agents such as pests and fungal diseases [8]. Furthermore, the poor hygiene of traditional grain storage encourages insects, pests, and rodent infestation. As a result, between 4.35% and 11.2% of cereal loss occurs at the storage stage due to a lack of effective storage technology, infestation by rodents, insect pests, and mycotoxin in most African countries [9].

In Ethiopia, the most common traditional storage tools used by smallholder farmers are *gotera*, *gumbi*, polypropylene and jute bags, and underground pitting. Gotera is an outside grain storage bin made of mud or trash-plastered basketwork covered with thatched roofing and raised off the ground with stones or a wooden platform [10]. Similarly, *gumbi* is an inside grain storage bin made of mud plaster mixed with teff straw. Moreover, storage hygiene, exposing sorghum grain to the sun, treating grain with cow urine, and mixing it with salt are the common cultural and traditional postharvest reduction practices in Ethiopia [11]. However, the traditional storage materials are poor in quality and cannot guarantee protection against major grain storage losses by rodents and insects [8].

Grain storage loss reports indicate that maximum losses occur during storage in the postharvest system in Ethiopia [12]. Insect pests and molds have been linked to stored grains in Ethiopia [13]. Rural farmers also faced the challenge with their products in terms of storage shelf life due to the damage of their wooden stand by termites [14]. Weevils and rodents also attack cereals and pulses that cause grain degradation [15]. In the country, the losses of cereal grains were averagely estimated as barley (12%), maize (30%), Teff (19%), wheat (11%), and other cereals (1%) [10] and Sorghum 3.3% [16]. Similarly, more than 50% of cereals are stored in such traditional storage tools which are ideal for insects, pests, and rodents multiplication [14]. Although most smallholder farmers keep grain for a relatively short period, significant postharvest losses occur at the storage stage [12].

Furthermore, 2% of cereals were wasted due to post-harvest losses in Ethiopia [10]. The average magnitude of postharvest loss also ranges from 15.5 to 27.2% for major grain crops and 23% for all crops in Ethiopia [17]. In general, quality storage technology is crucial in the food supply chain and it can reduce grain postharvest losses). Therefore, metal silo storage technology (Fig. 1) has emerged as an alternative and most effective solution as compared to traditional grain storage structures and chemicals [18]. Similarly, it is the best and most effective cereal storage technology which fully eliminates any pest or pathogen that may infiltrate the grains inside [19].

Despite the potential of cereal production, post-harvest storage loss in the study area remains high, and not much research has been done so far on what factors determine households' willingness to pay for metal silo cereal storage technology in northeast Ethiopia. Therefore, based on the above statements the study was intended to address the following key research questions: What factors determined smallholder farmers' willingness to pay for metal silo cereal storage technology? and How much are they willing to pay in the study area?

Fig. 1. metal silo cereal storage technology.

2. Research methods

2.1. Description of study area

The study was conducted in Gubalafto District, North Wollo Zone, Northeast Ethiopia (Fig. 2). It has an area of approximately 900.49 km^2 and is located at 11.57° N, 11.99° N latitude, 39.2° E, and 39.8° E longitude. It is bordered on the south by the South Wollo Zone, on the west by Delanta and Wadla, on the northwest by Meket, on the north by Gidan, on the northeast by Kobo, on the east by the Afar region and on the southeast by Habru District. The district is 521 km far away from the capital city of Ethiopia. The topography of the district is mostly characterized by a chain of mountains, hills, and valleys ranging from 1379 to 3809 m above sea level. Based on the national Census conducted by Ref. [20], Gubalafto district has a total population of 139,825 out of which 70,750 are men and 69, 075 are women. Gubalafto district has three agro-ecological zones: lowland that ranges from 1500 m to 1800 m; mid-altitude ranges from 1900 m to 2200 m and highland ranges from 2300 m to 3300 m above sea level. The agro-ecological distribution of the study area accounts for 17% of the lowland, 37% of the highland, and 46% of the land [21].

2.2. Sampling methods

A two-stage sampling technique was used to select the sampled households. In the first stage, out of 34 kebeles/villages of the district, four kebeles/villages were selected randomly using lottery methods. In the second stage, a total of 385 sample households were selected using a systematic random sampling technique based on the roster list of each household with a sample proportion following a scientific sample size determination formula developed in equation (1) [22]. The sampled proportions of households were set by the following formula (Table 1).

$$n = \frac{z^2 pq}{e^2} = \frac{1.96^2(0.5 * 0.5)}{0.05^2} = 385 \tag{1}$$

where Z is a standard normal value which is 1.96 for 95% confidence interval; n is the required sample size; p is the probability of success (0.5); q is the probability of failure (1-p)0.5; e is the margin of error (5%).

2.3. Data type, source and methods of data collection

Qualitative and quantitative data from primary and secondary sources was gathered. The primary data was collected using structured questionaries' followed by a face-to-face interviewing method and pretested interview in October 2021. Additionally, a focus group discussion and key informant interviews were held for qualitative data collection. A stated preference approach using a

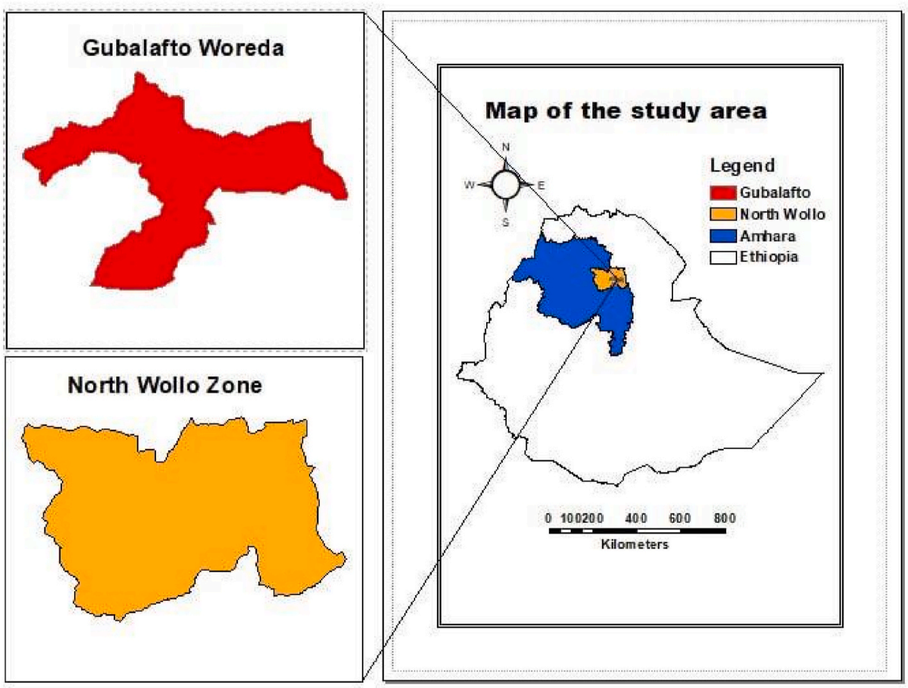

Fig. 2. Map of the study area.

Table 1
Sample size distribution.

Kebeles/Villages	Target population	Sample proportion households
Dorogbr	6600	107
Gedo	5750	94
Jarsa	5747	94
Amayemicha	5551	90
Total	23644	385

contingent valuation method was used to elicit households' WTP. Dichotomous choice questions followed by open-ended questions were employed to improve the estimate's precision.

Respondents were asked if they would be willing to pay for metal silo storage technology using two follow-up bid value questions, the second of which was predicated on the respondents' answers to the first. In a double-bound dichotomous choice format, sets of bid values are created by multiplying the first bid value by two if the respondent selects "yes" in response to the first offered bid value and by half if the respondent rejects it. Four starting bid values were employed in this study to answer the related scenario valuation question. To determine these beginning bid values, a pilot survey was applied with pretested interviews 25% of sampled household sizes were chosen randomly. These households' replies were excluded from the final analysis to avoid bias. As a result, the initial bids for the double-bounded dichotomous choice format were derived from the most frequently expressed bid values in the pilot survey. The initial bid made to respondents is the capacity of metal silos, which can store 300 kg of cereal.

Therefore, the first bid prices were 1875, 1925, 1975, and 2025 birr. Each of the four predetermined first bid values and the corresponding second bid was determined based on respondents' answers to the first question; these initial bid values were evenly distributed among the 385 sample household questionnaires. The respondents were then asked questions about their willingness to pay for metal silo storage technology. The cost of a single 300 kg metal silo storage unit was 7500 ETB (1 $ = 50.87 ETB at the time). Based on this cost, households paid 25% of the cost of the metal silo storage technology, with the manufacturer covering the remaining 75% of the cost. The manufacturing aims to expand metal silo storage technology for farmers, not profit maximizers.

Moreover, secondary data was also gathered from a variety of sources, including the woreda of the agriculture office and related offices, journal articles, and reports from various organizations.

2.4. Methods of data analysis and model specification

2.4.1. Descriptive and inferential statistics

Descriptive statistics such as mean, standard deviation, frequency, and percentages were used to compare and contrast various household characteristics. Moreover, the chi-square test and *t*-test were used to measure the association and mean the difference between dependent and independent variables.

2.4.2. Econometrics analysis

A binary probit model was used to determine the factors that are affecting the WTP decision of households. Based on [23], the relationship between the probability of the willingness to pay Pi and its determinant q is given as in equation (2).

$$\mathrm{Pi} = \beta \mathrm{qi} + \mu \mathrm{i} \tag{2}$$

where: $P_i = 1$ for $X \leq Z$; $i = 1, 2, \ldots\ldots, n$; qi is a vector of explanatory variables and is the vector of parameters.

The binary probit model computes the maximum likelihood estimator of given the non-linear probability distribution of the random error μ_i. The dependent variable P_i is a dichotomous variable which is 1 when a household is willing to pay and 0 if otherwise.

2.4.3. Seemingly unrelated bivariate probit model

The estimated correlation coefficient of the error terms in a bivariate probit model, where the error terms are assumed to have normal distributions with a mean of zero and a difference from zero. According to Ref. [24], a bivariate probit model can be specified in equations (3) and (4).

$$\mathrm{WTP1i} = \times i\beta 1i + \sum 1\mathrm{i} \tag{3}$$

$$\mathrm{WTP2i} = \times 2\mathrm{i}\beta 2\mathrm{i} + \sum 2\mathrm{i} \tag{4}$$

where: i = ith respondent's willingness to pay; β_1 and β_2 are unknown parameters to be estimated in the first and second equation, X is a vector of explanatory variables that can affect amounts of offered bid values for metal silo storage technology; WTP_1 and WTP_2 = unobservable random components in the first and second equations respectively; ε_1 and ε_2, are error terms normally distributed with mean zero and respective variances σ1 and, σ2 and have a respectively bivariate normal distribution with correlation coefficient ρ. Where, $\rho \neq 0$. The joint response probabilities for the offered initial and follow-up bids are (Yes, Yes), (Yes, No), (No, Yes), and (No, No) (equations (5)–(8)). The probability of responses of respondent I to the first and the second offered bid value is given by Ref. [24].

$$\Pr(\text{no, no}) = \Pr\left(\text{WTP1i} < t^2\right), \text{WTP2i} < t^2 = \Pr\left(\times \text{i}\beta1\text{i} + \sum 1\text{i} < t^1, \times \text{i}\beta2\text{i} + \sum 2\text{i} < t^2\right. \tag{5}$$

$$\Pr(\text{no, yes}) = \Pr\left(\text{WTP1i} < t^1, \text{WTP2i} \geq t^2 = \Pr\left(\times \text{i}\beta1\text{i} + \sum 1\text{i} < t^1, \times \text{i}\beta2\text{i} + \sum 2\text{i} \geq t^2\right.\right. \tag{6}$$

$$\Pr(\text{yes, no}) = \Pr\left(\text{WTP1i} \geq t^1, \text{WTP2i} < t^2 = \Pr\left(\times \text{i}\beta1\text{i} + \sum 1\text{i} \geq t^1, \times \text{i}\beta2\text{i} + \sum 2\text{i} < t^2\right.\right. \tag{7}$$

$$\Pr(\text{yes, yes}) = \Pr\left(\text{WTP1i} \geq t^1, \text{WTP2i} \geq t^2 = \Pr\left(\times \text{i}\beta1\text{i} + \sum 1\text{i} \geq t^1, \times \text{i}\beta2\text{i} + \sum 2\text{i} \geq t^2\right.\right. \tag{8}$$

where: where t^1 is the amount of the first bid (Bid 1) and t^2 amount of the second bid (Bid 2).

The mean willingness to pay is estimated by double bounded as stated in equation (9).

$$\text{MWTP} = \frac{-\alpha}{\beta} \tag{9}$$

The following formula developed in equation (10) is used for the maximum willingness to pay by open-ended questions.

$$\text{MWTP} = \sum_{i=1}^{Z} \text{WTPi/N} \tag{10}$$

3. Result and discussions

3.1. Linking socioeconomic factors with households' to willingness to pay tendency

Table 2 results showed that, the chi-square test result of dummy variables on willingness to pay decision for metal silo storage technology. The majority of sampled households (99.09%) were male-headed. Similarly, the table result endorsed that the proportion of willing to pay male and female-headed households were 94.56% and 5.43%, respectively. The chi-square test results revealed that sex of the household among willing and not willing to pay was statistically significant at 5%. The proportion of willing-to-pay married and unmarried-headed households was 91.66% and 8.33%, respectively. The proportion of married households was higher among willingness to pay (91.66%) than those not willing to pay married households (95.42%). The chi-square test results revealed that marital status among willing and not willing to pay was statistically significant at 5%.

The proportions of literate households were higher among willing households (94.2%) than not willing to pay (49.96%). The proportion of illiterate households among willing to pay households (5.8%) was lower than not willing-to-pay households (55.04%). The Chi-square test results showed that educational status among willing and not willing to pay was statistically significant at 10%. This study confirmed the finding of [25].

The proportion of land-owned households was higher among willing-to-pay households (93.30%) than not willing-to-pay households (59.63%). The chi-square test revealed that land ownership among those willing to pay and those not willing to pay was statistically significant at 1%. The proportion of households who got extension services among those willing to pay (89.85%) was higher than those not willing to pay households (21.10%). The chi-square test result revealed that extension service among willing and not-willing households was statistically significant at 1%.

The proportion of households who got credit access among those willing to pay (24.27%) was lower than those not willing to pay households (88.07%). The chi-square test revealed that access to credit among willing-to-pay and not willing to pay groups was statistically significant at 1%. Market accessibility contributes to income generation and minimizes transport costs. The proportion of market accessibility among willing to pay (73.55%) was higher than not willing to pay households (16.51%). The chi-square test revealed that market accessibility among willing and not willing-to-pay households were statistically significant at 1%.

About 78.90% of willing households were members of agricultural cooperatives, and 26.60%, of not willing households, were

Table 2
Proportion of households' characteristics by willingness to pay decision.

Variables	Category of Variables	Proportions (N = 385)		Overall N = 385 Frq (%)	X^2-Value
		Willing N = 276 Frq (%)	Not willing N = 109 Frq (%)		
Sex of household	Female	15 (5.43)	1 (0.91)	16 (4.15)	
	Male	261 (94.56)	108 (99.09)	369 (95.84)	4.00***
Land ownership	Yes	252 (91.30)	65 (59.63)	317 (82.33)	53.89***
Extension service	Yes	248 (89.85)	23 (21.10)	271 (70.38)	177.22***
Credit access	Yes	67 (24.27)	96 (88.07)	163 (42.33)	130.27***
Market accessibility	Yes	203 (73.55)	18 (16.51)	221 (57.40)	103.96***
Agricultural cooperative membership	Yes	218 (78.90)	29 (26.60)	246 (63.89)	93.22***

Note: ***and ** indicates statistically significant at 1% and 5% of significance level respectively.

members of agricultural cooperatives. The chi-square results showed that differences in agricultural cooperative membership within willing and not-willing households were estimated to be significant at a 1% significance level.

The *t*-test result in Table 3 showed the mean difference between continuous variables and households' willingness to pay decisions for metal silo storage technology. The result showed that the mean age of willing-to-pay households was 44.48 years while for non-willing to pay was about 55.97 years. The two-tailed test result endorsed that age was statistically significant at 1%, implying that the mean age of willing-to-pay households was less than not willing. This finding was consistent with [26]. The mean household sizes of willing and not willing households were 4.54 and 5.12 respectively. The *t*-test result revealed that household size was statistically significant among willing and not-willing households at 1%.

The mean income of willing-to-pay households was 5416.36 ETB while for not willing-to-pay households was about 1986.23 ETB. The *t*-test result endorsed that income was statistically significant at 1%. The mean farm sizes of willing-to-pay households were 1.35 ha while non-willing-to-pay was about 0.84 ha. The two-tailed test result showed that farm size was statistically significant at 1%. The mean of tropical livestock units was 4.77 among willing households while about 4.07 units from not willing households. The two-tailed test results endorsed that tropical livestock unit was statistically significant at 1% between willing and not willing households.

Distance to the market center is one of the factors for buying and selling agricultural inputs easily. The mean market distances of willing households were 55.27 while not willing to pay was 87.98 min.

3.2. Losses of sorghum at storage

Table 4 displays the results, which reveal that weevils easily proliferate and destroy sorghum grains during storage. From sampled households, approximately 6164 quintals of sorghum were produced in 2021/22 production season of northeast Ethiopia. However, 7% of sorghum was lost at the storage stage by the weevil.

Sorghum is mostly attacked by rodents, which causes product losses on the field and at the storage facility. In the storage facility, it is the third sorghum attacker after weevil and mold growth. The rodent frequently tore open the bag and dug a hole to attack the sorghum that was being stored. The result endorsed that 0.9% of sorghum was lost during storage.

Another reason for sorghum losses in storage is mold. The grain's moisture content increased to a point where mold may grow when cereals were kept in a tunnel. The growth of mold could increase the temperature and increase insect reproduction. A large population of insects produces more moisture, and this cycle is repeated more frequently over time.

Insects are known to cause quality deterioration through their excreta as they consume. Mold is generally a problem in grain that has been stored for more than 10 months. However, a problem occurred only a few in this month. About 34.80% of sampled households were lost 3.26% of sorghum from a total production of 6164 quintals.

Like rodents, birds also consume some grain but also contaminate a greater quantity with droppings. About 9.9% of sampled households lost 0.064% their grain from a total of 6164 quintals of sorghum, this means equal to 4 quintals (400 kg) of sorghum. Generally the total loss of sorghum at storage was 11.6% in northeast Ethiopia.

3.3. Determinants of willingness to pay for metal silo storage technology

The presence of multicollinearity was examined using the contingency coefficient for dummy variables and the variance inflation factor for continuous independent variables in Table 5 for the probit model. The result found that the problems are not serious. Because, the VIF between explanatory variables was less than 10, the contingency coefficient was less than 75%. Though several ways to deal with heteroscedasticity, checking whether each explanatory variable is responsible for the existence of heteroscedasticity or not is one way of dealing with such a problem [27].

3.3.1. Sex of household head

Sex of household was negatively and significantly determined willingness to pay decisions at 10% level of significance. The model result predicted that as a household is male-headed, the probability of willingness to pay for metal silo storage technology decrease by 11.3%, ceteris paribus. This suggests that households led by women were more likely to be willing to invest in metal silo storage technology. Females have also a desire to reduce their labor and use of energy via postharvest activities. Moreover, women are more likely to be involved in the storage, washing, and drying of cereal in the study area. This research supported [28] findings.

Table 3
Mean of household heads' characteristics by willingness to pay decisions.

′Variables	Willing Mean	Not willing Mean	Total sample mean	T-value
Age	44.48	55.97	47.73	8.94***
Household size	4.54	5.12	4.70	3.10***
Total annual income	5418.47	1986.23	4446.75	−12.79***
Farm size	1.35	0.84	1.20	−9.58***
Distance-to-market center	55.16	87.98	64.45	11.26***
Tropical livestock unit	4.77	4.07 (1.37)	4.57	−4.50***

Note: *** indicates statistically significant at 1% significance level.

Table 4
Extent of sorghum loss at storage stage.

Total sorghum production (quintal) or kg	Agent of storage sorghum loss	Sampled households Frq. (%)	Storage loss (quintal)	Storage Loss (kg)	Percentage loss
6164 (616,400 kg)	Weevil	351 (91.16)	477.25	47725	7%
	Mold	134 (34.80)	201.45	20145	3.26%
	Rodent	319 (82.85)	52.9	5290	0.9%
	Birds	38 (10)	4	400	0.064%
	Total		735.6	73560	11.16%

Source: (Computed from survey data, 2022)

Table 5
Probit model result of WTP.

WTP	dy/dx	Coef.	Std.err.	p-value
Sex of household head	−0.113	−1.597	0.850	0.060
Age of household head	−0.003	−0.015	0.009	0.111
Marital Status of household head	−0.047	−0.313	0.582	0.591
Household size	−0.004	−0.023	0.066	0.724
Educational Status of household head	0.200	0.833	0.246	0.001
log total household annual income	0.090	0.498	0.238	0.037
Farm size	0.110	0.610	0.330	0.065
Land ownership	0.103	0.475	0.252	0.059
Tropical livestock unit	−0.013	−0.071	0.080	0.372
Distance to center market	−0.002	−0.001	0.006	0.929
Agricultural-cooperative membership	0.032	0.170	0.25	0.495
Market accessibility	0.163	0.831	0.376	0.027
Extension service	0.211	0.935	0.259	0.000
Credit access	−0.037	−0.199	0.308	0.517
Constant		−2.781	2.207	0.208
	No of observation = 385			
	Prob > chi2 = 0.000			
	Pseudo r-squared = 0.615			
	Chi-square (14) = 282.380			
	Akaike crit. (AIC) = 206.443			

Note: Dependent variable; Willingness to pay for metal silo storage technology, *** and ** are statistically significant at 1% and 5% significance level, respectively.

3.3.2. *Total annual income*

Total annual income was statistically significant at 5% level and positively influenced households' willingness to pay decisions in metal silo storage technology. Keeping all other factors constant, an increase in the annual income of the household by 50 ETB increases the likelihood of households' willingness to pay for metal silo storage technology by 9%, implying households with higher income had a greater willingness to pay for metal silo storage technology than households have lower income. Similar to this, households used to higher revenue from prior output were more inclined to invest in alternative inputs for their farm in anticipation of high income than farmers whose production was only sufficient for hand-to-mouth living [29]. Acording to Ref. [30], annual on-farm income was a positive and significant influence on the willingness to pay decisions.

3.3.3. *Educational status of household head*

Education status had statistically a significant impact on households' willingness to pay decisions in metal silo storage technology at the 1% level. When all other variables are held constant, literate households are 20% more likely than illiterate household heads to be willing to pay for metal silo storage technology, suggesting that literate households are more knowledgeable about the search for new things and resources and more engaged in the economy. This research supported [31] findings.

3.3.4. *Farm size*

Farm size was statistically significant at 10% level and positively influenced households' willingness to pay decisions in metal silo storage technology. Keeping all other factors constant, as the farm size is increased by 1 ha, the likelihood of the household's willingness to pay for metal silo storage technology increases by 11%. This implies the farmers who have enough land can cultivate more crops and generate income. The land size of the farmers was an important factor that significantly influenced the willingness to pay for service [32].

3.3.5. *Extension service*

Extension service was found statistically significant at 1% level and positively influenced households' willingness to pay decisions in metal silo storage technology. Keeping all other factors constant, the households being getting extension service, the probability of being willing to pay for metal silo storage technologies increases by 21% compared to their counterparts. This implies extension services could increase the acceptance of technology in households. Hence, households who accessed an extension service are more willing to pay for metal silo storage technology than non-access. This study supports the findings of [33], who found that agricultural extension services made a contribution to the development of competent and effective farmers who could increase productivity by making efficient use of knowledge and information that was available from or could be produced by a variety of information sources.

3.3.6. Land ownership

Land ownership was found statistically significant at 10% level and positively influenced the household's willingness to pay decisions. Keeping other factors constant, being the households were a get property of secured land ownership, the likelihood of households' willingness to pay for metal silo storage technology could increase by 10.3%, implying households who owned land to be cultivated more. Therefore, they have more willing to pay for metal silo storage technology than their counterpart. This research supported [34] findings.

3.3.7. Market accessibility

It was statistically significant at 5% level and positively influenced households' willingness to pay decisions in metal silo storage technology. Keeping all other factors constant, households that access the market are 16.3% more likely to be willing to pay for metal silo storage technology. It implies that households that have market access enhance income generation and minimize transport costs. This study's findings are consistent with those of [35].

3.4. Households' mean WTP for metal silo storage technology

In the double-bounded dichotomous choice format, the mean value of the initial bid and second bid was 1184 birr and 11186 ETB, respectively (Table 6). In Table 7, the results showed that the mean WTP (with no control variables) was 5147 ETB because the double command directly estimates β the WTP formula is simply zβ [36].

Moreover, the mean willingness to pay for metal silo storage technology of households from the open-ended format was 4179 ETB per household per unit (Table 8).

3.5. Total willingness to pay for metal silo storage technology

According to Ref. [28], the processes to convert the ungrouped frequency distribution of data to a grouped frequency distribution, the results of the open-ended questions were sorted into class marks. Each class limit's class mark was calculated using statistical processes.

WTP households were also asked how much money they are willing to spend on metal silo storage technology, and the results from 276 households are presented in the table below. The class mark (midpoint of WTP amounts) was determined from the class intervals for the WTP amounts, and the total number of willing-to-pay households (col. 4) was calculated by multiplying the proportion of sample homes falling inside that boundary (col. 3) by the total population (23,644) divided by sampled household (385). Then, the total number of willing households to get metal silo storage technology by summing up each value of the total household of the sample distribution. Finally, the total willingness to pay was determined to be 74,128,653.5 ETB (Table 9).

In Fig. 3, the kinked demand curve shows the price (y-axis) of metal silos without a change of rate, and the number of households to purchase per unit of metal silo storage technology increases (X-axis).

4. Conclusion and recommendation

Grains provide the primary source of nutrition for Ethiopian people. Cereal crops such as maize, sorghum, and wheat, as well as grain legumes, play an important role in food, nutritional security ad income of smallholder farmers in the study area. However, weevils easily grow and destroy sorghum produce of smallholder farmers in northeast Ethiopia. As a result, the postharvest loss of sorghum at the storage stage was high (about 11.6%) of the total stored due to the effect of weevils, rodents, mold formation, and birds.

A probit model was used to analyze the determinant factors of farmers' willingness to pay for metal silo storage technology and a bivariate probit model was applied to estimate the farmers 'willingness to pay for metal silo storage technology. The bivariate probit

Table 6
Seemingly Unrelated Bivariate probit estimate of mean WTP1 and WTP2.

Variables	Coefficient	Std.err	p-value	mean
Initialbid1	−0.005	0.002	0.032**	1184
Constant	6.869	5.887	0.253	
Secondbid2	−0.001	0.0001	0.000***	11186
Constant	6.711	4.384	0.114	

LR test of rho = 0: chi^2 (1) = 6.345 Prob > chi^2 = 0.012.
Dependent variable; Willingness to pay for metal silo storage technology; *** and ** shows the value statistically significant at 1% and 5% level, respectively.

Table 7
Mean WTP of double-bounded dichotomous method.

	Coefficient	Std.err.	P -value	[95% Conf. interval]	
Beta -cons	5146.095	294.603	0.000	4568.684	5723.507
Sigma -cons	2881.974	288.768	0.000	2316	3447.949

Note: Dependent variable; Willingness to pay for metal silo storage technology, *** and ** are statistically significant at 1% and 5% significance level, respectively.

Table 8
Mean WTP in open-ended question format.

Variable	Obs	Mean	Std. Dev.	Min	Max
WTP	276	4178.714	1890.239	500	8000

Table 9
Total willingness to pay.

Class boundary C1	Midpoint C2	Sampling distribution C3	Total Household C4=C3*23644/385	Total WTP C5=C2*C4
500-2375	1437.5	49	3010	4,326,875
2376-4251	3313.5	60	3685	12,210,247.5
4252-6127	5189.5	129	7922	41,111,219
6128-8000	7064	38	2333	16,480,312
Total		276	16950	74,128,653.5

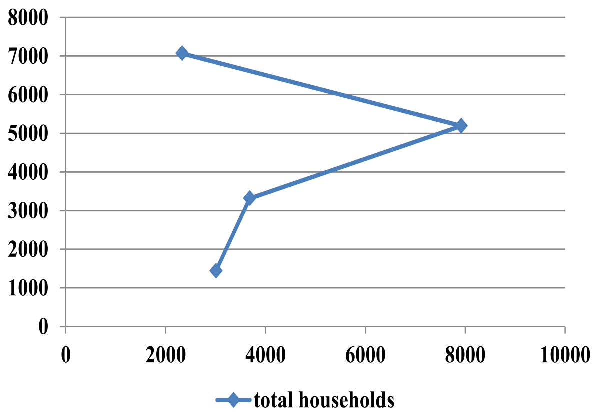

Fig. 3. Aggregate WTP demand curve of metal silo storage technology.

model is used to estimate the mean value of willingness to pay for metal silo storage technology.

The mean value of willingness to pay in the double-bounded question format was 5147 ETB. The result implies that households were more willing to pay for the initial and second bid values. With an open-ended system, lower than a double bound mean willingness to pay, the mean value of a farmer's willingness to pay was 4179 ETB which might be due to a human being wanting a free service from the government at the expense of others. Generally, the result of the study endorsed that households' willingness to pay for metal silo storage technology increases due to the poor quality of traditional sorghum storage materials and results in high loss and damage of the product quantitatively. The empirical findings also show that the households' willingness to pay for metal silo cereal storage technology increase as the households' income, livestock ownership, and access to extension services increase.

In general, the study comes to the conclusion that weevil assaults, mold infestation, and insect attacks are to blame for the substantial postharvest losses of sorghum at storage for prolonged durations in northeast Ethiopia. Moreover, the household's level of willingness to pay is contingent upon and different from location to location.

Based on the results from the descriptive and econometric analysis, the following policy implications are suggested to reduce the postharvest loss of sorghum. After harvesting, the grain should be cleaned and well-dried to reduce the effect of weevil, and mold formation in the storage. Education has been found a significant effect on households' willingness to pay decisions. Therefore, the district agriculture office and other stakeholders should create awareness for farmers to use metal silo storage technology as a sorghum postharvest loss minimization mechanism at the storage time. Similarly, agricultural research institutions should give training to farmers on the adoption and proper utilization of metal silo cereal storage technology. The government should also be expected to improve farmers' access to credit, market, and subsidies to increase their willingness to pay for metal silo cereal storage technology. Moreover, the farmers' mean value of willingness to pay of the open-ended format compared to the double-bounded format indicate the farmers wish to benefit from the government free service. Therefore, the local government and metal silo manufacturers should supply and offer the technology for farmers at right time and affordable price.

Consent for publication

Not applicable.

Ethical approval and consent to participate

Ethical clearance letters were collected from the University of Gondar to care for both the study participants and the researchers. During the survey, official letters were written for each district and kebele/villages/informed verbal consent was obtained from each client, and confidentiality was maintained by giving codes for each respondent rather than recording their name. Study participants were informed that clients have a full right to discontinue or refuse to participate in the study. Hence, all participants throughout the research, including survey households, enumerators, supervisors, and key informants were fully informed of the objectives of the study. They were approached friendly in and free moods until the end of this research.

Author contribution statement

Degu Gobezie Teshome: Conceived and designed the analysis; Analyzed and interpreted the data; contributed analysis tools or data; Wrote the paper.

Essa Chanie Mussa: Conceived and designed the analysis; Analyzed and interpreted the data; Wrote the paper.

Abebe Birara Dessie: Analyzed and interpreted the data; Contributed analysis tools or data; Wrote the paper.

Tadie Mirie Abate: Conceived and designed the analysis; Contributed analysis tools or data; Wrote the paper.

Degarege Yitayih Ayalew: Conceived and designed the analysis; Analyzed and interpreted the data.

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.e18223.

References

[1] P. Sofi, et al., Manipulation for the nutritional fortification of maize, J. Plant Breed 1 (6) (2009) 244–253.
[2] B. Shiferaw, et al., Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security, Food Secur. 3 (2011) 307–327.
[3] E. Mujuka, et al., Willingness to Pay for Postharvest Technologies and its Influencing Factors Among Smallholder Mango Farmers in Kenya, 2021.
[4] Y. Wang, Z. Yuan, Y. Tang, Enhancing food security and environmental sustainability: a critical review of food loss and waste management, Resources, Environment and Sustainability 4 (2021), 100023.
[5] K.D. Singh, et al., Main plant volatiles as stored grain pest management approach: a review, Journal of Agriculture and Food Research 4 (2021), 100127.
[6] T. Tefera, S. Mugo, Y. Beyene, Developing and deploying insect resistant maize varieties to reduce pre-and post-harvest food losses in Africa, Food Secur. 8 (1) (2016) 211–220.
[7] M. Totobesola, et al., A Holistic Approach to Food Loss Reduction in Africa: Food Loss Analysis, Integrated Capacity Development and Policy Implications, Food Security, 2022, pp. 1–15.
[8] M. Tadesse, M.J. Ali, Assessing Storage Insect Pests and Faecal Dropping of Rodent in Stored Grains in Two Districts of Southwestern Ethiopia, 2021.
[9] G.U. Benimana, C. Ritho, P. Irungu, Assessment of factors affecting the decision of smallholder farmers to use alternative maize storage technologies in Gatsibo District-Rwanda, Heliyon 7 (10) (2021), e08235.
[10] H. Hengsdijk, W. De Boer, Post-harvest management and post-harvest losses of cereals in Ethiopia, Food Secur. 9 (2017) 945–958.
[11] E. Mendesil, et al., Farmers' perceptions and management practices of insect pests on stored sorghum in southwestern Ethiopia, Protect. 26 (12) (2007) 1817–1825.
[12] A. Mohammed, A. Tadesse, Review of Major Grains Postharvest Losses in Ethiopia and Customization of a Loss Assessment Methodology. USAID/Ethiopia Agriculture Knowledge, Learning, Documentation and Policy Project, Addis Ababa, 2018.

[13] G. Bezabih, et al., Reducing postharvest loss of stored grains using plant-based Biopesticides: a review of past research efforts, Advances in Agriculture (2022) 2022.
[14] D. Befikadu, Postharvest losses in Ethiopia and opportunities for reduction: a review, Int. J. Sci. Basic Appl. Res. 38 (2018) 249–262.
[15] E. Demis, W. Yenewa, Review on major storage insect pests of cereals and pulses, Asian Journal of Advances in Research (2022) 41–56.
[16] F. Bachewe, et al., Farmers' grain storage and losses in Ethiopia, J. Agric. Food Ind. Organ. 18 (1) (2019), 20190059.
[17] S. Debebe, Post-harvest losses of crops and its determinants in Ethiopia: tobit model analysis, Agric. Food Secur. 11 (1) (2022) 1–8.
[18] F. Okori, et al., Grain hermetic storage and post-harvest loss reduction in sub-saharan Africa: effects on grain damage, weight loss, germination, insect infestation, and mold and mycotoxin contamination, Journal of Biosystems Engineering 47 (1) (2022) 48–68.
[19] K. Adhikari, et al., Agroecological Transformation for Sustainable Food Systems: Insight on France-CGIAR Research, Les dossiers d'Agropolis International. Special Partnership Issue, 2021.
[20] P.C. Commission, The 2007 Population and Housing Census of Ethiopia, 2010.
[21] W. Bahiru, et al., Assessing the impacts of rainfall variability on Teff production and farmers perception at Gubalafto district, North Easter, Ethiopia, Int J Earth Sci Geophys 6 (2020) 2–19.
[22] C.R. Kothari, Research methodology: methods and techniques, New Age International (2004).
[23] O. Oladele, Factors determining farmers' willingness to pay for extension services in Oyo State, Nigeria, Agric. Tropica Subtropica 41 (4) (2008) 165–170.
[24] T.C. Haab, K.E. McConnell, Valuing Environmental and Natural Resources: the Econometrics of Non-market Valuation, Edward Elgar Publishing, 2002.
[25] Y.H. Gebre, Evaluation of farmers' willingness to pay (WTP) for sesame seed driller machine rental service in kafta-humera district, western tigray, Ethiopia, Asian Journal of Agricultural Extension, Economics & Sociology 38 (8) (2020) 51–60.
[26] M. Dessale, Y. Habteselase, D. Abi, Households' willingness to pay for soil and water conservation practices on communal lands in South Wollo Zone, Ethiopia, Sustainable Water Resources Management 8 (4) (2022) 111.
[27] N. Assefa, Valuing the Economic Benefit of Irrigation Water: Application of Choice Experiment and Contingent Valuation Methods to Ribb Irrigation and Drainage Project in South Gonder, Ethiopia, Addis Ababa University Master's Thesis, 2012.
[28] K. Tassie, B. Endalew, Willingness to pay for improved solid waste management services and associated factors among urban households: one and one half bounded contingent valuation study in Bahir Dar city, Ethiopia, Cogent Environmental Science 6 (1) (2020), 1807275.
[29] G.Y. Ayana, Farmers'willingness to pay for soil conservation practices in gobu seyo district, eastern wollega zone, oromia national regional state of Ethiopia, 3 (2013-2017-1900), International Journal Of Agriculture And Environmental Research (2017).
[30] E. Asmare, K. Bekele, S. Fentaw, Households' willingness to pay for the rehabilitation of wetlands: evidence from Gudera wetland, Northwest Ethiopia, Heliyon 8 (1) (2022), e08813.
[31] G.K. Mezgebo, et al., Impact of community-based exclosure to smallholder farmers' livelihood and their willingness to pay: empirical evidences from Tigrai, Ethiopia, Environ. Dev. Sustain. 24 (2) (2022) 2598–2615.
[32] R. Dupdal, et al., Perception and economic impact of agromet advisory services: a case study of Thrissur AICRPAM centre of Kerala state, Indian Journal of Extension Education 56 (3) (2020) 10–16.
[33] D. Temesgen, T. Tola, Determinates of small holder farmers willingness to pay for agricultural extension services: a case study from Eastern Ethiopia, Afr. J. Agric. Res. 10 (20) (2015) 2152–2158.
[34] A. Gobena, D.J. Haji, D.L. Zemedu, Determinants of Farmers'willingness to Pay for Soil Conservation Practices: the Case of Jarso District, Eastern Hararghe Zone, Oromia Region, Ethiopia, Haramaya University, 2016.
[35] M.M. Neway, M.B. Zegeye, The determinants of household willingness to pay for irrigation water: in the case of Northern Showa, Amhara Region, Ethiopia, Water Resources and Irrigation Management-WRIM 11 (1–3) (2022) 8–21.
[36] A. Lopez-Feldman, Introduction to Contingent Valuation Using Stata, 2012.