Research article

On-farm genetic diversity of wheat (*Triticum aestivum* spp.) in Digalu Tijo District, Arsi zone, Ethiopia

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ABSTRACT

On-farm genetic diversity is the relative distribution of plant species. This study was undertaken to assess the on-farm genetic diversity of wheat landraces (*Triticum aestivum* spp) in Digalu and Tijo District. For this study, three farmer households’ kebeles were selected by cluster sampling (area sampling) method because they are found in the most dominant wheat landraces growing agro ecological areas. Data for this study was collected using questionnaires, field observation, interviews, focus group discussions, and document analysis. In total, 27 wheat landraces were reported to be grown two decades ago to the present day. Of these, only 9 wheat landraces are still cultivated by farmers. Among these, ‘Qamadi guracha’ is the most common growing landraces in the study area. The Shannon diversity index (H′) of growing wheat landraces ranges from 1.09 to 1.37 among the groups. The estimated genetic erosion for wheat landraces was found to be 66.7% due to the major factors: improved wheat varieties; the introduction of other more productive crops and wheat landraces low productivity. Food quality, Pests (for example, birds), disease resistance, market value, and straw quality were factors that initiated the farmers to maintain the genetic diversity of landraces on their farmlands. However, the preservation of wheat landraces is influenced by bottlenecks like the seed selection system, and insufficient crop yield. Regeneration of soil fertility, restoration of lost landraces, improvement of landraces, on-farm conservation by re-sowing, saving of seeds for the future, and ex-situ conservation are suggested for the restoration of wheat landraces diversity in Digalu and Tijo District.

1. Introduction

Genetic diversity is usually thought of as the amount overall of genetic variability [1]. On-farm genetic diversity also refers to the relative distribution of plant species [2]. Crop variety, in turn, refers to variation within the same and between different crops that include staple crops such as wheat in Ethiopia [3]. Wheat (*Triticum aestivum*) is the grain and the first crop to be domesticated and cultivated by human beings. Most wheat varieties in Ethiopia are landraces [5,6] and are traditionally grown [7]. Wheat varieties whose morphological and genetic composition is shaped by household farmers’ practices, natural selection pressure over generations of cultivation, and human selection [8]. They display genetic variation for useful quantitative and...
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qualitative characters \[1,9,10\]. Even if the wheat landraces are being genetically eroded, they are produced at altitudes of 1800–3500 m.a.s.l in Ethiopia \[11\]. The genetic erosion of tetraploid is the loss of wheat landraces from areas they adapted due to the introduction of productive semi-dwarf cultivars, improved varieties, and high selection pressure applied in breeding programmes \[12,13\]. On-farm genetic conservation is the continued cultivation of landraces genetic diversity by household farmers in centers of domestication that allows them to adapt to continually changing environmental conditions \[2\]. Even today, it is evident that Ethiopian farmers are practicing traditional farming of wheat landraces \[8\].

Moreover, knowledge about the level and extent of genetic diversity in wheat landraces on the farm is of great value for sustainable maintenance and utilization of genetic materials \[14,15\]. Estimating any possible loss of genetic diversity and its causes; tracing the available genetic variability is important for in situ or ex situ conservation of wheat landraces \[16\]. Thus, the documentation, estimating genetic erosion and its causes, and incentives why farmers conserving landraces were the motives that initiated the present study to assess the on-farm genetic diversity of wheat landraces (\textit{Triticum aestivum} spp.) for successful conservation in in-situ and ex-situ and sustainable utilization of the genetic materials of varieties in Digalu Tijo District, Arsi zone, Ethiopia. The objective of the study was to assess the on-farm genetic diversity of wheat landraces (\textit{Triticum aestivum} spp.) in Digalu Tijo District, Arsi Zone, Ethiopia.

2. Material and methods

2.1. Description of the study area

Digalu Tijo is one of the 25 districts found in the Arsi zone of Oromia Regional State. Its borders are Tiyo to the north, Tena to the east and Munessa to the west, and Lemmu-Bibelio woreda to the south. It is about 198 km south of Addis Ababa and 98 km from Adama town. The district contains one urban town and 27 rural kebeles i.e. 28 kebeles in total within a 92,698.51 km\(^2\) area. It is located at the latitude of 7\(^\circ\)35\('\)57\("\)–7\(^\circ\)55\('\)43\("\)N and longitude of 38\(^\circ\)59\('\)40\("\)–39\(^\circ\)24\('\)31\("\)E (Fig. 1); and its elevation ranges from 2000 to 4000 m.a.s.l. The District’s woynadega agroecology kebele represents areas with mid-altitude (2000–3000 m.a.s.l.), and it receives annual rainfall that ranges 900–2000 mm and its mean annual temperature ranges from 18 to 25 \(^\circ\)C. The dega agroecology kebeles represent areas with altitude (3000–3500 m.a.s.l) and they are receiving mean annual rainfall and temperature ranges from 1500 to 2600 mm and

Fig. 1. The map of Digalu and Tijo District.
10.9–21 °C [17,18]. 2007, the national census reported that the total population of Digalu and Tijo district was 140,466, of whom 69,503 were males, 70,963 were females, and 14,080 or 10.02% of its population were urban dwellers.

2.2. Geology and soil type in the study area

According to Ref. [19], the geomorphology of Ethiopia is variable and it is generally the result of repeated volcanic and tectonic events with the associated erosion of Mesozoic sedimentary and volcanic rocks, and the deposition process. According to Digalu Tijo District Agricultural Office Annual Report [20], its physiographic diversity is characterized by highlands and flat-topped plateaus. Regarding its soil types, about 44% of the soil type is red, 35% of the soil type is black and 21% is brown soil types Digalu Tijo district Agricultural Office Annual Report [20].

2.3. Study design

This study was conducted from September to November 2016 because these months were the cropping seasons when the wheat landraces become well-grown and easy to get the real sample in the study area. Owing to this, the researcher selected these months to collect a reliable sample of wheat landraces and data. A descriptive survey research method was employed because it is suitable for describing the existing situation and investigating phenomena in their natural setting and it presents opportunities to combine both quantitative and qualitative i.e., to assess the on-farm genetic diversity of wheat landraces cultivated by farmers. To do this, two kebeles from Dega and one kebele from woynadega were selected by using the purposive sampling technique because they are found in the dominant wheat-growing agroecology area.

2.4. Study subject/target groups

The source of the population for the study was household farmers in the Digalu Tijo District of three sampled kebeles. This was because farmers are found in the kebeles of dominant wheat landraces growing agroecology areas. In this case, both the male and female household farmers were considered as some female household farmers present in these kebeles.

2.5. Sample size and sampling methods

There were 4832 identified total household farmers in the three sampled kebeles of the study area [21]. Among these, the sample size (n) determination for the study was carried out through the following formula cited from Ref. [22] as follows:

\[ n = \frac{Z^2pqN}{e^2(N-1)} + \frac{Z^2pq}{N} \]

where, \( n \) = the desired sample size; \( N \) = the size of the household population in the three sampled kebeles (4832) at a Confidence level of 95% and 5% precision, \( Z \) = the critical value containing the area under the normal curve = 1.96, \( e \) = the desired precision level (5% precision = 0.05), \( p \) = an estimated proportion attribute present in the population (0.1) and \( q = 1 - p(0.1 = 0.9) \)

By substituting these values in the above formula the sample size ‘n’ was calculated as follows:

\[ n = \frac{(1.96)^2(0.1)(0.9)(4832)}{(0.05)^2(4832 - 1)} + \frac{(1.96)^2(0.1)(0.9)}{4832} = 134 \text{ sample household respondents} \]

Thus, a total of 134 household farmers were determined as the sample size. In addition, 9 DA workers and 3 district agricultural experts were selected. A stratified proportional probability sampling technique was used to divide and allocate the sample size (134) to each of the three selected sample kebeles as it did not constitute a homogeneous group.

Accordingly, the principle of probability is proportional to size, which means kebeles that, had large numbers of farmer households, based on the measure of size, were given greater probabilities. Then, the proportional allocation formula was employed by dividing the number of household farmers from each kebele/stratum by the total study population and multiplying by \( n \).

| Sampled kebeles  | Total households farmers (N) | Respondent households (n) |
|------------------|-----------------------------|--------------------------|
| Gushattemala     | 1371                        | 38                       |
| Borkitu          | 1852                        | 51                       |
| Digalubora       | 1609                        | 45                       |
| Total            | 4,832                       | 134                      |
The formula for proportional allocation from the stratum/kebele = \( n \times P_i \)

where \( n \) = the sample size selected from three sample kebeles in this case 134 head of households, \( P_i \) = the proportion of household population includes from the stratum/kebele. Based on this, Gushatemala \((n = 1371\) households) = 134 * 1371/4832 = 38 sample respondents, Burkitu \((n = 1852\) households) = 134 * 1852/4832 = 51 sample respondents and Digalu Bora \((n = 1609\) households) = 134 * 1609/4852 = 45 sample respondents. The result was summarized in (Table 1).

2.6. Sources of data and instruments of data collection

2.6.1. Sources of data

Data were collected from both primary and secondary sources. The primary data were collected from household farmers; DA workers and Woreda Agricultural Experts. To enrich the information gathered through other tools, secondary data were collected from Arsi/Kulumsa/Agricultural Research Institute (published data) (see Refs. [23,24]).

2.6.2. Instruments of data collection

To gather reliable, rich, and deep data from the subjects of study on on-farm genetic diversity of wheat landraces, the researcher employed the following five data collecting instruments.

2.6.2.1. Observation checklist. To assess critically about on-farm diversity of wheat landraces at the time of the study, which is own, to highly cultivated, field observation was employed in the study area.

2.6.2.2. Questionnaire. To collect data from 134 sampled farmers, the semi-structured questionnaires with open-ended and closed-ended questions were prepared and distributed. During data collection, a questionnaire was translated into Afaan Oromo.

2.6.2.3. Interview. To acquire detailed information and to fill the gap that was not covered by the questionnaire, an individual interview was used. In this case, the eight open-end of interviews preferred to collect data from DA and the district’s Agriculturally Experts. During data collection, interview guideline was used; and it was translated into Afaan Oromo.

2.6.2.4. Focus group discussion (FGD). A total of three group discussions were conducted (one in each kebele) with ten key informants to reinforce the questionnaires and find out any hidden information that could be missed. To do this, farmers were assigned based on their farming experiences of wheat landraces and made them discuss and investigate the main issues of associated questions.

2.6.2.5. Documents analysis. To enrich the information gathered through other tools; and to discover the existing facts about wheat landraces in the study area, document analysis was conducted. The researcher prepared a checklist as a guideline to conduct the analysis of data obtained from documents.

2.7. Data management and analysis procedure

The data gathered through all the data gathering tools was analyzed with quantitative and qualitative data analysis methods (numerically and narrative) systems. Following this, data gathered through document analysis and FGD were analyzed based on the specific categories set concerning the research questions.

Quantitative data were organized according to their sequences-coded, tabulated, and analyzed using statistics software (for example, correlation bivariate and descriptive statistics). The qualitative data was organized and triangulated by cross-checking all tools and evaluating the results of the quantitative findings in different ways.

2.7.1. Analysis of genetic diversity of wheat landraces

The data gathered through all the data gathering tools about the diversity of wheat landraces was analyzed systematically with quantitative (presented in numbers) and qualitative (described based on some quality) data analysis method systems. In addition, the Shannon diversity index \( H' \), is a useful measurement of diversity, and has better discriminant ability in the situation when the number of varieties and their proportional abundance remain constant [25], estimated as follows:

\[
H' = - \sum_{i=1}^{S} p_i \ln p_i
\]

where, \( S \) = total number of species, \( p_i \) = is the proportion of each Variety in the sample, \( \ln \) = log base n.

Obtained results were compared diversity indices, i.e., (low, \( H' = 1.1 \), medium, \( H' = 3.5 \) and high, \( H' = 4.5 \)) [26].

2.7.2. Sorensen similarity index

A similarity that relies on the presence or absence of the wheat landraces among sampled kebeles was measured by the Sorensen similarity index which is the most common binary similarity coefficient. The obtained results were compared with the Sorensen similarity index which should not be greater than 0.5 [26].
Sorensen's coefficient is expressed as $S_s = \frac{2a}{(2a + b + c)}$

where $a =$ number of landraces common to the two kebeles, $b =$ number of landraces unique to the first kebele, $c =$ number of landraces unique to the second kebele, often, the coefficient is multiplied by 100 to give a percentage similarity index. Dissimilarity is then computed as:

$$D_s = \frac{b + c}{(2a + b + c)}$$

or $1 - S_s$

### 2.7.3. Correlation analysis of agronomic features of wheat landraces

To examine the presence of an association between the number of wheat landraces and farmlands size, correlation analysis was computed. According to Ref. [27], a positive association is expected between large-sized farmlands and the number of wheat landraces because on wider farmlands farmers can produce more wheat landraces. Additionally, the presence of association among maturity time and productivity in kg/ha, average stem length and productivity in kg/ha, and maturity time and average stem length of wheat landraces in the study area, Pearson correlation relationship were computed using SPSS, version 16. The results were compared with standard ‘r’ values, ($r \geq 0.9 =$ very strong relationship, $0.8 \leq r < 0.9 =$ strong relationship and $0.7 \leq r < 0.8 =$ acceptable relationship [22]).

### 2.7.4. Estimation extent of on-farm genetic erosion

The present extent of on-farm genetic erosion of wheat landraces in the study area was calculated using the formula of [28] and it is given as:

$$GE = 100\% - GI$$

where $GE$ is genetic erosion and $GI$ is genetic integrity which is given as:

$$GI = \frac{N_2}{N_1} \times 100\%$$

where $N_1$ is the number of landrace varieties collected in previous times and $N_2$ is the number of presently collected landrace varieties.

### 2.7.5. Preference ranking

Preference ranking was made for 9 wheat landraces in terms of their end-use purposes by 9 key informants. Each rank was given an integer value 1-9 and the most important item was given the highest value (9), while the least important assigned the smallest value (1). The informants were given a list of wheat landraces and asked to rank them from the highest to lowest (least) in decreasing order. The rank of each variety was determined by adding up these values for all informants.

### 2.7.6. Ethical consideration

Ethical permission to undertake the study was obtained from Ambo University. An official letter for collaboration was sent to

### Table 2

Demographic characteristics of the farmers.

| Items                  | Alternatives | Respondents | Percentage |
|------------------------|--------------|-------------|------------|
| Sex                    | Male         | 120         | 89.5%      |
|                        | Female       | 14          | 10.5%      |
|                        | Total        | 134         | 100%       |
| Age in year            | 25–35        | 20          | 14.9%      |
|                        | 36–45        | 72          | 53.7%      |
|                        | 46–55        | 26          | 19.4%      |
|                        | 56 and above | 16          | 11.9%      |
|                        | Total        | 134         | 100%       |
| Educational Background | Illiterate   | 0           | 0%         |
|                        | Read/Write   | 71          | 52.98%     |
|                        | Primary      | 58          | 43.3%      |
|                        | Secondary    | 4           | 0.03%      |
|                        | Preparatory  | 1           | 0.007%     |
|                        | College      | 0           | 0%         |
|                        | University   | 0           | 0%         |
|                        | Total        | 134         | 100%       |
| Family size            | 2–3          | 13          | 9.7%       |
|                        | 4–6          | 80          | 59.7%      |
|                        | 7 and above  | 41          | 30.8%      |
|                        | Total        | 134         | 100%       |
| Farming experience in year | 1–6       | 10          | 7.5%       |
|                        | 7–12         | 37          | 27.6%      |
|                        | 13 and above | 87          | 64.9%      |
|                        | Total        | 134         | 100%       |
Digalu Tijo District Administration. Respondents were informed before conducting the interview or filling out the questionnaire voluntarily. A consent letter was attached to each questionnaire, and respondents were guaranteed that the confidentiality of their responses or private information was protected. The right of the respondent to take part or to withdraw from the interview was esteemed.

3. Results

3.1. Demographic characteristics of the respondents

Demographic Characteristics of the 134 household farmers were collected in the study area. This was based on respondents’ sex, age, educational background, family size, and farming experience in years (Table 2).

3.2. Wheat varieties cultivated by farmers

3.2.1. Modern wheat varieties

A total of 34 wheat varieties were documented. Among these, only 7 (20.7%) types of improved wheat varieties were grown mainly in the study area presently. These were described by farmers based on their phenotypic traits (for example, seed color, and plant height), maturity time, end-uses quality, and yield in quintals per hectare (Table 3).

3.3. On-farm genetic diversity of wheat landraces

3.3.1. Genetic diversity of wheat landraces

A total of 27 wheat landraces were identified by farmers of the three sampled kebeles of the study area. From those identified landraces, 18 (66.6%) of them were lost and only 9 (33.3%) are being cultivated presently by farmers.

3.4. Distribution of existing wheat landraces

Of currently being cultivated wheat landraces in the study area, ‘Qamadiguracha’ is the most frequently cultivated and common to three sampled kebeles; whereas ‘Ganabasi’ was the least and rarely cultivated; ig. 2.

3.4.1. Analysis of wheat landraces diversity by Shannon index

The diversity of wheat landraces was estimated based on the number of varieties collected. As a result, the Gushatemala kebele showed the highest diversity (\(H = 1.37\)) followed by Digalubora kebele (\(H = 1.32\)). Burkitu kebele was found to be less diverse in terms of the number of varieties collected in this study area (\(H = 1.09\)) (Table 4).

3.4.2. Sorenson similarity index of the wheat landraces

The Sorenson similarity index was used to detect similarities of wheat landraces among the three sampled kebeles of the study area. More similarity coefficient (0.33) was observed in the group of landraces at Digalubora and Burkitu kebeles. Less similarity index (0.25) was observed between Gushatemala and Burkitu (Digalubora) kebeles (Table 5).

3.4.3. Correlation analysis between wheat landraces distribution and farmland

3.4.3.1. Sizes. The distribution of wheat landraces and the size of farmlands in the study area was 78% related and the relationship is a strong positive and significant (\(p = 0.01\)) (Table 6).

Regarding the correlation analysis of some agronomic features for wheat landraces, the stem length and maturity time had a significant positive correlation (\(p \leq 0.01\)), and the productivity in quintal per hectare was also positively correlated with maturity time and significant at (\(p \leq 0.05\)). However, productivity per hectare was negatively corrected with stem length (Table 7).

Table 3

| No | Name of wheat variety | Introduced year | Seed color | Productivity/kg/ha | Average Stem length | Maturity time (month) | End-uses                  |
|----|-----------------------|-----------------|------------|---------------------|---------------------|-----------------------|--------------------------|
| 1  | ‘Manigudo’            | 2007            | White      | 37,000              | 58.36 cm            | 5                     | beverage                |
| 2  | ‘Digalu’              | 1997            | White      | 38,690              | 68.54 cm            | 4                     | Bread/gruel             |
| 3  | ‘Hidase’              | 2008            | White      | 42,140              | 57.47 cm            | 4                     | Bread/kollo             |
| 4  | ‘Dhakeba’             | 2003            | White      | 38,240              | 62.12 cm            | 4                     | Bread/’Mulu’            |
| 5  | ‘Fuse’                | 2001            | White      | 32,100              | 58.57 cm            | 4                     | Bread/bever             |
| 6  | ‘Ogolcho’             | 2006            | White      | 35,100              | 73.15 cm            | 4                     | Bread/injera            |
| 7  | Kingsberg             | 2008            | White      | 423,600             | 62.19 cm            | 4                     | Bread/gruel             |
3.5. Vernacular name and agronomic characteristics of wheat landraces

Farmers described wheat landraces based on phenotypic traits (for example, seed color, and plant height), maturity time, end-use quality, and agronomic characteristics. For instance, white-colored wheat seeds (for example, “Israeli”); purple/red colored varieties of seeds (for example, “Keeyi”); black-colored varieties of wheat seeds (for example, ‘Qamadiguracha’) but ‘Fatate’ have the mixture of...
white and black colored wheat seeds; see Fig. 3(A, B). Furthermore, wheat landraces reached maturity between 4 and 6 months, and they were purposively used for different end-use purposes (for example, for making bread, ‘injera’, gruel, beverages, etc.) (Table 8).

‘Qamadi guracha’ has black seeds and long hulls in phenotypic; Fig. 4. Its introduction year was not known and reached maturity at 5 months into the study area. According to the farmers, these landraces are the most drought, pests, and disease-resistant. Additionally, farmers ‘Qamadi guracha’ is most preferred for making bread, ‘injera’, gruel, and beverage. Furthermore, it has good qualities of straw and shelf life than other wheat landraces (Table 8).

‘Bondi’ has hulls, white seeds, and no spikes Fig. 5(A, B). Its introduction year into the study area was not known. According to respondents, ‘Bondi’ can tolerate drought and low soil fertility conditions; therefore, it gives better yields than other landraces such as ‘Qamadi guracha’. The flour of ‘Bondi’ is used for making ‘injera’ and bread of good taste and quality, and homemade porridge.

‘Israeli’ is non-spikes, white wheat has big seeds and a similar plant stands as ‘Bondi’. As a result, some farmers had confused this landrace with ‘Bondi’ and only experienced farmers could discern the difference between the two landraces Fig. 6(A, B). It was introduced into the study area in 1967. According to respondents, agronomically, this landrace requires fertile soils; susceptible to drought and cold and it loses easily the hulls as drying. It reached maturity in five months. Additionally, bread made from ‘Israeli’ is regarded by the farmers as good as that made from modern wheat. Its grains were also preferred for making ‘aka’i or kollo in the study area.

‘Keeyi’, which is also known as ‘Qamadi dima’ meaning ‘red –wheat’, has hulls and small spikes Fig. 7 (A, B). According to the farmers, this landrace was introduced into the study area in 1983. Concerning the agronomic characteristics of ‘Keeyi’, it was widely adapted to disease, drought, pests, and low soil moisture; it is usually grown at the end of the rainy season on residual moisture. Moreover, ‘Keeyi’ was used for making the beverage, ‘injera’, and bread in the study area (Table 8).

‘Eskirimo’ is non-spikes, has red seeds, and a long stem length that measured about 59.9 cm Fig. 8(A, B). It was introduced into the study area in 1979. Farmers also responded that this wheat landrace was tolerant to drought and lodging; it had a long maturity period of about six months and yielded about 24.36 quintals per hectares per year. ‘Injera’ made from ‘Eskirimo’ was regarded by the farmers as good as that made from barley. Its flour was also preferred for making bread in the study area.

‘Inkoye’, which is also red–seeded, has hulls; Fig. 9(A, B). It was introduced into the study area in 1959 E. C. The Farmers, DA workers, and district Agricultural Experts reported that ‘Inkoye’ had better adaptation to lodging, low fertile soils, diseases, and cooler temperatures in the study area. Its maturity time, average stem length, and productivity per hectare per year were five months, 64 cm, and 32 kuintals/hectare respectively. It was mainly used for the preparation of bread, beverage, ‘injera’, and rarely for making gruel (Table 8).

‘Fatate’ (‘Sergagna’), which is the black and white seeded, has hulls and long spikes (Fig. 10). Most farmers of the survey area reported that ‘Fatate’ can reach maturity in five months and is mainly grown at high altitude areas of the study area. It could resist lodging and pests and need black soil. The straw of ‘Fatate’ was used for traditional roofing and fodder for animals. This wheat landrace was also highly preferred for making bread, ‘injera’, and beverage (Table 8).

‘Ganabasi’, which is the wheat landrace, has white seeds (Fig. 10). Most farmers in the survey area reported that ‘Ganabasi’ could reach maturity in five months. Nevertheless, farmers from Burtitu reported that this landrace needs only about four months until maturity presumably because of lower altitude, warmer temperature, and faster development in the kebele. The fertile soil was required for better yields. Despite its height, lodging is not a problem. ‘Ganabasi’ was highly preferred for making ‘injera’ and beverage in the study area (Table 8).

‘Bokake’, which is blackish-seeded, has short spikes and red-hulls. It was introduced into the study area in 1964. The majority of the farmers in the study area reported that ‘Bokake’ reached maturity in five months. It could resist lodging and pests. It needs black soil and be sowed with barely. It was used for making bread, ‘Kollo’, beverage, and gruel (Table 8).

3.5.1. Preference ranking of wheat landraces in terms of end-use purposes

Key informants ranked the nine wheat landraces based on their end-use purposes by giving 9 for most valuable and 1 for least
valuable. The scores given to each landrace as per informant preference were added and ranked. Consequently, ‘Kamadi guracha’ was ranked first and ‘Eskirimo’ preferred least in terms of end-use purposes (Table 9).

3.6. On-farm genetic erosion and its causes of wheat landraces

3.6.1. The extent of on-farm genetic erosion of wheat landraces

Many farmers (97.8%) and DA workers replied that the number of landraces has been decreasing starting from the last 20 years up to 2017. As a result, from a total of 27 wheat landraces that were listed by farmers, 18 of them were lost and they were reduced to 9 landraces that are being cultivated on the site presently (Table 9).

3.6.2. Factors responsible for the genetic erosion of wheat landraces

In the present study, about 67(50%), 34(25.4%), 17(12.2%), and 10 (7.5%) of farmers responded the majority of wheat landrace had been lost due to four main factors: relatively low productivity of wheat landraces, the introduction of modern wheat variety or

### Table 8
Preference ranking for wheat landraces in their end-uses (1–9): (9, for most Preferred and 1, for least preferred).

| Vernacular Name of wheat landraces | Key informants | Score | Rank |
|-----------------------------------|----------------|-------|------|
| 'Inkoye'                          | 2 6 8 9 3 4 7 8 1 | 50    | 6    |
| 'Keeyi'                           | 8 7 2 9 8 7 1 5 5 | 54    | 5    |
| 'Qamadiguracha'                   | 9 9 8 9 8 8 4 8 81 | 1     |
| 'Bondi'                           | 1 5 9 7 2 9 4 7 9 | 57    | 4    |
| 'Bokake'                          | 3 9 7 5 9 6 6 7 65 | 2     |
| 'Fatate'                          | 4 8 6 6 7 5 3 3 4 | 51    | 7    |
| 'Israelii'                        | 9 6 3 4 1 9 5 8 9 | 61    | 3    |
| 'Ganabasi'                        | 5 2 1 3 4 3 2 9 2 | 41    | 8    |
| 'Eskirimo'                        | 6 3 8 1 5 2 7 1 3 | 37    | 9    |

Fig. 4. The non-spikes, ‘Bondi’.

Fig. 5. ‘A’ seeds of Isira’el and ‘B’- Israeli with hulls.
hexaploid wheat (example, ‘Hidase’ and ‘Digalu’), the introduction of other more productive crops (example, barley, and maize), and land degradation/soil infertility/respectively (Table 10, see also [29]; the preprint manuscript available online at https://www.biorxiv.org/content/10.1101/2022.03.07.483220v1). In addition to this, the document analysis also showed that more frequent
Fig. 9. ‘A’- ‘Fatate’ seeds; ‘B’-Fatate with straw.

Fig. 10. Seed of ‘Ganabasi’ wheat landrace.

Table 9
List of lost and existing wheat landraces.

| No | Name of lost wheat landraces | Name of existing wheat landraces | Total |
|----|------------------------------|---------------------------------|-------|
| 1  | ‘Salamayo’                   | ‘Qamadi guracha’                |       |
| 2  | ‘Dashini’                     | ‘Inkoye’                        |       |
| 3  | ‘Babani’                      | ‘Fatate’                        |       |
| 4  | ‘Holande’                     | ‘Bondi’                         |       |
| 5  | ‘Shukar’                      | ‘Israeli’                        |       |
| 6  | ‘Keniya’                      | ‘Ganabasi’                       |       |
| 7  | ‘Butuji’                      | ‘Eskirimo’                       |       |
| 8  | ‘Galama’                      | ‘Keeyi’                          |       |
| 9  | ‘Wabe’                        | ‘Bokake’                         |       |
| 10 | K-6290-Balk                   |                                 |       |
| 11 | ‘Itana’                       |                                 |       |
| 12 | ‘Lakach’                      |                                 |       |
| 13 | ‘Hayibo’                      |                                 |       |
| 14 | ‘Ingilizi’                    |                                 |       |
| 15 | ‘Romani’                      |                                 |       |
| 16 | ‘Firustana’                   |                                 |       |
| 17 | ‘Shorima’                     |                                 |       |
| 18 | ‘Mitike’                      |                                 |       |
| Total | 18                          | 9                                | 27    |
occurrences of cold temperatures and changes in market prices were the factors that might cause the loss of wheat landraces from the survey site (see Table 11).

3.7. Factors that contribute to on-farm conservation of wheat landraces

About 46%, 28%, and 26% of farmers responded that the food quality, market value, and resistance to a pest, birds, and diseases of wheat landraces were the major factors that made them preserve the wheat landraces on their farmlands respectively (Table 12). Additionally, document analysis indicated that the big seed size, long shelf life, and straw quality of some landraces were moderate incentives that made some farmers conserve them.

3.8. Major bottlenecks influencing the conservation of wheat landraces

According to the 52(38.8%), 31(23.1%), 23(17.2%), and 21 (15.6%) respondents, seed selection system, insufficient crop yields, insufficient land holding, and soil infertility were major bottlenecks that hindered the conservation of wheat landraces in the study area respectively (Table 13).

3.9. Farmers’ roles to conserve wheat landraces for future

According to the respondents, the major and least factors contributing to the future conservation of wheat landraces were re-sowing on farmlands using organic fertilizers (manure, compost, etc.) and on-farm seed selection respectively (Table 14).

3.10. The naming of wheat landraces

Farmers in the study area used to name the wheat landraces varieties by using seed color, maturity time, and food quality which have their meanings. For instance, ‘Kamadi guracha’ (Afaan Oromo) was named after its black seed color. ‘Inkoye’ was named after its very small seed, which usually has good food quality. ‘Ganabasi’ (Afaan Oromo see Fig. 10(A, B) was named a ‘winter – crosser’ meaning it could be used in the winter season due to its surplus. ‘Bokake’ (Afaan Oromo) was named after it ‘expands’ while its seeds are cooked. Likewise, ‘Fatate’ (Amharic) means a mixture of white and black seeds of wheat landraces. Bondi (Afaan Oromo) was named after its market value which could buy ‘boundi or birr’; see Fig. 2.

4. Discussion

In total, 27 wheat landraces were reported to be grown two decades up to now. Of these, only 9 wheat landraces are still cultivated by farmers. Among these available landraces, ‘Qamadi guracha’ is the most common in the study area. The computed Shannon diversity index of currently growing wheat landraces ranges from 1.09 to 1.37 among the groups. This shows that there was a highly diverse wheat landrace at present in the study area relatively. The estimated genetic erosion for wheat landraces was found to be 66.7% due to major factors: the introduction of modern wheat varieties; the introduction of other more productive crops; landraces low productivity; and infertility of soil. Food quality, Pests (for example, birds and insects), disease resistance, market value, and straw quality were factors that initiated the farmers to maintain the genetic diversity of landraces. However, the Preservation of these landraces is influenced by bottlenecks like seed selection systems, soil infertility, and insufficient crop yields.
In the present study, in total 27 wheat landraces were identified that had been cultivated in the past 20 years to the present from the sampled kebeles in Digalu and Tijo districts of Arsi Zone. Similarly, Faris Hailu [30] indicated that there was a rich diversity of wheat landraces, which contained 15 to 37 varieties, in the Arsi highlands. About 26 wheat landraces were nearly identified by Tesfaye [31] from Akaki and Lume Districts of East Shoa, and [32] also discovered 20 different landraces from Ambo and Dandi of West Shoa. Furthermore, 21 durum wheat landraces, 11 of which were collected from North Shoa and the remaining 10 from Bale [14,33].

The Shannon diversity index of wheat landraces was estimated based on the number of varieties collected. Accordingly, the Gushatemala kebele showed the highest diversity ($H'=1.37$) followed by Digalubora kebele ($H'=1.32$). Burkitu kebele was found to be less diverse in terms of the number of varieties collected in this study area ($H'=1.09$). Similarly, Brown [1] indicated that the diversity estimated based on several wheat landraces (Shannon diversity index), Arsi has a higher diversity index ($H'=1.31$) than other Ethiopian wheat-producing areas such as North Shoa.

Sorenson similarity index among wheat landraces of the study area ranged from 0.25 to 0.33 which is not above 0.5. This indicated that there were low similarities in wheat landraces composition among the study kebeles; and also implied that there were wheat landraces diversity in Digalu and Tijo districts of Arsi Zone. The existence of low similarities among wheat landraces implied that all the kebeles are important in terms of the diversity of wheat landraces. This finding can be confirmed that the low similarity index existence among landraces indicated that the diversity of wheat landraces and related to dissimilar habits for growing and human selection on landraces [26]. On the other hand, the correlation analysis of the distribution of wheat landraces and the size of farmlands in the study area was 78% correlated. The relationship was acceptable and positive because the ‘r-value is between 0.7 and 0.8. According to Bishaw [27], a positive association is expected between large-sized farmlands and the number of wheat landraces because on wider farmlands farmers can produce more wheat landraces.

The correlation analysis of some agronomic features (between stem length and maturity, productivity in kg per hectare and maturity time, productivity in quintal per hectare, and stem length) for wheat landraces was done. In this line, the stem length and maturity time had a significant positive correlation ($p \leq 0.01$). In the same way, productivity in kg per hectare was positively correlated with maturity time and significant at ($p \leq 0.05$). This finding can be confirmed that the longer the maturity time, the higher the grain yield of wheat landraces which indicates a positive correlation between the two [27]. However, productivity in quintal per hectare was negatively correlated with stem length and number of wheat landraces. A similar finding was reported by Ref. [34] that the grain yield is negatively correlated with the average stem length of Ethiopian wheat landraces.

The study showed wheat landraces with diverse morphological features (e.g. seed color, stem length, and head appearance). For example, landraces such as ‘Inkoye’, ‘Eskirimo’, and ‘Keeyi’ have red/purple seed color whereas ‘Kamadiguracha’ and ‘Bokake’ have
Black/blackish colored seeds but ‘Fatate’ is a mixture of white and black colored seeds. Similarly, Zeven [35]; in the study conducted in the central and southeastern highlands of Ethiopia, indicated that a purple color seed was originally only found in cultivated wheat landraces of Ethiopia. Some wheat landraces have no spikes whereas others have very long spikes; some are big-seeded but others have small seeds. Moreover, there are specific endemic characteristics for some of the tetraploid wheat species in Ethiopia, such as big grain, spikeless or with spikes, and beardless or half-bearded hard durum wheat [15,36].

On the other hand, the wheat landraces exhibited differences in other agronomic characteristics. Some were adapted to less fertile soils, whereas others need fertile soil; others exhibited differential responses to diseases, pests (for example, insects and birds), adaptation to soil infertility, and lodging. This is similar to the idea stated as “in history, Ethiopian tetraploid wheat landraces, disease, pest, drought resistance and other stresses, adaptation to low soil fertility and other characteristics are the useful agronomic remarks exhibited by them” [37]. Tesemma et al. [38] also stated that Ethiopian wheat landraces are usually mixtures of different agro-types having wider gene pools within one population that make them to adapt the change of climatic and edaphic factors.

Moreover, Key informants ranked the nine wheat landraces based on their end-use purposes by giving 9 for most valuable and 1 for least valuable in the study area. In this line, ‘Qamadi guracha’ was ranked first and ‘Eskirimo’ was preferred least. This indicated that ‘Qamadi guracha’ is the most valuable in making end-use products such as bread, ‘injera’, beverage, gruel, and broth in the study area. This finding re-affirmed that some landraces such as ‘Tikur sende’ are used for a specific purpose such as for brewing local beer or spirits; as a result, therefore, it can be ranked at the top of others in North Shoa of Amhara region [5,27].

In the current study, the number of wheat landraces has been decreasing from the last 20 years up to this year (2017) from 27 to 9 in the study area. Consequently, the overall on-farm loss (genetic erosion) of wheat landraces diversity in the survey area was found to be 66.6% (Table 10). A similar scenario was indicated by Negash [32] from West Shoa that the genetic erosion of landraces was found to be 75.0% and 61.5%, for Ambo and Dandi districts respectively; and [30] also discovered the overall genetic erosion in the in Ethiopia, 32.0%, 35.3%, 55.9%, 84.4%, and 84.0% erosion was found for $T. durum$, $T. turgidum$, $T. aestivum$, $T. polonicum$, and $T. dicoccon$ respectively. In this study, the estimated level of genetic erosion was 66.6% which is higher than species that are said to be genetically eroded (i.e., $GE = 23-43$%) (IBC, 2001). Furthermore [39], argued that a loss of diversity of landraces implies a big threat to the reduction of the pool of genetic material available for breeding to enhance productivity and ensure environmental stability.

In this study, the major factors responsible for the genetic erosion of wheat landraces were low productivity of landraces, the introduction of improved wheat varieties (for example, ‘Digalu’ and ‘Hidase’), the introduction of other more productive crops (for example, barley), and infertility of soil/land degradation. The previous study [30] reported that the most important factors for loss of landraces were reduction in land size (cultivated area), displacement by released/modern varieties of hexaploid wheat and teff, reduced benefit from the landraces, and displacement by other crops and chat in Ethiopia. Other factors like climate change and the long maturity time of landraces were also causes of genetic erosion of wheat landraces in the Ambo and Dandi Districts [32]. In addition, drought is also one factor of genetic erosion in tetraploid wheat landraces, especially in the eastern part of Ethiopia [15,16].

In the present study, the major factors responsible for the continued cultivation of wheat landraces by the farmers were: food quality, pest resistance, and market value. Additional minor factors such as seed size, long shelf life, and straw quality were moderate incentives that made the farmers conserve the wheat landraces. Similarly, Geleta and Grausgruber [32] explained that many farmers initiated to conserve of some wheat landraces might be due to their unique end-use quality and wide adaptation to changing environments that are obtained from wheat landraces but not from improved varieties. For these reasons, the majority of the farmers were committed to conserving the genetic diversity of wheat landraces for the future in in-situ by re-sowing on farmlands, saving/managing seeds for the future, and using organic fertilizers. Similarly, Eticha et al. [40] argued that sustained on-farm conservation, saving for the future and sustainable utilization will ensure the continuous conservation of wheat landraces in Ethiopia.

Insufficient land holding, a seed selection system, and insufficient crop yield were major bottlenecks that influence the conservation of wheat landraces by farmers. This finding agrees with Teshoma [41] who indicated that the poor yield of the landraces and short rainy season period since most landraces are long maturing types would inhibit continuous production of the wheat landraces in some regions of Ethiopia [42]. also explained that the expansion of improved bread wheat varieties and low soil fertility would inhibit the continuous production of wheat landraces in Ethiopia. In addition, Wheat is the most dependable crop for resource-poor highland farmers where poor soil fertility, frost, waterlogging, soil acidity, and soil degradation are the major yield-limiting factors, and where other cereals fail to grow [43].

Vernacular or local names were given for wheat landraces by farmers and have their meanings. For instance, ‘Qamadiguracha’ (Afaan Oromo) is named after its black seed color, ‘Inkoye’ is named after its very small seed, which usually has good food quality. ‘Kenya’ most probably this variety is named after its original seed source. The names are simple and easily understood by farmers and are also important to maintain the identity of varieties. Gelata and Grausgruber [32] indicated that the wheat landraces could be named based on their seed colors, food quality, the appearance of the head, and local name.

5. Conclusion

Digalu and Tijo is the district with diverse wheat landraces cultivation area of Arsi Zone, Ethiopia. Of these, wheat landraces growing in Dega kebeles were found to be more diverse with an overall $H^’$ value (1.34) than those collected from Woynadega kebeles with $H^’$ value (1.09). Of 27 wheat landraces identified by farmers, only 9 landraces are cultivated presently. Among the available wheat landraces, ‘Qamadiguracha’ is predominantly grown in the district due to its high-end-use qualities. The overall genetic erosion in wheat landraces reached 66.6% in Digalu and Tijo districts. The loss of wheat landraces was accounted to major factors: the introduction of modern wheat varieties; the introduction of other more productive crops; landraces’ low productivity; and the infertility of soil. Food quality, Pests (for example, birds and insects), disease resistance, market value, and straw quality were factors...
that initiated the farmers to maintain the diversity of wheat landraces. However, the Preservation of these landraces is influenced by bottlenecks like seed selection systems, soil infertility, insufficient crop yields, and short rainy seasons.

6. Recommendation

The regeneration of soil fertility alongside the re-introduction of lost landraces; improvement of landraces, on-farm conservation (in-situ) by re-sowing, saving of seeds for the future, seed bank conservation (ex-situ) are suggested for the restoration of wheat landraces diversity in DigaliTijo District.

Authors’ contribution

Author 1: Played role in conceiving and designing the experiments; performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Author 2: Played role in conceiving and designing the experiments; performed the experiments; analyzed and interpreted the data; contributed reagents, materials, analysis tools or data; wrote the paper.

Author 3: Played role in conceiving and designing the experiments; performed the experiments; analyzed and interpreted the data; contributed reagents, materials, analysis tools or data; wrote the paper.

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Declaration of competing interest

I, the corresponding author verified that there is no competing interest in this manuscript.

Appendix A. Supplementary data

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