# Effects of Seed Rates on Seed Quality and Seed Multiplication Factor of Bread Wheat (*Triticum Aestivum* L.) in Early Generation Seed Classes Under Rain-Fed Conditions in Amhara Region, Ethiopia

**Tilaye Anbes\*[A] , Belayneh Shibie[B] and Yematw Chane[A]**

[A] Adet Agricultural Research Center, P.O. Box 8, Bahir Dar, Ethiopia
[B] Debre Brehan Agricultural Research Center, P. O. Box 112, Debre Berhan, Ethiopia

*Corresponding author; email: tilayean43@gmail.com

## Abstract

Seed is a vital agricultural resource for enhancing crop production and productivity. However, a variety of variables limit bread wheat seed output and quality, including an insufficient seed rate for early generation seed production. The experiment was conducted in three districts, Adet, Debre Tabor, and Enewari, over two years (2020 and 2021) under rain-fed conditions to determine the optimal seeding rate for early-generation seed classes of bread wheat. Treatments included factorial combinations of five seeding rates (50, 75, 100, 125, and 150 kg.ha$^{-1}$) and two seed classes, breeder and basic seeds. A randomized complete-block design with three replications was employed. A combined study across years and locations revealed that the interaction effect of seed rate and seed class was not significant ($P > 0.05$) for the parameters of days to heading, days to maturity, plant height, spike length, seed yield, and seed multiplication ratio. The combined results showed that seed rate had a substantial effect on bread wheat spike length, yield, and seed multiplication ratio. Lower seed rates resulted in a higher seed multiplication ratio at all three locations. Increasing the seed rate from 50 to 150 kg.ha$^{-1}$ increased seed yield from 2555.2 kg.ha$^{-1}$ to 3235.2 kg.ha$^{-1}$, although the difference in seed yield between 125 and 150 kg.ha$^{-1}$ was statistically insignificant ($p>0.05$ for the combined study). Finally, seed rates as low as 125 kg.ha$^{-1}$ can be employed for all seed classes to boost early-generation seed output in the three locations and similar agroecologies.

Keywords: economic analysis, seed qualit, seed yield, standard germination

## Introduction

Wheat is one of the most widely cultivated crops globally (FAOSTAT, 2022), and its adaptability enables it to be grown in a diverse range of soil and climate conditions (Cui et al., 2022). Wheat is the most important cereal, serving as the primary source of food for most people worldwide (Xue et al., 2021) and as a feed material (Sönmez et al., 2022). Ethiopia is the second-largest wheat producer in sub-Saharan Africa, following South Africa, and is solely under rain-fed conditions (Netsanet et al., 2017). The wheat is planted during the main meher rainy season, from June to August, and harvested from October to January. Wheat is also the fourth largest cereal crop produced by nearly 35% of smallholder farmers in Ethiopia, following tef (*Eragrostis* tef), maize (*Zea mays*), and sorghum (*Sorghum bicolor*) (CSA, 2022). On the other hand, the demand for wheat is growing at an average annual rate of 9% (Khan et al., 2020). Hence, Ethiopia remains a net importer of wheat due to a gap between production and consumption levels (Hodson, 2020). Wheat is one of the most important crop plants in the world. (FAO, 2022). Wheat primarily grows in the range of 1500 to 3000 m above sea level in Ethiopia, where the need for chilling temperatures is met (Daba, 2017). According to Falola et al. (2017), it is the world's second most important cereal crop after rice.

Plant population density in bread wheat is a significant agronomic characteristic that might affect crop output and seed quality (Zhang et al., 2016). According to Tanner et al. (1991), cultivars with low tillering capacity or weak emergence should use higher seed rates, based on seed rate trials conducted in Ethiopia. Nevertheless, no studies have been done on the benefits or drawbacks of reduced seed rates, particularly concerning early generation seed multiplication under national seed production

initiatives. Increasing plant density from 135 to 405 plants.m$^{-2}$ (Tian et al., 2017) or 75 to 300 plants.m$^{-2}$ (Yang et al., 2019) significantly increased grain yield and other parameters.

Quality seeds are the most economical and efficient input to agricultural development (Alemu, 2010). Quality seeds can directly contribute up to 45% of the total production (Abebe and Alemu, 2017). The contributions of all other production factors are highly dependent on the quality of the seed. The ultimate productivity of different inputs, which build the environments that enable the plant to perform well, is determined by seed quality. The use of seeds from improved varieties is crucial to the future of food security in Ethiopia, as it can contribute to increased production and productivity. According to Gaur et al. (2010), yield per plant, or multiplication ratio, is more significant in the production of early generation seed (EGS) than yield per unit area. The task at hand involves rectifying the seed conversion ratio (SMR) across many categories. Good agronomic methods can increase the conversion ratio. The seed multiplication ratio is influenced by seed rate, a significant agronomic element. Breeder seed can be more efficiently converted into other classes when the seed rate is lower. Increased breeder seed production (Sandhu, 2013), quick access to early generation seed, and larger seeds result in higher vigor (Nik et al., 2011). Increased seed rates result in reduced seed multiplication ratios, seed and variety replacement rates, and an increase in the number of farmers using farm-saved seed (Gastel et al., 2002).

Low seed rates, conventional sowing techniques, incorrect row spacing, and delays in sowing are some of the factors contributing to low wheat yields (Iqbal et al., 2010). Many farmers in developing nations believe that using a higher seed rate than recommended is an effective way to control weeds and reduce crop production risks. It is not advisable to plant more seeds than recommended, as this can lower the quality of the seeds, particularly in terms of size and weight. Farmers should closely follow all recommended seed production procedures rather than using higher rates.

The increase in planting material above what is planted is referred to as the "multiplication ratio." Reducing the seed rates from 100 to 50 kg.ha$^{-1}$ resulted in an increase in the seed multiplication ratio from 40.6 to 82.6. 826 kg of seed may be produced from a 10 kg nucleus seed of wheat grown at a rate of 50 kg.ha$^{-1}$ (Karta et al., 2015). Within Ethiopia's fast-track wheat variety release programs, lower seed rates accelerate the availability of early-generation seeds (Karta et al., 2015). This experiment aimed to determine the proper seeding rate for the bread wheat early generation seed class to produce early generation seeds.

## Materials and Methods

*Description of The Study Area*

The field experiment was conducted at three sites (Adet, Debre Tabor, and Enewari) in the wheat belt of Ethiopia (Figure 1). The Adet Research Center is located at 37° 30'1.8"N latitude and 11° 16'30.3"E longitude, with an altitude of 2240 meters above sea level. The mean annual rainfall of Adet Agricultural Research Center (AARC) is 1250 mm, ranging between 860 mm and 1771 mm (Sewagegne, 2003). It has Nitosol and Cambisol soil types, characterized by undulating hills and varied physiography. The average annual maximum temperature of AARC is 25.50°C and the average minimum temperature is 9.20°C. Enewari is located at 9.8$^{0}$ 52' North and 39$^{0}$ 10' East at an altitude of 2,680 m above the sea level. The Enewari receives a mean annual rainfall of 929 mm, with average maximum and minimum temperatures of 21.4°C and 9.0°C, respectively. The soil type of the experimental site is classified as Vertisol with clay loam texture. Debre-Tabor is found at 11°88 'N latitude and 37o98' E longitude and at an altitude of 2,591 m above sea level with a soil type of Nitosol. It receives a mean annual rainfall of 1050 mm, with average maximum and minimum temperatures of 21.37°C and 10.77°C, respectively (Wallelign, 2015). Enewari is located at the latitude of 9°53'N and a longitude of 39°08'E, representing vertisol areas in geographical coordinates of 9°47'N and 38°54'E to 9°53'N and 39°13'E. The altitude of Enewari was 2680 m.a.s.l. The minimum and maximum temperature is 7.3 and 18.2°C, with an average annual rainfall of 977 mm. The data on climatic parameters such as rainfall, maximum and minimum temperature recorded at Adet meteorological stations and Debre Tabor districts for the 2020 and 2021 cropping seasons are indicated in Figure 2.

*Treatments and Experimental Design*

The experiment was comprised of 5 x 2 factorial combinations involving seed rate and seed classes (breeder and basic seed), respectively. There were a total of 10 treatment combinations, each with five seeding rates (50, 75, 100, 125, and 150 kg.ha$^{-1}$. The experiment was laid out in a randomized complete block design with three replications. Each treatment combination was assigned randomly to the experimental units within a block. The Ogolcho variety with an inter-row spacing of 20 cm was used.

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The gross plot size was 3 m x 2 m (6 m²). The space between blocks was 1 m, while spacing each plot in a block was 0.5 m. The net plot size (harvestable area) was used by excluding two outer rows on both sides of each plot and a 50 cm row length at both ends of the rows to avoid possible border effects. Thus, the harvestable net plot size was 3 m x 1.6 m (4.8 m²) (the central eight rows).

*Experimental Materials and Agronomic Practices*

The experimental field was plowed twice using a tractor. The first plowing was done in mid-February, and the second plowing was done at the end of May. The final plowing was conducted manually using a local implement called 'mekotikocha', and seed plots were leveled on July 15; planting was performed on the same date. The improved variety of seed was obtained from the Adet Agricultural Research Center. The array, Ogolcho, widely grown by farmers in the area, was used for the field experiment. Wheat seeds were sown by drilling in 2 m long rows 20 cm apart from each other in each plot at the seed rate as per treatment on July 15, 2020. The full rate of the NPS fertilizer (100 kg.ha⁻¹) and one-third of the nitrogen fertilizer (33 kg.ha⁻¹ urea) were applied as a basal application before planting for all plots and incorporated into the soil. The remaining 67 kg.ha⁻¹ urea was applied as side-dressing at the mid-tillering stage of the crop (35 days after emergence). In addition to the treatments, uniform field management, disease, pest, and weed control, as well as cultivation, were performed on all plots according to the recommendations made for the crop.

*Initial Seed Quality Test of Bread Wheat*

A physiological seed quality test was conducted in the seed laboratory for all seed samples before planting. The initial seed test result meets the minimum
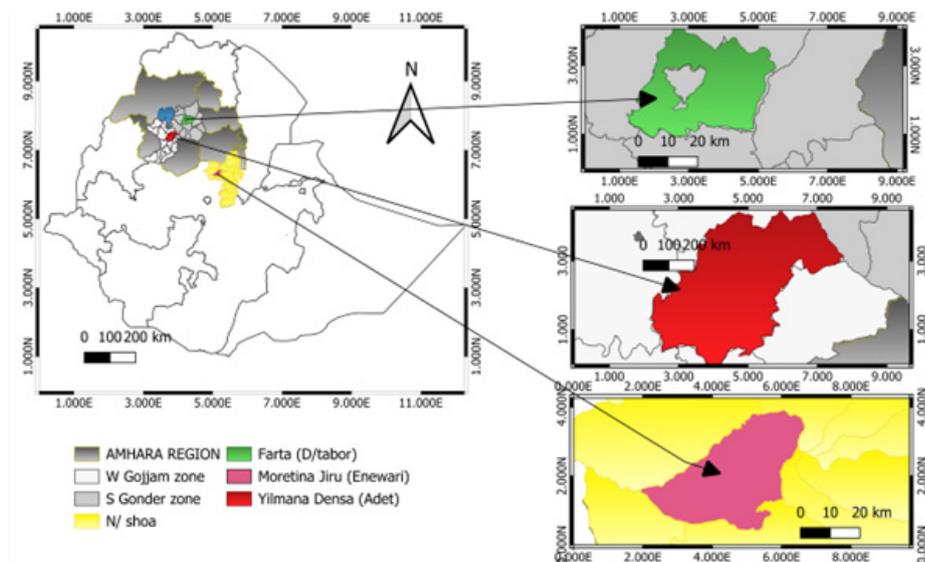


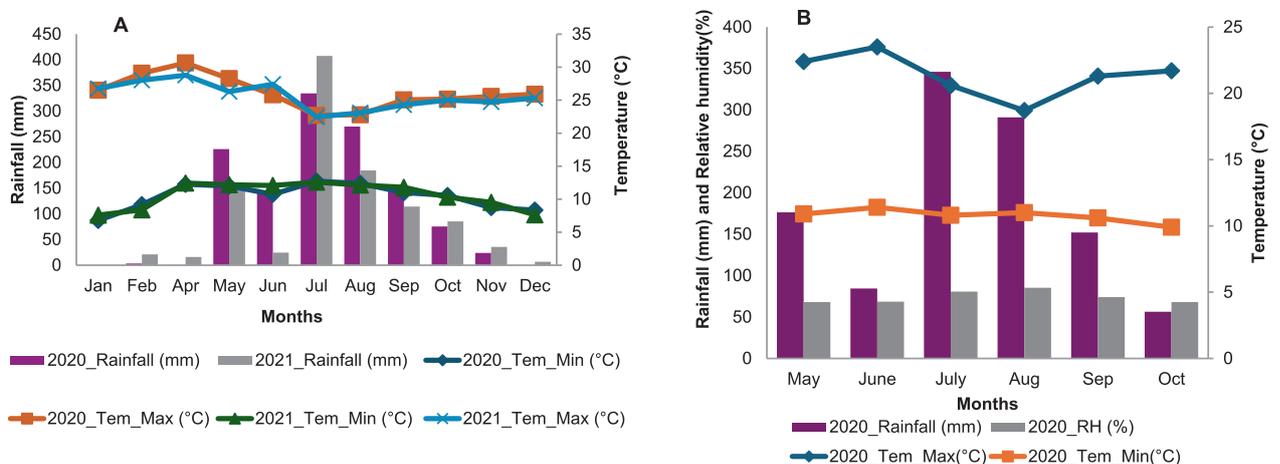Figure 1. The map of the study districts of the Amhara region, Ethiopia.



Figure 2. Monthly rainfall, maximum, and minimum temperature of Adet (**A**) and Debre (**B**) at the Tabor district.

requirements of the Ethiopian seed certification standard. The mean values for the purity percentage, germination percentage, and moisture content of both seed classes are indicated in Table 1.

*Data Collection and Measurements*

Days to heading (days) were recorded by counting the number of days from the date of sowing up to the date of heading based on visual observation. Days to physiological maturity (days) were recorded by counting the number of days from the date of sowing up to the date when 90% of the crop stands in a plot changed to light yellow color based on visual observation. Plant height (cm) was measured as the height from the soil surface to the top of the spike (awns excluded). It was recorded as the average of ten randomly selected primary tillers from each plot at physiological maturity. Ten spikes were randomly selected from each plot for spike length measurements. Each spike was measured from the base of the spike to the apex to record the spike length.

One thousand seed weights (g) were counted at random from each plot, and an electronic balance recorded their weights. Seed yield (t.ha$^{-1}$) is the bread wheat bundles of each plot were sun dried and then threshed separately. The seed weight of each plot was recorded in kilograms and then subsequently converted into tons per hectare.

Seed multiplication ratio is calculated for each treatment combination following the equation by Van Gastel et al. (2002):

$$P = Y/R$$

Where P is the seed multiplication ratio, Y is the pure seed yield, and R is the seed rate.

Standard germination percentage was conducted on all seed samples collected from various sources. Four hundred (400) seeds from the pure seed component were separated into four replicates of 100 seeds each, which were then sown on top of paper medium. The first seed count was initiated after four days, whereas the final seed count concluded after

eight days of seed germination. The seeds were incubated at 20°C for 8 days to assess germination percentage, as indicated by the International Seed Testing Association (ISTA, 2008).

Seedling shoot and root lengths were measured at the 8-day final count; the seedlings' shoot and root lengths were measured using the standard germination test. After 8 days of seeding, ten normal seedlings were picked at random from each replicate. The shoot length was measured from the site of attachment to the embryo (endosperm) to the seedling's tip. Similarly, the root length was determined from the point of attachment to the embryo (endosperm) to the tip of the root. The shoot and root length averages were calculated by dividing the total shoot or root lengths by the total number of normal seedlings assessed (ISTA, 2008).

Seedling dry weight was calculated for ten randomly selected seedlings from each replication, which were removed from the embryo and placed in paper bags before being dried in an oven at 80°C for 24 hours. The dried seedlings were weighed to the nearest milligram using a sensitive scale, and their average dry weights were calculated.

Each sample was assigned two vigor indices, vigor index I and II. Seedling vigor index I was computed by multiplying standard germination by the average sum of shoot and root length after eight days of germination, while vigor index-II was produced by multiplying standard germination by mean seedling dry weight (AOSA, 1983).

The speed of germination was counted on 100 seeds and replicated four times from each sample. The seeds were sown on top of blotter paper and kept at room temperature (20°C) for a maximum of 8 days. The speed of germination (GS) was calculated as suggested by Maguire (1962). The number of normal seedlings was counted daily for up to 8 days and then divided by the total number of days to calculate the percentage of normal seedlings. The same was added till the final count as per the following formula.

GS= $\dfrac{\text{number of normal seedlings}}{\text{number of days to first count (4}^{\text{th}}\text{)}}$ +… ..+ $\dfrac{\text{number of normal seedlings}}{\text{number of days final count(10}^{\text{th}}\text{)}}$

Table 1. Initial physical and physiological seed quality of breeder and basic seeds of the two years (2020 and 2021)

| Seed class | 2020 | | | 2021 | | |
|---|---|---|---|---|---|---|
| | Purity (%) | Germination (%) | Moisture content (%) | Purity (%) | Germination (%) | Moisture content (%) |
| Breeder seeds | 99.25 | 86 | 11 | 99.15 | 88 | 10.5 |
| Basic seeds | 98 | 85.5 | 10.5 | 98.5 | 86 | 11 |

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*Statistical and Economic Analysis*

The analysis of variance (ANOVA) was computed for the agronomic and laboratory parameters using the GLM procedures of SAS (Statistical Analysis System) version 9.4 computer software program (SAS Institute Inc., 2012). Significance of differences between means was expressed using the least significant difference (LSD) test at P< 0.05 probability. Statistically significant treatments were subjected to an economic analysis using the partial budget procedure to determine the treatment combination that would yield acceptable returns at low risk for early-generation seed producers (CIMMYT, 1988). The mean seed yield data across locations and years were adjusted down by 10% and subjected to a partial budget analysis.

Economic profit was calculated using the formula [(seed yield x seed sale price) – (seed cost)]. Financial analysis was performed using the prices in Ethiopian Birr (ETB) of the inputs prevailing at the time of their use, as well as the bread wheat seed yield at the time of harvest under seed sale market conditions. All costs and benefits were calculated on a hectare basis in Ethiopian Birr (Birr.ha$^{-1}$). The cost of 1 kg of Ogolcho bread wheat variety seeds was 55.78 ETB. The cost varied for each treatment, and treatments were ranked in order of ascending variable cost. Dominance analysis was used to eliminate treatments that cost more but produce a net benefit greater than the lowest-cost treatment. The marginal rate of return (MRR) was calculated

for each non-dominated treatment using the formula: MRR between treatments 1 and 2 = [change in net benefit (NB2- NB1)/change in TVC (TVC2 – TVC1)] × 100, and a minimum acceptable MRR of 100% was assumed. Thus, an MRR of 100% implies a return of one ETB on every ETB of expenditure in the given variable input.

## Results and Discussion

The homogeneity test was applied for all agronomic parameters of bread wheat data in each location and year. The homogeneity of variance test results for all agronomic parameters of the bread wheat data revealed that the data were homogeneously distributed. Analysis of variance (ANOVA) for the effects of locations, year, seed rate, seed class, and their interactions on all bread wheat parameters measured during the investigation are presented in Table 2. Seed rate and seed class interaction had no significant influence (P > 0.05) on days to maturity, plant height, spike length, seed yield, or seed multiplication ratio. The interaction between seed rate and seed class had a substantial (P < 0.05) effect on the number of seeds per spike and 1000 seed weight. Only the days to maturity and seed multiplication factors were significantly influenced by the interaction of year and seed rate. Bread wheat's days to heading, days to maturity, spike length, seed yield, and seed multiplication ratio were significantly affected (P < 0.05) by the interaction between year and seed class. Growing years per season and locales had a

Table 2. Mean square value of seed rate and seed class on phenological, growth, yield, and yield-related traits of bread wheat combined over locations and years (2020 and 2021)

| Source of variation | Df | DTH | DTM | PH | SL | NKPS | SY (kg.ha$^{-1}$) | SMR | TSW |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean square value | | | | | |
| Year | 1 | 26.45* | 12718** | 2630** | 26** | 764** | 2658685** | 553** | 149.6** |
| SC | 1 | 0.006ns | 2ns | 84.87ns | 0.08ns | 3.36ns | 219105ns | 46.57ns | 101.1ns |
| SR | 4 | 449** | 731.1** | 44.22ns | 1.4* | 193** | 2938418** | 4998** | 20.4* |
| Loc | 2 | 167** | 2295** | 4657** | 7.1** | 206** | 3764002** | 379** | 3827.5** |
| Loc*Year | | 19.12* | 440.3** | 73.07ns | 0.56ns | 59.6ns | 8906824** | 1220** | 543** |
| SR*SC | 4 | 4.81ns | 6.4ns | 52.33ns | 0.53ns | 59.33* | 101738.5ns | 36.45ns | 40.75** |
| SC*YR | 1 | 32.94* | 120** | 0.78ns | 1.21* | 26.8ns | 9122668** | 1274*** | 23ns |
| SR*YR | 4 | 5.86ns | 69.83** | 35.14ns | 0.49ns | 30.4ns | 275050.9ns | 88.58* | 18.6ns |
| SR*Loc | 8 | 5ns | 131.6** | 30.89ns | 0.41ns | 28.2ns | 517392.38* | 90.77* | 10.79ns |
| SC*Loc | 2 | 20* | 0.27ns | 32.68ns | 0.23ns | 7.9ns | 727363.98* | 92.5ns | 64.34** |
| SC*SR*YR*Loc | 4 | 6.64ns | 72.76** | 38.52ns | 0.5* | 3.6ns | 970662** | 147.8** | 48.54** |

Notes: ns, *, and ** indicate non-significant, significant, and highly significant at the 5% level of probability, respectively. DTH, days to heading; DTM, days to maturity; PH, plant height; SL, spike length; NKPS, number of kernels per spike; SY, seed yield; SMR, seed multiplication ratio; TSW, thousand seed weight; SR, seed rate; SC, seed class; YR, year; Loc, location.

substantial (P < 0.01) effect on yield and yield attributes (Table 2). The measured features differ across growth years due to different rainfall circumstances. In the case of bread wheat, all phenological stages are susceptible to fluctuations in air temperature. High temperatures promote increased plant metabolic activity, as well as the acceleration of physiologic processes that dictate its growth and development (Moreno et al., 2018).

The interaction of location, year, seed class, and seed rate had a significant influence (P<0.05) on bread wheat days to maturity, spike length, seed yield, seed multiplication ratio, and 1000 seed weight (Table 2). Only days to maturity, seed yield, and seed multiplication factors were significantly impacted (P < 0.05) by the interaction between seed rate and location. Additionally, the interaction between seed class and location had a significant (P < 0.05) impact on days to heading, seed multiplication factors, and 1000-seed weight. The combined investigation across locations and two years revealed that seed rate has a considerable influence on the seed multiplication ratio. However, it was sincere due to the seed class or the interactions of those treatments.

*Days to Heading*

The days to heading of bread wheat plants were significantly affected by the main effect of seedling rate (P < 0.001). However, it was not significantly affected by the main effects of seed class and its interaction with seed rate (P> 0.05). The maximum number of days to heading (69.14 days) was recorded for the seed rate of 50 kg.ha$^{-1}$, followed by a seed rate of 75 kg.ha$^{-1}$ (67 days). The shortest number of days to heading (60.3 days) was recorded for the seed rate of 150 kg.ha$^{-1}$. This result revealed that crops headed earlier (60.3 days) when planted at a higher seeding rate (150 kg ha-1) and headed later (69.14 days) when grown at a lower seed rate (50 kg ha$^{-1}$) (Table 3). The earliest days of heading at higher seed

rates may be attributed to competition among plants for soil nutrients, which could have accelerated the phenological development of the crop (Zelalem et al., 2024).

*Days to Maturity*

Days to 90% physiological maturity of bread wheat plants were significantly affected by the main effects of seeding rate (P< 0.001). However, it was not significantly (P>0.05) affected by the main effects of seed class and its interaction with seed rate. The seed rate of 150 kg.ha$^{-1}$ exhibited early maturity (108.28 days), which may be due to the increased plant population, resulting in increased intra-plant competition for nutrients and light, and causing plants to stay in the heading and maturity stages for a shorter period. This may have also contributed to the reduction in grain filling period, because heading and maturity at higher seed rates occurred faster than at lower seed rates. The delayed day to physiological maturity with the lowest seed rate of 50 kg.ha$^{-1}$ (119.06 days) can be attributed to increased vegetative growth resulting from reduced intraspecific competition for light and subsurface critical nutrients. Similarly, significant differences were detected because of seed rate on days to physiological maturity (Wondimu et al., 2022). Days to maturity were significantly affected by the two-way interaction between seed rate and location (p = 2.2 × 10^ (-16). The highest DTM recorded from the interaction of 50 kg.ha$^{-1}$ of seed rate with Enewari (129.17 days), whereas the shortest was obtained from the interaction of 150 kg.ha$^{-1}$ seed rate with Adet (105.83 days) (Fig.3A). Increase in seeding rate from 50 to 150 kg.ha$^{-1}$ and Enewari to Adet decreased the days to 90 % physiological maturity of bread wheat from 129.17 to 105.83 days and vice versa. This may be due to the increased plant population, which creates intra-plant competition for resources such as water, nutrients, and light, as well as the differences in growing conditions between locations. This, in turn, led plants to stay on the plant
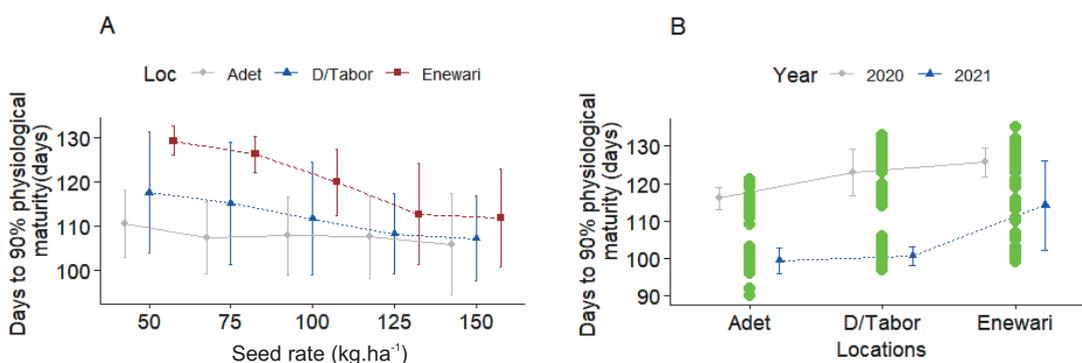
Figure 3. Ggline plot of the interaction effect of seed rate and locations on days to 90% physiological maturity (A) and location and years on days to 90% physiological maturity (B) of bread wheat in the different districts.

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for longer, heading and reaching maturity. This result aligns with Zelalem et al. (2024), who reported that delayed physiological maturity may have contributed to the reduction in grain filling period, as heading and maturity were hastened more at a higher seed rate than at a lower seed rate. Additionally, the combined effect of locations and year was significant (p = 2.2e-16) on days to physiological maturity. The highest DTM (125.67 days) was recorded in the Enewari districts in 2020, and the lowest (99.43 days) was recorded in the Adet districts in 2021 (Fig. 3B). Climatic factors, including temperature, precipitation, light, humidity, and frost, significantly impact agricultural production. These factors influence crop growth, development, and yield by affecting various processes like photosynthesis, water availability, and plant physiology (Joshi and Amalkar, 2009).

*Spike Length*

Spike length of bread wheat was significantly affected by the main effects of seeding rate (P< 0.05). However, it was not significantly affected by the main effects of seed class and its interaction with seed rate (P> 0.05). The longest spike length (8.23 cm) was measured at a seed rate of 50 kg.ha$^{-1}$, while the shortest (7.77 cm) was measured at a seed rate of 150 kg.ha$^{-1}$ (Table 3). Spike length was greater at the lower seed rate than at the higher seed rate of 150 kg.ha$^{-1}$. This could be owing to increased free space between plants at lower seed rates and less intra-plant competition for available resources, resulting in longer spike lengths and shorter plant heights (Wondimu et al., 2022). The result is in harmony with the findings of Wondimu et al. (2022), who suggested that increasing seed rates resulted in shorter spike length and decreasing seed rates resulted in longer spike length per plant.

*Seed Yield*

Seed yield is the outcome of various physiological, biochemical, and phenological processes occurring in the plant system. The homogeneity test results for the seed yield at each location showed that the data were homogeneously distributed. The combined analysis over locations and years showed that seed yield was significantly influenced by seed rate. However, neither the main effect of seed class nor its interaction with seed rate influenced this parameter. The highest seed yield (3235.2 kg.ha$^{-1}$) was obtained from the highest seed rate (150 kg.ha$^{-1}$), although statistically comparable to that obtained from the 125 kg.ha$^{-1}$ seed rate (Table 3). The lowest seed yield (2555.2 kg.ha$^{-1}$) was obtained from the lowest seed rate (50 kg.ha$^{-1}$) (Table 3). Seed yield varied significantly with seed rates in a similar manner across all years and locations tested (Table 3). Similarly, Bitwoded et al. (2022) reported that the maximum grain yield was achieved with an increase in seed rate, while low and the highest seed rates produced the minimum grain yield. The combined effect of seed rate and locations on seed yield was significant (p = 0.0189339) (Figure 4A). The highest SY (3608.6 kg.ha$^{-1}$) was observed at a seed rate of 125 kg.ha$^{-1}$ in the districts of Adet (Figure 4A), it was statistically at par with the result obtained in plots seeded with 150 kg.ha$^{-1}$ with similar locations and Debre Tabor, whereas the lowest (2218.63 kg.ha$^{-1}$) seed yield was recorded the seed rate of 50 kg.ha$^{-1}$ with at the location of D/tabor (Figure 4A). Generally, the seed yield at Adet was higher than that at Debre Tabor and Enewari, as the Adet area is characterized by a mid-altitude, heavy soil type with higher temperatures and a faster developmental rate, which likely increases the yield (Figure 4A).
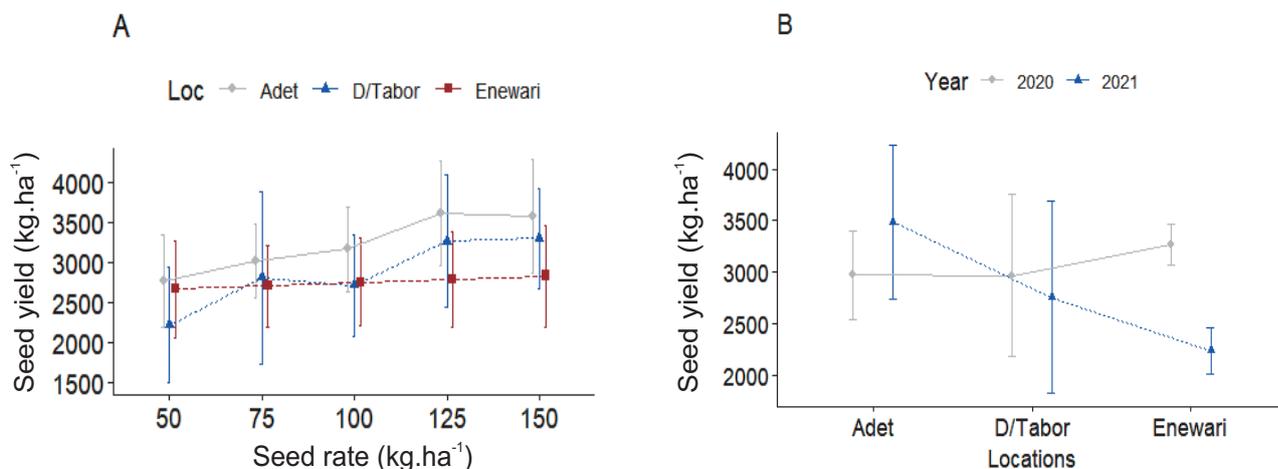


Figure 4. Ggline plot of the interaction effect of seed rate and locations on seed yield (A) and locations and years on seed yield (B) of bread wheat at the different districts.

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The interaction effect of locations and year on seed yield was significant (p = 2.205e-14) (Figure 4B). The highest seed yield (3484.54 kg.ha$^{-1}$) was observed in 2021 at Adet districts, which was statistically comparable to the result obtained in plots seeded with Enewari (3266.45 kg ha-1) districts within the same year. In contrast, the lowest seed yield (2236.42 kg.ha$^{-1}$) was recorded at the Enewari location in 2021 (Figure 4A). Similarly, Shitaye et al. (2023) reported that the effects of year and location on wheat seed yield were highly significant across all years of their study.

*Seed Multiplication Ratio*

The average seed multiplication ratio was 33.16 (Table 3) in the districts. The maximum seed multiplication ratio was 51.3 when the seed rate was 50 kg.ha$^{-1}$. This means that if 10 kg of early-generation bread wheat seed is sown at a rate of 50 kg.ha$^{-1}$, the expected yield is 331.6 kg of seed, provided proper agronomic management is employed. Due to the inadequacy of early-generation seeds from breeding

plots, this is a significant option for improving rapid seed multiplication. This finding was consistent with that of Karta et al. (2015), who reported a maximum seed multiplication ratio of 82.6 at a seed rate of 50 kg.ha$^{-1}$ in Kulumsa. This means that if one has 10 kg of nucleus seeds.

*Number of Seeds per Spike*

A seed rate of 50 kg.ha$^{-1}$ combined with a seed class of basic seed produced the highest number of seeds per spike (48.6). In comparison, a lower number of kernels per spike (40.35) was recorded from the combination of breeder seed with a seed rate of 150 kg.ha$^{-1}$, though statistically comparable to that obtained from 50 kg.ha$^{-1}$ and 150 kg.ha$^{-1}$ combinations with both seed classes (Table 4). This can be attributed to the seed filling period, during which the food translocated from the leaf is reduced due to severe competition at the maximum seed rate, resulting in a lower seed yield. This study's findings were consistent with those of Tilaye and Belyneh (2024), who indicated that the larger seed number produced at the lowest seed rate

Table 3. Response of bread wheat on days to heading, maturity date, plant height, spike length, seed yield, and seed multiplication ratio to seed rate and seed class combined over locations and years

| Treatments | Days to heading | Days to maturity | Plant height (cm) | Spike length (cm) | Seed yield (kg) | Seed multiplication ratio |
|---|---|---|---|---|---|---|
| Seed rates (kg.ha$^{-1}$) | | | | | | |
| 50 | 69.14[a] | 119.06[a] | 86.13 | 8.23[a] | 2555.20[c] | 51.30[a] |
| 75 | 67.00[b] | 116.17[b] | 87.23 | 8.10[ab] | 2846.300[b] | 38.00[b] |
| 100 | 65.53[c] | 113.06[c] | 87.75 | 7.95[bc] | 2878.70[b] | 28.90[c] |
| 125 | 62.47[d] | 108.257[d] | 89.20 | 7.78[c] | 3221.10[a] | 25.85[d] |
| 150 | 60.3[e] | 108.28[e] | 87.30 | 7.77[c] | 3235.20[a] | 21.73[e] |
| LSD (0.05) | 1.08 | 1.07 | ns | 0.24 | 216.14 | 2.73 |
| Seed class | | | | | | |
| Breeder seed | 64.88 | 113.10 | 86.84 | 7.95 | 2982.21 | 33.66 |
| Basic seed | 64.9 | 113.30 | 88.21 | 7.98 | 2912.43 | 32.65 |
| LSD (0.05) | ns | ns | ns | ns | ns | ns |
| Year | | | | | | |
| Year 1(2020) | 65.28[a] | 121.61[a] | 83.70[b] | 7.59[b] | 3068.86[a] | 34.9[a] |
| Year 2(2021) | 64.51[b] | 104.80[b] | 91.35[a] | 8.35[a] | 2825.79[b] | 31.4[b] |
| LSD (0.05) | 0.68 | 0.68 | 1.81 | 0.15 | 136.7 | 1.73 |
| Locations | | | | | | |
| Adet site | 64.07[b] | 107.77[c] | 87.39[b] | 7.63[c] | 3229.53[a] | 36.00[a] |
| D/tabor site | 66.82[a] | 111.90[b] | 84.80[c] | 8.30[a] | 2860.99[b] | 31.41[b] |
| Enewari site | 63.8[b] | 119.93[a] | 90.38[a] | 7.97[b] | 2751.44[b] | 32.00[b] |
| LSD (0.05) | 0.84 | 0.83 | 2.21 | 0.19 | 167.42 | 2.12 |
| CV | 3.56 | 2.03 | 6.98 | 6.44 | 15.71 | 17.66 |

Notes: Means in the same column followed by similar letters are not significantly different from each other at the 5% level of probability.

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was due to increased light penetration through the plant canopy of malt barley. The findings were also in line with Zelalem et al. (2006), who reported that increasing the rate of seeding decreased the number of grains per spike.

*One Thousand Seed Weight*

The maximum value of thousand seed weight (35.83 g) was recorded at a seed rate of 125 kg.ha$^{-1}$ for the basic seed class, though statistically at par to that obtained from 75 kg.ha$^{-1}$ under a similar seed class (Table 4). The lowest thousand-seed weight (31.11 g) was obtained from a seed rate of 150 kg.ha$^{-1}$ for the basic seed class (Table 4). This could be due to the high density induced by a rising number of spikes, which enhances competition and reduces the availability of photosynthesis for grain filling, resulting in a decrease in thousand-kernel weight due to the high plant population. Seeds with a higher TSW have better milling quality and ensure better emergence (Yekoye et al., 2023). The result agrees with (Usman, 2022), who reported that the higher seed rate in

bread wheat resulted in decreased 1000-seed weight. Similar findings were consistent with those of Wondimu et al. (2022), who reported that increasing seeding rates significantly decreased kernel weight of bread wheat and vice versa. Grain weight differs in its responses to temperature and location, suggesting that wheat grain filling is closely related to optimal nutrients, temperature, and location. The interaction between seed rate and location was significant ($p < 0.05$) (Figure 5A). Similarly, the interaction between year and location on TSW was significant ($p = 2.2 \times 10^{-16}$) (Figure 5B). The highest TSW (43.43 g) was at a seed rate of 150 kg.ha$^{-1}$ with at Enewari, it was statistically at par with the result obtained in plots seeded with 125 kg.ha$^{-1}$ with similar locations, however, the lowest TSW (24.6 g) was at a seed rate of 100 kg.ha$^{-1}$ with at D/Tabor (Figure 5 A). Considering the locations by year interaction effect, the largest (46.39 g) TSW was observed at a location of Enewari in the year 2021 while the lowest (25.48 g) was at D/Tabor in 2021, it was statistically at par with the result obtained in plots seeded with in the year of 2020 with similar locations (Figure 5 B).

Table 4. The interaction effects of seed rate and seed class on the number of seeds per spike and thousand seed weight of bread wheat combined over locations and years (2020 and 2021)

| Seed rates (kg.ha$^{-1}$) | Number of seeds per spike | | 1000 seed-weight (g) | |
|---|---|---|---|---|
| | Breeder seeds | Basic seeds | Breeder seeds | Basic seeds |
| 50 | 46.33[ab] | 48.60[a] | 34.63[b] | 33.34[c] |
| 75 | 46.22[ab] | 45.42[ab] | 33[bc] | 35.15[a] |
| 100 | 43.17[bc] | 44.73[bc] | 33.96[bc] | 33.42[c] |
| 125 | 45.39[b] | 41.63[c] | 31.33[cd] | 35.83[a] |
| 150 | 40.35[cd] | 42.45[c] | 33.83[bc] | 31.11[cd] |
| LSD (0.05) | 7.30 | | 4.60 | |
| CV (%) | 10.16 | | 8.39 | |

Notes: Means in the same column followed by similar letters are not significantly different from each other at the 5% level of probability.
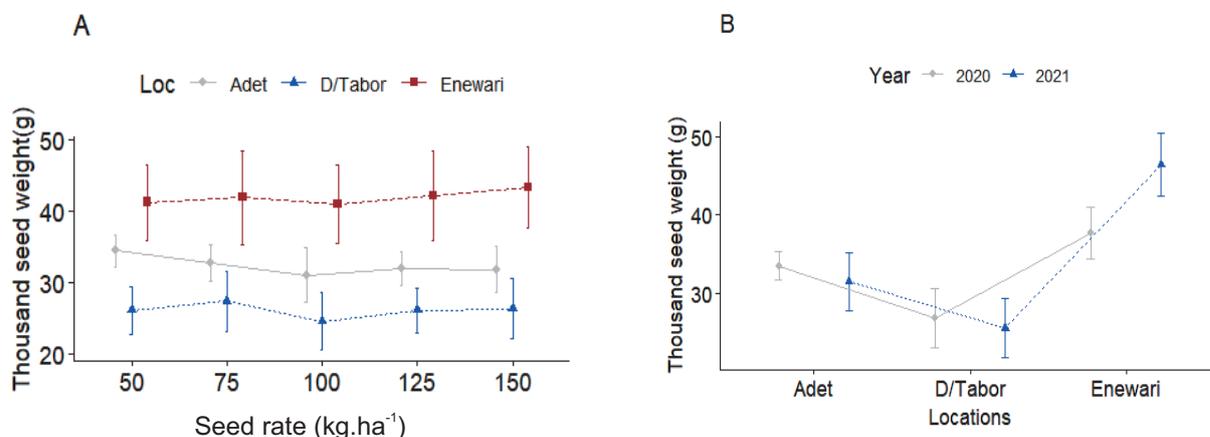


Figure 5. Ggline plot of the interaction effect of seed rates and locations (A), and location and years (B), on thousand seed weight of bread wheat at the different districts.

*Physical and Physiological Quality Parameters of Bread Wheat Seed*

The homogeneity test was applied for all physical and physiological quality parameters of bread wheat data in each location and year. The homogeneity of variance test result for the physical and physiological quality parameters of bread wheat revealed that the data were homogeneously distributed. The combined over-location analysis of variance for purity percentage, standard germination, speed of germination, seedling dry weight, seedling length, vigor index I, and vigor index II in 2020 and 2021 are presented in Table 5. The main effect of seed rate and seed class, as well as their interactions, did not significantly (P > 0.05) affect all physical and physiological quality parameters of bread wheat seed. However, except for root length and seedling vigor index, all physical and physiological quality parameters of bread wheat were significantly (P <0.05) influenced by the growing years/seasons (Table 5). Additionally, except for inert matter, standard germination and seedling dry weight, all quality parameters were significantly (P < 0.05) influenced by the combined effects of locations (Table 5). Except for seedling dry weight, the fourth interaction among year, location, seed rate, and seed class significantly (P < 0.05) affected all physical and physiological quality parameters of bread wheat early generation seed. However, the interaction between seed rate and location did not significantly (P > 0.05) affect the physical and physiological quality parameters of bread wheat, except for pure seed and inert matter (Table 5).

Table 6 shows the average mean of pure seed, standard germination, speed of germination, average shoot length, average root length, seedling dry weight, vigor index I, and vigor index II for the bread wheat crop. Except for the root length and seedling vigor index (I), all seed quality measures were unaffected by different seed classes, seed rates, and their interactions. However, they did vary significantly across years. This finding is consistent with Tilaye and Belayneh (2024), who found no differences in the physiological quality of malt barley seeds derived from low plant-density crops. Years have a substantial influence on quality traits, including standard germination, germination speed, seedling dry weight, shoot length, and vigor index (Table 5). Similarly, Bitwoded et al. (2022) reported that seedlings with well-developed shoot and root systems would withstand any adverse conditions and provide better seedling emergence and seedling establishment in the field. All quality treatments meet the Ethiopian seed quality standards established for seed classes of bread wheat. As prescribed in the Ethiopian National Seed Standard for bread wheat (Table 6), the minimum requirements for purity and germination percentage (98% and 90%, respectively, for breeder and basic seed) were met, according to the Quality and Standards Authority of Ethiopia (QSAE, 2017).

*Economic Analysis of Seed Yield in Response to Seed Rate Combined Over the Three Locations*

The economic analysis revealed that the highest net benefit of Birr 154,728.10 ha$^{-1}$ was recorded at a seed rate of 125 kg.ha$^{-1}$, with a marginal rate of return of

Table 5. Mean square values for effects of seed rate, seed class, and their interaction on bread wheat physical and physiological seed quality traits combined over locations and years (2020 and 2021)

| Source of variation | Df | PS | SG | SPG | SDW | SL | RL | SVI | SVII |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Mean square value | | | | |
| YR | 1 | 2.1** | 862.4** | 99.9** | 0.09** | 144.1** | 0.47ns | 3583804.5ns | 1104** |
| SC | 1 | 0.16ns | 26.57ns | 0.0001ns | 0.00ns | 0.11ns | 0.14ns | 25278.8ns | 6ns |
| SR | 4 | 0.1ns | 12.22ns | 0.9ns | 0.00ns | 1.08ns | 0.43ns | 39484ns | 3.43ns |
| Loc | 2 | 2.86** | 23.94ns | 971.6** | 0.00ns | 1196** | 393.76** | 25899389** | 72.29** |
| SR*SC | 4 | 0.09ns | 6.59ns | 2.27ns | 0.00ns | 0.36ns | 0.58ns | 5009.5ns | 6.6ns |
| SC*YR | 1 | 0.14ns | 0.09ns | 1.43ns | 0.00ns | 3.92* | 13.31** | 325813.8** | 2.96ns |
| SR*YR | 4 | 0.44** | 7.27ns | 2.69ns | 0.00ns | 0.11ns | 0.82ns | 27296ns | 3.94ns |
| SR*Loc | 8 | 0.19* | 2.05ns | 0.75ns | 0.00ns | 0.44ns | 1.99ns | 35467ns | 6.1ns |
| SC*Loc | 2 | 0.05ns | 14.97ns | 0.49ns | 0.00ns | 2.17* | 3.27ns | 66705ns | 4.3ns |
| SC*SR*YR*Loc | 4 | 0.63** | 23.55** | 8.75** | 0.00ns | 2.63** | 3.66** | 144289.7** | 57.47** |

Notes: ns, *, and ** indicate non-significant, significant, and highly significant at the 5% level of probability, respectively; PS: pure seed; SPG: speed of germination; SG: standard germination; SL: shoot length; RL: root length; SDW: seedling dry weight; SVI: seedling vigor index one and SVII: seedling vigor index two; SR: seed rate; SC: seed class; YR: year; Loc: location.

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1131.19%.  This was followed by a net benefit of Birr 138,953 ha⁻¹ from a seed rate of 100 kg.ha⁻¹, with a marginal rate of return of 18.8%. This means that for every Birr 1.00 invested in 125 kg.ha⁻¹, producers can expect to recover the Birr 1.00 and obtain an additional Birr 11.31. In contrast, the lowest net benefit (Birr 125,477.1 ha⁻¹) was recorded at a seed rate of 50 kg.ha⁻¹ (Table 7). The most economically attractive yield of bread wheat early generation seed production in the study area was achieved at a seed rate of 125 kg.ha⁻¹, characterized by a low cost of production and higher benefits.  Therefore, the use of a 125 kg.ha⁻¹

Table 6. Average mean of purity percentage, standard germination, speed of germination, seedling dry weight, shoot length, root length, seedling vigor index I, and vigor index II of seed rate and seed class combined over locations and years

| Treatments | Purity (%) | Standard germination (%) | Germination speed | Seedling dry weight (g) | Shoot length (cm) | Root length (cm) | Seedling vigor index I | Seedling vigor index II |
|---|---|---|---|---|---|---|---|---|
| Seed rates (kg.ha⁻¹) | | | | | | | | |
| 50 | 99.74 | 94.55 | 24.76 | 0.09 | 12.06 | 12.93 | 2368.25 | 8.30 |
| 75 | 99.82 | 95.92 | 24.98 | 0.09 | 12.13 | 13.06 | 2415.76 | 8.55 |
| 100 | 99.80 | 95.72 | 24.65 | 0.09 | 11.90 | 12.82 | 2367.27 | 8.37 |
| 125 | 99.80 | 95.67 | 25.00 | 0.10 | 12.17 | 13.00 | 2410.31 | 9.00 |
| 150 | 99.80 | 95.03 | 24.87 | 0.09 | 11.77 | 12.86 | 2342.89 | 8.83 |
| LSD (0.05) | ns | ns | ns | ns | ns | ns | ns | ns |
| Seed class | | | | | | | | |
| Breeder seeds | 99.56 | 95.74 | 24.87 | 0.09 | 12.00 | 12.96 | 2391.45 | 8.44 |
| Basic seeds | 99.62 | 95.00 | 24.86 | 0.09 | 11.99 | 12.91 | 2370.34 | 8.79 |
| LSD (0.05) | ns | ns | ns | ns | ns | ns | ns | ns |
| Year | | | | | | | | |
| Year 1(2020) | 99.49 | 93.19$^b$ | 24.11$^b$ | 0.06$^b$ | 11.11$^b$ | 12.88 | 2239.79 | 6.13$^b$ |
| Year 2(2021) | 99.49 | 97.57$^a$ | 25.60$^a$ | 0.11$^a$ | 12.90$^a$ | 12.98 | 2522.00 | 11.09$^a$ |
| LSD (0.05) | ns | 0.88 | 0.32 | 0.001 | 0.24 | ns | ns | 0.79 |
| Locations | | | | | | | | |
| Adet site | 99.6 | 94.85 | 22.26$^c$ | 0.08 | 14.32$^b$ | 13.65$^b$ | 2660.78$^b$ | 7.4$^b$ |
| D/Tabor site | 99.36 | 95.22 | 22.82$^b$ | 0.09 | 14.85$^a$ | 15.00$^a$ | 2852.92$^a$ | 8.89$^a$ |
| Enewari site | 99.81 | 96.07 | 29.5$^a$ | 0.10 | 6.86$^c$ | 10.00$^c$ | 1629$^c$ | 9.54$^a$ |
| LSD (0.05) | ns | ns | 0.40 | ns | 0.30 | 0.44 | 74.41 | 0.97 |
| CV | 0.22 | 3.14 | 4.42 | 30.80 | 6.80 | 9.41 | 8.64 | 31.18 |

Notes: Means in the same column followed by similar letters are not significantly different from each other at the 5% level of probability.

Table 7. Economic analysis of seed rate on seed yield (qt.ha⁻¹) of bread wheat, combined over locations and years (2020 and 2021)

| Seed rates | Seed yield (Qt.ha⁻¹) | Adjusted seed yield (Qt.ha⁻¹) | Gross benefit (ETB.ha⁻¹) | Total variable cost (ETB.ha⁻¹) | Net benefit (ETB.ha⁻¹) | Marginal rate of return (%) |
|---|---|---|---|---|---|---|
| 50 | 25.55 | 22.995 | 128266.1 | 2789 | 125477.1 | - |
| 75 | 28.46 | 25.614 | 142874.9 | 4183.5 | 138691.9 | 947.60 |
| 100 | 28.79 | 25.911 | 144531.6 | 5578 | 138953 | 18.80 |
| 125 | 32.21 | 28.989 | 161700.6 | 6972.5 | 154728.1 | 1131.19 |
| 150 | 32.35 | 29.115 | 162403.5 | 8367 | 154036.5D | |

Notes: ETB, Ethiopian Birr; D, dominance.

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seeding rate for bread wheat was profitable and recommended for early-generation seed production in the study area and similar agroecologies.

## Conclusions

The results indicated that lower seed rates gave better seed multiplication factors at all the tested locations. In the laboratory experiment, the seed samples from all tested location treatments met the minimum requirements for bread wheat quality seed certification standards of Ethiopia. Increasing the seed rate from 50 to 150 kg.ha$^{-1}$ has increased seed yield combined across the tested locations. However, the difference in seed yield between seed rates of 125 and 150 kg.ha$^{-1}$ is statistically insignificant. The combined location's economic analysis also showed that a 125 kg.ha$^{-1}$ seed rate was more profitable than the other seed rates. Therefore, it was concluded that a seed rate of 125 kg.ha$^{-1}$ is the optimum rate for both seed classes of bread wheat to accelerate early generation seed production when integrating high inputs and intensive agronomic management in the three tested locations and similar agroecology.

## Acknowledgment

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