**Climate Smart Agriculture through Adaptation and Participatory Technology Evaluation of Improved Bread Wheat Variety in the Dry Low- and Mid-land Parts of Waglasta Zone, Ethiopia**

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**Abstract**

The experiment was conducted to evaluate and promote lowland (heat-tolerant) and midland improved wheat varieties with the participation of farmers, thereby creating awareness and demand about the new wheat varieties in the target areas. About twenty-two bread wheat varieties—eight varieties were evaluated in the lowland areas of Abergele and the rest of them were evaluated in the midland areas of Sekota under the 2021 irrigation season. Both sets were conducted using RCBD design. From these trials, four varieties with a standard check of the Sekota-1 variety were advanced for participatory technology trials at Sekota and Lalibela districts in the 2023 irrigation season. The promotion trial was accomplished using a simple or single block design. FREG members were selected purposefully to include all social segments of the community, with female participants of 20 %. The performance of varieties in the two sets of experiments showed a highly significant difference (p <0.01) among treatments in most of the traits. In the lowland set of the experiment, Gambo, Fentale-1, and Fentale-2 performed best over the other varieties. Sora, Tay, and Deka showed good performance in the majority of the traits evaluated in the experiment. In yield and other important traits, Fentale-2 showed consistent performances; grain yield was 1962.8 kg/ha and 2960 kg/ha both in adaptation trail and technology promotion programs, respectively. In addition, the farmers also selected Fentale-2 as first over other advanced varieties in both locations. Therefore, the Fentale-2 variety should be pre-scaled up and recommended for Abergele, Sekota, Lalibela, and similar agroecologies in irrigation season.

Key words: Adaptation, Heat tolerant, Lowland, Midland, Promotion

**Introduction**

Wheat is the most widely cultivated cereal crop in the world, providing 8% of primary main crop commodities production in the world, and is cultivated on 219 million hectares of land with 770.9 million tons produced (FAO, 2023). Ethiopia is one of the wheat producing countries in Africa, next to South Africa. Wheat is the fourth largest cereal crop produced by more than four million smallholder farmers, which accounts for14.62% of the grain crop area in the country (Central Statistical Agency, 2021). Wheat is also produced by more than 4.5 million smallholder farmers on 1.9 million hectares of land in Ethiopia and in the Amhara region, wheat is also produced by 1.9 million smallholder farmers on more than half million hectares of land with an average productivity of the country and the region of 3046 kg/ha and 2831 kg/ha, respectively (CSA, 2021). Wheat is growing mostly in the mid- and high-land areas of Ethiopia, which have adequate rainfall and altitude ranges of 1900 - 2300 and 2300 - 2700, respectively (Tariku *et al*., 2022). In recent years, Ethiopia has initiated a project to scale out irrigated wheat in the lowland and midland areas during offseason production. The overall potential of the country’s irrigable land has been reached to 3.7 million hectares, 5 % of which has been under irrigation (Descheemaeker, 2014). The irrigation potential and access are higher all over Ethiopia, particularly in the low-land part of the country, but the exploitations of this potential lower share of the country’s economy as compared to the rest of the world (Hordofa *et al*., 2008). The production of bread wheat under irrigation has a positive impact on livelihoods by diversifying the dietary consumption of each household, but the income of the household has not yet increased (Nigussie *et al.*, 2015). The im00000portance and demand for wheat products are expected to double in the future, which might worsen the import burden on the country. It is also an important staple food crop in Ethiopia; 12% of daily per capita consumption accounts for 75% of the population in the diets of several Ethiopians, providing approximately 15% of the caloric intake for the country’s over 90 million people (FAO, 2015; Descheemaeker, 2014). Wheat is used as the local main food of enjera as well as Qolo, Tella, Dabokolo, Genfo, and bread beyond industrial input for pasta and macaroni products *(*Nigussie *et al*., 2015). In addition, wheat straw is used as a feed for animals in agro-pastoralist communities. Wheat cropping is at risk from new and more aggressive pests and diseases, diminishing water resources, limited available land, and unstable weather conditions owing to climate change (CIMMYT, 2016). As a result, the government of Ethiopia focuses on improving the production and productivity of wheat crops in both irrigation and rainfed production seasons and increasing wheat market linkage *(IFPRI*, 2015). Hence, the government plans to substitute the import of wheat products by 2025 through domestic products, which could save about three million dollars of foreign currency from importing wheat products. To boost wheat productivity, the government is striving to cultivate wheat in different agroecologies including the dry lowland areas of the country, by which wonderful results have been recorded.

Participatory technology evaluation has several advantages: it amplifies crop production and productivity, accelerates the adoption rate of varieties, and facilitates farmers learning and empowerment of technologies (Grandgirard *et al*., 2002). The techniques of improved varieties to be promoted and adopted by farmers are through assessing the requirement and availability of land races in the hands of the farmers, participatory rural appraisal, and participatory variety technologies (Witcombe *et al.*, 1996). Although wheat is essential for diverse item of home food preparation, there is still an imbalance between supply and demand, which forces the country to spend foreign currency for a long period of time importing wheat products. The problem of low wheat production and productivity potential in the country is associated with soil fertility and erratic rainfall, particularly biotic and abiotic stresses generally (Kidane *et al*., 2023). Therefore, evaluating, selecting and promoting heat-tolerant and improved wheat varieties with the participation of farmers; thereby creating awareness and demand about the new wheat varieties in the target areas were the main objectives of this finding.

**Materials and Methods**

**Adaptation trial**

**Description of the study areas**

The adaptation trial was conducted in the lowland area of Abergele (Belitarif or set I) and the midland area of Sekota (woleh or set II) during the 2021 irrigation season. Sekota is located in 12°, 32', 03.62'' N and 39°, 03', 22.62'' E with altitude 2070 m.a.s.l., and Abergele is located at 12°, 53', 43.05'' N and 38o, 56', 39.76'' E with altitude 1334 m.a.s.l. Lalibela is also located at 12°, 03', 05.24'' N and 39°, 02', 27.62'' E, with an altitude 2177 m.a.s.l. (Figures 1 and 2).

Table 1: Weather condition of Trial sites (Abergele, Sekota and Lalibela) in 2021 and 2022

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Location | Parameters | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| Abergelle 2021 | RH | 38 | 43.25 | 31.5 | 37.5 | 55.38 | 49.25 | 82.12 | 81.06 | 72 | 66.69 | 55.94 | 51.38 |
| WS | 2.2 | 2.11 | 3.18 | 2.75 | 1.97 | 2.61 | 1.73 | 1.55 | 1.86 | 2.18 | 2.06 | 2.18 |
| Max T° | 31.04 | 32.58 | 34.92 | 34.87 | 32.96 | 34.08 | 26.62 | 27.07 | 28.28 | 26.83 | 28.12 | 29.88 |
| Min T*°* | 10.43 | 11.83 | 12.99 | 15.81 | 15.91 | 15.96 | 14.95 | 15.25 | 12.69 | 12.51 | 12.16 | 9.4 |
| Mean T*°* | 20.735 | 22.205 | 23.955 | 25.34 | 24.435 | 25.02 | 20.785 | 21.16 | 20.485 | 19.67 | 20.14 | 19.64 |
| C Amount | 7.42 | 35.55 | 21.23 | 55.23 | 59.56 | 56.79 | 86.04 | 75.31 | 58.34 | 48.55 | 23.74 | 14.19 |
| UV-index | 6.23 | 6.18 | 7.42 | 6.59 | 6.4 | 6.2 | 4.91 | 5.61 | 6.21 | 6.13 | 5.97 | 5.93 |
| Sekota 2021 | RH | 40 | 44.5 | 35.12 | 40 | 53.81 | 48.94 | 80.06 | 76.94 | 65.19 | 61.62 | 52.25 | 49.94 |
| WS | 2.79 | 2.42 | 4.01 | 3.5 | 2.56 | 2.98 | 2.29 | 1.75 | 2.2 | 3.16 | 3.01 | 2.86 |
| Max T° | 27.93 | 29.56 | 31.25 | 30.96 | 30.15 | 31.22 | 25.58 | 24.94 | 26.23 | 24.99 | 26.93 | 28.01 |
| Min T*°* | 12.88 | 13.58 | 13.95 | 16.94 | 16.96 | 16.94 | 14.7 | 15.5 | 15.96 | 14.23 | 14.1 | 11.19 |
| Mean T*°* | 20.405 | 21.57 | 22.6 | 23.95 | 23.555 | 24.08 | 20.14 | 20.22 | 21.095 | 19.61 | 20.515 | 19.6 |
| C Amount | 8.82 | 43.77 | 14.78 | 46.28 | 52.26 | 53.17 | 85.36 | 75.24 | 58.44 | 49.94 | 27.81 | 16.07 |
| UV-index | 6.23 | 5.9 | 7.49 | 6.83 | 6.38 | 6.3 | 4.59 | 5.46 | 5.92 | 5.85 | 5.84 | 5.86 |
| Sekota 2022 | RH | 57.19 | 49.38 | 41.12 | 40.75 | 35.94 | 53.94 | 79.56 | 79.12 | 67.31 | 61.62 | 50.56 | 48.62 |
| WS | 2.52 | 2.86 | 3.66 | 3.38 | 3.41 | 2.89 | 2.12 | 2.38 | 2.37 | 3.05 | 3.02 | 2.45 |
| Max T° | 26.29 | 29.53 | 31.36 | 30.99 | 31.99 | 32.14 | 24.52 | 25.12 | 25.75 | 25.19 | 26.43 | 27.29 |
| Min T*°* | 12.94 | 15.55 | 16.07 | 16.85 | 18.68 | 16.8 | 15.6 | 15.48 | 16.23 | 14.66 | 14.09 | 13.69 |
| Mean T*°* | 19.615 | 22.54 | 23.715 | 23.92 | 25.335 | 24.47 | 20.06 | 20.3 | 20.99 | 19.925 | 20.26 | 20.49 |
| C Amount | 39.43 | 34.38 | 26.99 | 33.97 | 22.58 | 63.93 | 85.59 | 85.1 | 66.04 | 38.7 | 16.12 | 37.95 |
| UV-index | 5.48 | 6.3 | 6.91 | 6.97 | 6.95 | 5.74 | 4.62 | 4.67 | 5.51 | 5.97 | 6.07 | 5.07 |
| Lalibela 2022 | RH | 58.94 | 53.38 | 45.31 | 45.5 | 39.69 | 55.5 | 78.94 | 79 | 68.69 | 63.88 | 52.31 | 51.69 |
| WS | 2.48 | 2.62 | 3.36 | 3.39 | 3.51 | 3.3 | 2.54 | 2.65 | 2.68 | 3.12 | 2.94 | 2.28 |
| Max T° | 22.99 | 26.14 | 27.95 | 27.75 | 28.66 | 28.67 | 21.96 | 21.58 | 22.56 | 22.25 | 23.45 | 24.33 |
| Min T*°* | 10.9 | 12.69 | 12.99 | 13.98 | 15.55 | 14.83 | 13.57 | 13.4 | 14.46 | 11.8 | 11.7 | 11.26 |
| Mean T*°* | 16.945 | 19.415 | 20.47 | 20.865 | 22.105 | 21.75 | 17.765 | 17.49 | 18.51 | 17.025 | 17.575 | 17.795 |
| C Amount | 39.43 | 34.38 | 26.99 | 33.97 | 22.58 | 63.93 | 85.59 | 85.1 | 66.04 | 38.7 | 16.12 | 37.95 |
| UV-index | 5.48 | 6.3 | 6.91 | 6.97 | 6.95 | 5.74 | 4.62 | 4.67 | 5.51 | 5.97 | 6.07 | 5.07 |

*Where; RH – Relative Humidity in percent; WS – Wind speed in meter per second; Max T - Maximum Temperature in °C ; Min T - Minimum Temperature in °C; Mean T-Mean Temperature in °C, C Amount – Cloud Amount in percent ; UV-index - All Sky Surface UV Index*

Source: National Meteorology Service Agency (NMSA) report in 2021 and 2022

*Where; RH – Relative Humidity in percent; WS – Wind speed in meter per second; Max T° - Maximum Temperature in °C ; Min T° - Minimum Temperature in °C; Mean T°-Mean Temperature in °C, C Amount – Cloud Amount in percent ; UV-index - All Sky Surface UV Index*

**Figure 1: Graphical representation of trial sites weather condition in 2021 and 2022**



Figure 2: Map of the experimental areas

**Planting Materials**

Twenty-two commercially available bread wheat varieties were evaluated in two set at two locations. Of these, eight varieties were evaluated in the lowland area of Abergele which were released as heat-tolerant varieties for the irrigation production season. The remaining 14 varieties were evaluated in the mid-land area of Sekota during the 2021 irrigation season, which was released for rainfed production seasons (Table 1). These sets of experiments were conducted based on the characteristics of the varieties and their agro-ecological range (Table 2).

Table 2: List of released bread wheat varieties

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| No. | Genotype | Year of released  | Target agro ecology | Released for | Source  | Testing area for  |
| Adaptation  | PTE |
| 1 | Amibara1 | 2015 | Lowland | Irrigation season | Werer | Abergele |  |
| 2 | Amibara2 | 2017 | Lowland | Irrigation season | Werer | Abergele |  |
| 3 | Ardi  | 2019 | Lowland | Irrigation season | Werer | Abergele |  |
| 4 | Fentale1  | 2015 | Lowland | Irrigation season | Werer | Abergele |  |
| 5 | Fentale 2 | 2017 | Lowland | Irrigation season | Werer | Abergele | Sekota, Lalibela |
| 6 | Gambo  | 2011 | Lowland | Irrigation season | Werer | Abergele | Sekota, Lalibela |
| 7 | Luci  | 2013 | Lowland | Irrigation season | Werer | Abergele |  |
| 8 | Werer 2  | 2013 | Lowland | Irrigation season | Werer | Abergele |  |
| 9 | Alidero  | 2007 | Midland | Rain-fed  | Holeta  | Sekota |  |
| 10 | Adet -1 | 2020 | Mid/highland | Rain-fed  | Adet | Sekota | Sekota, Lalibela |
| 11 | Deka  | 2018 | Low/midland | Rain-fed  | Kulumsa | Sekota |  |
| 16 | Danda’a  | 2010 | Mid/highland | Rain-fed  | Kulumsa | Sekota |  |
| 13 | Netsanet  | 2020 | Mid/highland | Rain-fed  | Sirinka  | Sekota |  |
| 14 | Hibist  | 2018 | Mid/lowland | Rain-fed  | Sirinka  | Sekota |  |
| 15 | Hidasie  | 2012 | Mid/highland  | Rain-fed  | Kulumsa | Sekota |  |
| 16 | Kakaba  | 2010 | Low/midland | Rain-fed  | Kulumsa  | Sekota | Sekota, Lalibela |
| 17 | Kingbird  | 2015 | Highland  | Rain-fed  | Kulumsa  | Sekota |  |
| 18 | Lemu  | 2016 | Highland  | Rain-fed  | Kulumsa | Sekota |  |
| 19 | Ogolicho  | 2012 | Midland  | Rain-fed  | Kulumsa | Sekota |  |
| 20 | Sorra  | 2013 | Moisture deficit | Rain-fed  | Sirinka  | Sekota |  |
| 21 | Tay  | 2005 | Mid/highland | Rain-fed  | Adet | Sekota |  |
| 22 | Wane  | 2016 | Mid/highland  | Rain-fed  | Kulumsa | Sekota |  |
| 23 | Sekota-1 | 2013 | Moisture deficit | Rain-fed  | Sekota |  | Sekota, Lalibela |

**Experimental Design and Procedure**

Both sets of experiments were conducted using a randomized complete block design (RCBD) with three replications. The area of each plot was 3\*1.2 m2 with spacing between plots and replications of 0.5 m and 1 m, respectively. The sowing method of both sets of the trial was dressed via row planting systems that were apart by 0.2m. All agronomic practices were done equally and appropriately as per the crop requirements and recommendations. Irrigation was applied at 7-10 days and 5-7 day interval for the midland (Sekota) and lowland (Abergele) sets of trials, respectively. The sources of water in all locations were from the river through canal outlets up to the station, and the plot was irrigated using a furrow irrigation system. The amount of water received by each plot was measured using the soil pressing method to test the soil moisture manually and the textures of the soil visually. The fertilizers were adopted directly from the main season production package for wheat in the districts. Based on these, 100 NPS kg/ha and 50 Urea kg/ha (split application at sowing and knee stage of the plant height) were applied for the experiment in the adaptation trials.

**Data Collection**

**Phonological and Growth Stage Traits**

Days to heading (days): the data for heading were recorded as the number of days from crop emergence to 50% heading, which was measured during observation.

Days to grain filling (days): this was the period that was the range between days to heading to days to maturity.

Days to Physiological maturity (days): it is the number of days of crop growing period between emergence and 95% of crop maturity stage.

Plant height (cm) was measured at the end of crop growing time (maturity stage), which was calculated by taking the average height of randomly selected plants, measured from the ground to the tip of the panicles out of the awns.

**Yield and Yield Component Traits**

Spike length (cm) is the average height of ten spikes in each plot that is measured from the base of the spike to the last order of the spikelet, excluding awns.

Number of seeds per spike: this was calculated by counting ten representative spike seeds from the plot and the average result.

Biomass yield (kg/ha) was recorded by weighing the total above ground parts of the four central rows of each plot at the time of harvest.

Thousand seed weight (g): weight of 1000 seeds from each experimental plot.

Grain yield (kg/ha): the grain yield was expressed as kilo grams per hectare, which was first recorded from each plot and measured in grams per plot when the moisture content of the seed reached 12%.

**Participatory technology evaluation (PTE)**

Experimental site and materials

The trial was conducted in the waglasta zone of the Sekota woreda (Woleh) and Lalibela (Medage) districts during the 2022/23 irrigation season.

About five (5) varieties were selected from the two adaptation trials and further evaluated using the participatory technology evaluation (PTE) approach. Fentale-2 and Gambo were selected from the low land set, whereas Kakaba and Adet-1 were selected from the mid land set. The Sekota-1 variety was included as a standard check for both locations (Sekota and Lalibela).

**Experimental design and procedures**

In the participatory technology evaluation (PTE), a plot size of 10\*10 m2 was used in both locations. The experimental design was a simple (single) block that contained five plots with a spacing of 1 m between the plots and 0.2 m between rows. All agronomic practices were applied equally and appropriately according to crop requirements and the recommendations. Irrigation was applied at 7-10 day interval in both districts using a furrow irrigation system. The water sources at both locations were from the river through the canal outlets up to the station of the experiment. The amount of water received by each plot was measured using the soil pressing method to test the soil moisture manually and the textures of the soil visually. The fertilizer rates were adopted directly from the main season production package for wheat in the districts. Based on these results, 100 kg/ha NPS and 50 kg/ha Urea (split application at sowing and knee stage of plant height) were applied.

 **FREG establishments and set selection criteria**

Two FREGs were established in two districts, Sekota (Woleh) and Lalibela (Medage). The group members in both districts were selected based on the advice of the development agents (Das) and important informers. The FREGs were selected purposively to contain 20% female-headed members in both locations that were involved in the technology evaluation and selection program on color preference, full endosperms for flour, and other preferable traits. The group members also contained the chairman and secretary, who facilitated all FREG activities with researchers and extension workers in each trial district. The FREG members were oriented toward the selection methods and schedules of the technology evaluation. These group members prepared their own action plans, and the researchers and extension workers participated only in facilitation and guidance. In each district, the FREG members discussed each other and set selection criteria to evaluate and select the best variety for the districts. The ranking methods were as follows: very good, two as good, three as neutral, four as poor, and five as very poor for each variety. Fortunately, the farmers’ mentioned that earliness, spike length, tiller capacity, and vegetative performance were prioritized in both districts.

**Statistical Analysis**

Analysis of variance (ANOVA) was performed to test the level of significance among the genotypes for all traits. All quantitative data were subjected to analysis of variance using Gen Stat 18th edition (64 bit). Fishers protected least significant difference (LSD); 1% and 5% were used for means comparison, although ANOVA had revealed the differences among genotypes in the traits. In the promoted activities, all quantitative data were analyzed using simple descriptive statistics, and qualitative data were analyzed using the pair-wise ranking method to identify farmers’ variety selection criteria in each district and a weighted ranking matrix table to prioritize those selected criteria.

**Results and Discussions**

The analysis of variance for yield component and grain yield at Abergele woreda (Belitarif kebele) and Sekota (woleh) was performed separately as a different set of experimental materials in both locations.

**Phonological Traits**

Analysis of variance for days to heading and maturity traits indicated a highly significant difference (P<0.01) among genotypes in both heat-tolerant (Abergele) and midland (Sekota) areas. Based on the analysis of variance, all varieties were headed within or less than two months at Abergele. These results show that the 50% heading date of eight lowland wheat varieties ranged from 48 to 57 days, and its average heading date of 52 days. Out of this, Ardi (44 days) variety reached in a short period of time, whereas Werer 2 (56 days) variety took a long period of time to head which is related to Yohannes et al. (2023); Degife & Demis, (2020). At Sekota, 50% days to heading ranged from 62 to 78 days, and the average heading date was 69 days. In this set of trials, Deka (62 days) took a short period of time, whereas Lemu (78 days) took a long time to head. This result agrees with the finding of Yohannes et al.(2023), who stated that Ardi and Deka varieties are headed earlier than other varieties in the lowland and midland areas. The same mark with days to heading: Ardi (68 days) variety matured earlier than fentale 1, Gambo, and Werer 2 (85 days), which took a long period of time to mature physiologically, and the earliest maturity date was recorded on the Ogolicho (103 days) variety, whereas a long period of time to maturity was observed on the Alidero (114 days) variety in the heat-tolerant and midland sets, respectively (Tables 3 and 4). The maturity date determines the yield, and its component means that early maturing varieties are not always true. This is because of the climatic conditions of the environments, such as temperature, which has an important effect on maturity and yield with yield-related traits. As the temperature increases during the grain filling period of wheat, it shortens the maturity time of the crops and decreases the yield potential of the genotypes (Islam & Wardlawb, 1978).

**Yield and yield-related traits**

Based on the analysis of variance, highly significant (P<0.01) and significant differences (P<0.05) were observed among varieties for the growth habit (plant height) trait in sets of trials at Abergele and Sekota, respectively. For this trait, at Abergele short plant height was recorded by Amibara 2 and Ardi (69 cm), whereas the shortest plant height was recorded by Hidasie and Lemu (61 cm) at Sekota (Tables 3 and 4). The longest plant height was observed in the Fentale 1 (82 cm) and Tay (74 cm) varieties on the lowland (Abergele) and midland (Sekota) sets, respectively. In the lowland set, the highest biomass yield was gained from Fentale1 (7152.8 kg/ha), followed by Amibara 1 (6805.6 kg/ha) and Gambo (6666.7 kg/ha) varieties, while the lowest biomass yield was recorded by the Ardi (4270.8 kg/ha) variety (table 3). Grain yield and thousand seed weight were obtained after harvesting of the crop and measured while the moisture content of the kernel reached 12.5%. The thousand seed weight is highly affected by genetic variation in wheat. Similar findings have been reported by Yohannes *et al* ., (2023). The mean seed weights of a thousand seeds ranged from 29.667 to 42 g. Based on this, the highest and lowest thousand seed weight was confirmed from the varieties Gambo (42.333 g) and Werer 2 (29.667 g), which show the same trend with the finding of Degife & Demis (2020), who reported that the weight of thousand seed ranges from 25 g to 46.67 g. Results: The analysis variance for grain yield revealed a highly significant difference (P<0.01) among varieties, which presented the highest yield gain from the Gambo (2043.8 kg/ha) variety, followed by the Fentale 1 (1987.8 kg/ha) and Fentale 2 (1962.8 kg/ha) as paralleled to the other varieties, and the lowest yield recorded Werer 2 (962.5 kg/ha) and Lucy (1198.6 kg/ha) varieties. In a study by Degife and Demis (2020), the Gambo variety ranked first, followed by Lucy varieties, but in this finding, Lucy gave the lowest yield (Table 2). In the midlands, the highest biomass yield was recorded for the Sora variety (4790 kg/ha), while the lowest was recorded for the Lemu variety (3046 kg/ha). The highest thousand seed weight was recorded on the Wane (43 g) variety, followed by the Hidasie (42 g) variety, whereas the lowest thousand seed weight was recorded on the Tay (23 g) variety (Table 4). The analysis variance for grain yield revealed highly significant differences (P<0.01) among varieties; the highest mean grain yield was recorded on the Sora (1719.8 kg/ha) variety, followed by Tay (1597.6 kg/ha) and Deka (1589.6 kg/ha) as compared to the lowest yielded Alidero (580.2 kg/ha) variety and the other varieties (table 4). This result agrees with the findings of Mekonnen *et al*., (2017), who reported that Sora (3341 kg/ha) variety showed good performance and gave a high yield with stable genotypes across different environments in rain-fed moisture stress areas. In the contrast, Degenet *et al*., (2021) reported that the Alidero variety showed good performance in the rainy season in the highland areas of north-western Dabat. This indicates that the variety was highly affected by changes in temperature; the temperature increase from 25 to 30 °C had greater effects on the grain filling time of the crop (Islam & Wardlawb, 1978).

Table 3: Mean grain yield and other agronomic traits of eight lowland heat-tolerant wheat varieties tested in waghimra zone at Abergele woreda (Belitarif) in 2020/21

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| varieties  | DH | DM  | PH (cm) | SL (cm) | SPS  | BM (kg/ha) | TSW(g) | GY (kg/ha) |
| Amibara 1 | 55bc | 82ab | 80ab | 9abc | 46a | 6805.6a | 40ab | 1492a |
| Amibara 2 | 48e | 70 c | 69d | 8bc | 36abc | 4444.4bc | 33bc | 1169.1bc |
| Ardi  | 44f | 68c | 69cd | 8c | 32bc | 4270.8c | 40ab | 1155.2bc |
| Fentale1  | 55abc | 85a | 82a | 10a | 45a | 7152.8a | 38ab | 1987.8a |
| Fentale 2 | 51d | 78b | 76abc | 9ab | 38abc | 6250a | 42a | 1962.8a |
| Gambo  | 54c | 85a | 76abcd | 10a | 41ab | 6666.7a | 42a | 2043.8a |
| Lucy  | 57a | 78b | 74bcd | 8c | 37abc | 6111.1a | 36abc | 1198.6bc |
| Werer 2  | 56ab | 85a | 70cd | 8bc | 30c | 5902.8ab | 29.667c | 962.5c |
| Mean | 52 | 79 | 74.875 | 9.175 | 38.242 | 5950.5 | 37.74 | 1496.5 |
| LSD (5%) | \*\* | \*\* | \*\* | \* | \* | \*\* | \* | \*\* |
| Cv (%) | 1.6 | 3.37 | 5.41 | 10.08 | 16.6 | 14.34 | 11.99 | 13.57 |

*Where; DH-Days To Heading; DM – Days To Maturity; PH- Plant Height; SL – Spike Length; SPS- Seed Per Spike; BM- Biomass TSW- Thousand Seed Weight; GY- Grain Yield*

Table 4: Mean grain yield and other agronomic traits of fourteen midland wheat varieties tested in waghimra zone at Sekota woreda (woleh) in 2020/21

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Varieties | DH | DM | PH(cm) | SL(cm) | SPS | BM(kg/ha) | TSW(g) | GY(kg/ha) |
| Alidero  | 77a | 114a | 69abc | 9a | 45ab | 3118d | 34ab | 580.2f |
| Adet-1 | 73b | 109cde | 66bcd | 7bcd | 40abcde | 3650bcd | 36ab | 1132.3de |
| Deka  | 62f | 105ghi | 68abcd | 7cd | 39abcde | 4114abc | 39ab | 1589.6ab |
| Danda’a  | 71bc | 111bc | 66abcd | 7cd | 42abc | 3948abcd | 40ab | 1229.2cd |
| ETBW6753  | 67cde | 108cdef | 72ab | 7d | 41abcd | 4246ab | 41ab | 1458bc |
| Hibist  | 65ef | 106fghi | 64cd | 7cd | 39abcde | 3457bcd | 39ab | 1324.7cd |
| Hidasie  | 69bcd | 110cd | 61d | 7d | 39abcde | 3654bcd | 42a | 1195.5de |
| Kekeba  | 66de | 107defg | 67abcd | 8bcd | 35de | 3960abcd | 38ab | 1461.1bc |
| kingbird  | 65def | 104hi | 62cd | 7d | 38bcde | 3341bcd | 32bc | 1281.9cd |
| Lemu  | 78a | 113ab | 61cd | 8ab | 39abcde | 3046d | 36ab | 969.7e |
| Ogolicho  | 65def | 103i | 68abcd | 8abc | 34e | 3162cd | 37ab | 1210.1de |
| Sora  | 67de | 107defg | 72ab | 7bcd | 36cde | 4793a | 40ab | 1719.8a |
| Tay  | 72b | 110cd | 74a | 8abcd | 38abcde | 4772a | 23c | 1597.6ab |
| wane  | 65ef | 107efgh | 66abcd | 7d | 45a | 4141ab | 43a | 1125de |
| Mean | 69 | 108 | 67 | 7 | 39 | 3814 | 37.316 | 1276.8 |
| LSD (5%) | \*\* | \*\* | \* | \*\* | \* | \*\* | \* | \*\* |
| CV (%) | 3.18 | 1.6 | 7.05 | 7.96 | 11.09 | 14.92 | 15.79 | 11.29 |

*Where; DH-Days To Heading; DM – Days To Maturity; PH- Plant Height; SL – Spike Length; SPS- Seed Per Spike; BM- Biomass TSW- Thousand Seed Weight; GY- Grain Yield*

**Participatory technology evaluation (PTE)**

**Grain and Biomass Yield**

Grain and biomass yields are the main concerns of farmers and stakeholders that can determine whether to accept and reject new technologies (Mihiretu, 2020). There were significant differences in grain yield and biomass traits, indicating that the performance of the varieties differed in terms of yield and biomass. In the combined mean, the highest yield was obtained from the Fentale-2 (2960 kg/ha) variety, followed by Adet-1 (2480 kg/ha), Gambo (2360 kg/ha), and Sekota-1 (2280 kg/ha), second, third, and fourth, respectively, whereas Kakaba (1960 kg/ha) ranked the lowest. In addition to grain yield, there was also a significant difference between varieties in biomass yield; the highest yield was obtained from the fentale-2 variety (6560 kg/ha), whereas the lowest was observed in the Kakaba variety (5040 kg/ha), as shown in Figure 3. In both locations farmers amplified, Fentale-2 first, whereas Kakaba and Adet-1 ranked last in Sekota (Woleh) and Lalibela (Medage), respectively (Table 9). A similar finding was obtained by Yohannes et al, (2023), who revealed that fentale-2 was first selected by farmers in both experimental areas of Metema and Belesa, whereas Adet-1 and Ogolicho were placed in last rank.

Figure 3: Grain yield performance of bread wheat in irrigation season

 **Maturity date**

Based on the combined mean, all varieties reached physiological maturity within a short period. Of these varieties, Kakaba (94 days) showed shorter maturity period than the other varieties while Adet-1 variety (108 days) took a long time to mature. Farmers explained that the maturity date determines the rank of selection among varieties; when the variety matures, it is exposed to autumn rain and leads to production under quality seed. Based on the maturity date, farmers ranked Kakaba first and Adet-1 last (Table 5).

Table 5: Mean grain yield and main traits

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variety | MD | SL(cm) | TSW (g) | BM(t/ha) | GY(kg/ha) |
| Sekota-1 | 103 | 8.2 | 39 | 5920 | 2280 |
| Adet-1 | 108 | 7.6 | 50.3 | 6560 | 2480 |
| Kekeba | 94 | 7.8 | 39.1 | 5040 | 1906 |
| Fentale-2 | 103 | 10.2 | 54.7 | 7200 | 2960 |
| Gambo  | 100 | 8 | 47.6 | 5280 | 2360 |
| Mean | 101.6 | 8.36 | 46.14 | 6000 | 2397 |
| Max | 108 | 10.2 | 54.7 | 7200 | 2960 |
| Min | 94 | 7.6 | 39 | 5040 | 1960 |
| STDEV | 5.128353 | 1.052616 | 6.950755 | 894.4 | 380.78 |

**Qualitative data analysis**

**Farmers training / Orientation**

At both locations the FREG members were trained on the package, selection criteria and method of evaluation. In Sekota (Woleh) district, 25 participants were trained on the technology. In Lalibela (Medage) districts a total of participants were trained on the same topic as in Sekota districts; among these, 20 females had participated in the training in both locations (Table 6)

Table 6: Number of trainee stakeholders

|  |  |  |  |
| --- | --- | --- | --- |
| Districts | FREG members | Expert | Researcher |
| Sex | M  | F | M  | F | M  | F  |
| Sekota | 13 | 6 | 2 | 1 | 2 | 1 |
| Lalibela | 15 | 9 | 3 | 0 | 3 | 1 |

**Field days/ visiting**

At the vegetative and physiological maturity stages of the crop, field days/ visiting programs were organized by the Sekota Dryland Agricultural Research Center (SDARC) in separate session for ARARI management and SDARC staff with farmers and stakeholders, respectively. At the vegetative stage, the ARARI staff, along with some SDARC staff, visited and evaluated the technology promotion trial in both locations. During this stage, the performances of the varieties were not clearly distinguished; rather, the team evaluated the overall management of the trial. However, at physiological maturity, field days were organized in both locations. During these sessions, participants were model farmers, development agents (DAs), woreda experts, and researchers from various disciplines. A total of 87 participants; 39 from Sekota and 48 from Lalibela visited the participatory technology evaluation trial in both districts (Table 7).

Table 7: Field day/visiting Event participants

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Districts  | FREG  | Das | Expert | Researcher | ARARI team | Total |
| Sex | M  | F | M | F | M  | F | M  | F  | M  | F | M+F |
| Sekota  | 19 | 4 | 3 | 2 | 2 | 1 | 3 | 1 | 4 | 0 | 39 |
| Lalibela  | 23 | 11 | 3 | 0 | 3 | 1 | 2 | 1 | 4 | 0 | 48 |

**Technology evaluation and selection**

Although the selection criteria for the farmers were the same in the districts, their weighting and ranking methods were different. Earliness, spike length, tiller capacity, and vegetative performance were the major traits in both districts. Earliness, spike length, tiller capacity, and vegetative performance ranked first, second, third, and fourth in Sekota (Woleh) and second, first, third, and fourth ranks in Lalibela (Medage), respectively, as shown in Table 8. The weight matrix ranking analysis revealed that there was a difference between the selection and evaluation of the varieties; the variety that had greater value from the total, choice, ranks first, and vice versa. In both districts, Fentale-2 was ranked first in all traits districts except tiller capacity. The varieties selected by the FREGs, Fentale -2 were ranked first, followed by Sekota-1 and Gambo in both districts.

Table 8: Ranked criteria and weighted by farmers group at Sekota (woleh) and Lalibela (Medage) districts.

|  |  |  |
| --- | --- | --- |
| Criteria | Sekota | Lalibela |
| Weight | Rank | Weight | Rank |
| Earliness | 1 | 1st | 2 | 2nd |
| Spike length | 2 | 2nd | 1 | 1st |
| Tiller Capacity | 3 | 3rd | 3 | 3rd |
| Vegetative Performance | 4 | 4th | 4 | 4th |

Table 9: summary of major farmers weighting criteria of wheat varieties and their preference rankings at Lalibela (Medage) and Sekota (Woleh) districts in 2021/2022 irrigation season

|  |  |  |  |
| --- | --- | --- | --- |
| Weighted parameter | Score X weight | Varieties at Lalibela (Medage) | Varieties at Sekota (Woleh) |
| Sekota-1 | Adet-1 | Kekeba | Fentale-2 | Gambo | Sekota-1 | Adet-1 | Kekeba | Fentale-2 | Gambo |
| Earliness | Score  | 3 | 5 | 1 | 2 | 4 | 3 | 5 | 1 | 2 | 4 |
| Weight  | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 |
| Score X weight | 6 | 10 | 2 | 4 | 8 | 3 | 5 | 1 | 2 | 4 |
| Spike length | Score  | 2 | 5 | 4 | 1 | 3 | 2 | 4 | 5 | 1 | 3 |
| Weight  | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 |
| Score X weight | 2 | 5 | 4 | 1 | 3 | 4 | 8 | 10 | 2 | 6 |
| Tellering Capacity | Score  | 1 | 3 | 4 | 2 | 5 | 1 | 2 | 5 | 3 | 4 |
| Weight  | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Score X weight | 3 | 9 | 12 | 6 | 15 | 3 | 6 | 15 | 9 | 12 |
| Vegetative performance | Score  | 2 | 4 | 5 | 1 | 3 | 2 | 5 | 4 | 1 | 3 |
| Weight  | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Score X weight | 8 | 16 | 20 | 4 | 12 | 8 | 20 | 16 | 4 | 12 |
| ∑(score x weight | 19 | 40 | 38 | 15 | 38 | 18 | 39 | 42 | 17 | 34 |
| Rank | 2 | 4 | 3 | 1 | 3 | 2 | 4 | 5 | 1 | 3 |

**Conclusion and Recommendation**

The analysis of variance revealed a significant differences among varieties in both sets of the experiment (p<0.01) in the majority of the evaluated traits. In the midland set, the Sora and Tay varieties performed better than the other varieties in almost all traits. In the lowland/ heat-tolerant set, the Gambo, Fentale-1, and Fentale-2 varieties exhibited outstanding performance.

In terms of yield and other important traits, Fentale-2 showed consistent performances in adaptation trials and in participatory technology evaluation programs. Amplifying these, the farmers also selected Fentale-2 first over other advanced varieties in the participatory technologies evaluation program in both districts. Therefore, the Fentale-2 variety should be pre scaled up and recommended for Abergele, Sekota, Lalibela and similar agro ecologies during the irrigation season.

**Acknowledgment**

The authors express their deepest gratitude and respect to the labor that have taken the data honestly and worked with minimum amount of wage.

**Conflict of Interest**

The author declared that there are no relevant financial and non-financial conflicts of interest.

**Data Availability**

The data and materials supporting the result and analysis, presented in this paper will be available upon special request for academic and research purpose.

**Funding statements**

The research leading to these results has not received specific grant from any funding agency.

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**References**

Central Statistical Agency (CSA). (2021). Farm Management Practices (Agricaltural Sample Survey) 2020/21 (2013 E.C.). *Central Statistical Agency*, *III*(12), 19–49.

CIMMYT. (2016). *CIMMYT | International Maize and Wheat Improvement Center*.

CSA. (2017). Federal democratic republic of Ethiopia, Central statistical agency. Agricultural sample survey 2016/17, report on Livestock and livestock characteristics. *Population*.

Degenet, Y., Azene, Y., Gashaw, M., & Takele, A. (2021). *Participatory variety selection of bread wheat ( Triticum aestivum L .) in highland areas of North*. *2*(2), 34–39.

Degife, G., & Demis, E. (2020). *Evaluation of Lowland Released Bread Wheat ( Triticum aestivum L .) Varieties under Irrigation in Raya Valley Southern Tigray ,*. *7*(3), 9–14.

Descheemaeker, K. (2014). *Irrigation water productivity as affected by water management in a small- scale irrigation scheme in the Blue Nile Basin I R R I G AT I O N WAT E R P RO D U C T I V I T Y A S A F F E C T E D B Y WAT E R M A NAG E M E N T I N A S M A L L - S C A L E I R R* . *January 2011*. https://doi.org/10.1017/S0014479710000839

FAO. (2023). World Food and Agriculture – Statistical Yearbook 2023. In *World Food and Agriculture – Statistical Yearbook 2023*. https://doi.org/10.4060/cc8166en

Grandgirard, J., Poinsot, D., Krespi, L., Nénon, J. P., & Cortesero, A. M. (2002). Costs of secondary parasitism in the facultative hyperparasitoid Pachycrepoideus dubius: Does host size matter? *Entomologia Experimentalis et Applicata*, *103*(3), 239–248. https://doi.org/10.1023/A

Hordofa, T., Menkir, M., Bekele, S., & Erkossa, T. (2008). *Irrigation and Rain-fed Crop Production System in Ethiopia*. 27–36.

Islam, S., & Wardlawb, I. F. (1978). *The Effect of Temperature on Kernel Development in Cereals*.

Kidane, D., Janssens, P., Dessie, M., Tilahun, S. A., Adgo, E., Nyssen, J., Walraevens, K., Assaye, H., Yenehun, A., Nigate, F., & Cornelis, W. M. (2023). Effect of deficit irrigation and soil fertility management on wheat production and water productivity in the Upper Blue Nile Basin , Ethiopia. *Agricultural Water Management*, *277*(November 2022), 108077. https://doi.org/10.1016/j.agwat.2022.108077

Maruja Salas, Xu Jianchu, and T. T. (2004). Field Manual: Participatory Technology Development (PTD). *Yunnan Science and Technology*, *7*–*5416*–*1871*–*3/Q•89*.

Mekonnen, A., Yosef, G., & Gashaw, A. (2017). *Evaluation of bread Wheat ( Triticum aestivum L .) Genotypes under Moisture Deficit Conditions*. *2*(2), 38–48.

Mihiretu, A. (2020). *Participatory Evaluation and Promotion of Improved Bread Wheat Technology in the Dry lands of Wag-lasta , Ethiopia : Challenges and Prospects Participatory Evaluation and Promotion of Improved Bread Wheat Technology in the Dry lands of Wag-lasta , Ethiopi*. *August*. https://doi.org/10.26725/JEE.2019.4.31.6370-6380

Nigussie, A., Kedir, A., Adisu, A., Belay, G., Gebrie, D., & Desalegn, K. (2015). *Bread wheat production in small scale irrigation users agro-pastoral households in Ethiopia : Case of Afar and Oromia regional state*. *7*(4), 123–130. https://doi.org/10.5897/JDAE2014.

Tariku, A., Begna, T., & Asrat, Z. (2022). *Evaluation and adaptability study of improved bread wheat varieties to irrigated areas of Chiro Districts of West Harerghe Zone , Eastern Ethiopia*. *04*(2), 18–21.

*The Wheat Supply Chain in Ethiopia : Patterns , trends , and policy options Nicholas Minot James Warner Solomon Lemma Leulsegged Kasa Abate Gashaw Shahidur Rashid International Food Policy Research Institute ( IFPRI )*. (2015).

Witcombe, J. R., Joshi, A., Joshi, K. D., & Sthapit, B. R. (1996). Farmer participatory crop improvement. I. Varietal selection and breeding methods and their impact on biodiversity. *Experimental Agriculture*, *32*(4), 445–460. https://doi.org/10.1017/s0014479700001526

Yohannes Azene Alemu, S. Y. L., & Wassie, and T. K. (2023). *Adaptation and Promotion of Improved Beard Wheat ( Triticum aestivum L . ) Varieties under Irrigation Condition in*. *8*(4), 361–374. https://doi.org/10.9734/AJRCS/2023/v8i4217