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Research Article

Optimizing seeding rates for irrigated bread wheat (*Triticum aestivum* L.) varieties in the lowland area of Jawi, northwestern Ethiopia

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Abstract: *Bread wheat (Triticum aestivum* L.*) is one of the main food security crops in sub-Saharan Africa. The Ethiopian government is putting a great effort into increasing the production of bread wheat under various production systems to narrow the gap between demand and supply. There is no agronomic recommendation for wheat production produced under irrigation conditions. Thus, this study was initiated to identify the optimum seeding rates of different wheat varieties for the highest-yield and profitability in the lowland area of northwestern Ethiopia under irrigation conditions in 2020/2021. The experiment was laid out using a randomized complete block design with three replications. The treatments are five levels of seeding rates (100, 125, 150, 175 and 200 kg ha^{-1}) and three bread wheat varieties (Fentale-2, Kakaba and Ogelcho). Wheat yield and yield component data were statistically subjected to analysis of variance using SAS-JMP-16 software. Results revealed that the performance of wheat varieties in the lowland area of Jawi was promising irrespective of their yield differences. The study showed the highest number of total and effective tillers per unit area; and biomass and grain yield were recorded when varieties Fentale-2, Kakaba and Ogelcho were planted at a seed rate of 200 kg ha^{-1}, 175 kg ha^{-1} and 200 kg ha^{-1}, respectively.The same varieties gave a grain yield of 3.99 t ha^{-1}, 3.47 t ha^{-1} and 3.44 t ha^{-1}, respectively. On the other side, maximum net benefit and marginal rate of return were obtained when the variety Fentale-2 was planted at a seeding rate of 200 kg ha^{-1} (NB = 65,778.8 ETB ha^{-1} and MRR = 224 %) followed by the same variety at the seed rate 175 kg ha^{-1} (NB = 63,402.4 ETB ha^{-1} and MRR = 297 %). Thus, it can be concluded that planting variety Fentale-2 with 200 kg ha^{-1} seed rate under irrigation condition is the promising agronomic practice in lowland agro-ecology of Jawi area. However, further research is also recommended by considering the appropriate planting time and the irrigation water requirement.*

Keywords: Keywords: *Bread wheat, Fentale-2, Grain yield, Production system*
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1. Introduction

In Sub-Saharan African countries such as Ethiopia, bread wheat has become one of the most important strategic cereal crops due to its role in food security, import substitution and the supply of raw materials for the agro-processing industry (Getinet *et al.*, 2020; Derebe *et al.*, 2021). Ethiopia is ranked the 1st, 2nd and 18th wheat producer in sub-Saharan Africa

(Brasesco *et al.,* 2019), Africa and the world, respectively, by producing 5,700,000 metric tons (USDA, 2020). In Ethiopia, there are four crop production systems per year: (1) rain-fed season (dry land farming); (2) under irrigation conditions (growing crops during off-season)) (3) *Belege* production season; (4) crop production through residual moisture (Takele, 2019). Despite the possibility of various production seasons, bread wheat is produced mostly during the main rainy season (Meher cropping). Thus, during the 2019/2020 main (rain-fed) growing season, the country's total production was 5.3 million on 1.8 million hectares of land accounting for approximately 18% of the country's total cereal production produced during the same production season, with an average productivity of 2.97 t ha^{-1} (CSA, 2020; USDA, 2020). Moreover, the rain-fed bread wheat production system is only limited to mid and highland areas of the country that lay between 6^o and 16^o N latitude and 35^o and 42^o E longitudes and at an altitude range of 1500 to 3000 m.a.s.l (meters above sea level) (Bekele *et al.*, 2000).

The human population in Ethiopia increased geometrically (Bitew *et al.*, 2021) while local wheat production under rainy season is only growing at a rate of 7.8%. On the other hand, the demand for wheat is growing at an average rate of 9% per year (khan *et al.,* 2020). Hence, Ethiopia remains a net importer of wheat as a result of a gap between production and consumption levels (Hodson, 2020). Therefore importing about 1.5 million tons of wheat annually is draining 300-400 million USD from the national treasury (FAOSTAT, 2021). Enhancement of bread wheat production is thus expected to be achieved through expansion of irrigation agriculture, mechanization (Mihratu *et al.,* 2018), land expansion (EIAR, 2020), provision of quality agricultural inputs, use of economically viable and ecologically adaptable varieties for lowland areas (Gedifew, 2022) and application of good agronomic practices for all crop production systems (Khan *et al.,* 2020).

Ethiopia has extensive irrigation potential estimated to exceed 5.3 million ha for crop production (Seleshi *et al.,* 2010). The duration of the irrigation varies on agro-ecologies (Fitih *et al.,* 2020). The irrigation potential in the low land (<1500 m.a.s.l) areas of the country is one of the intact potential for wheat production, which helps to make the country self-sufficient in wheat within a short period (EIAR, 2020). Changing the current low level of wheat production is the key agenda for the government of Ethiopia (Gebreselassie *et al.,* 2017). The agriculture sector aspires not only to bring food self-sufficiency to the nation but also to penetrate the international market and export large quantities of agricultural products including wheat by leveraging the country's full potential. In this regard, more than 400,000 ha of wheat were cultivated under irrigation in the year 2021/22 production season across the entire country (Gedifew, 2022).

The national irrigated lowland wheat research and development program reported the possibility of increasing the national wheat productivity from 0.30 t ha^{-1} to 0.50 t ha^{-1} by implementing the irrigated wheat production system (Gedifew, 2022). Globally, rain-fed crop yields are about 50% lower than yields obtained under irrigated conditions. However, the productivity of wheat under irrigation in Ethiopian conditions is about 2.5 -5 ton ha^{-1}, which is lower than the attainable yield of the crop (6.5 ton ha^{-1}) (EIAR, 2020). This is mainly because, crop management practices such as seeding rate, improved variety, soil management, planting methods etc. implemented for the production of wheat under irrigation are mainly based on the recommendations for wheat production under rain-fed conditions. This situation may contribute to the low level of wheat yield in the irrigated production system of Ethiopia, which necessitates optimization of the agronomic practices including the seeding rate.

Generally, there is no recommended agronomic practice for bread wheat production under irrigation conditions. Rather, crop management practices for irrigated wheat crop are mainly based on recommended rates for the respective fed production system. Seeding rate is the most important agronomic practice which needs great emphasis for enhanced yield of the crops cultivated under the various production systems (Amare and Mulatu, 2017). Depending on the production systems and agro-ecology, research results indicated that the use of proper seed rate encourages nutrient availability, and proper sun-light penetration for photosynthesis. Similarly, the use of proper seed rate encourages a good soil environment for the uptake of soil nutrients and water use efficiency, and consequently increases the production and productivity of the crop (Alemayehu, 2015).

Selection of better-performing bread wheat varieties is also the basic step in enhancing the productivityof wheat (Nizamani *et al.*, 2014). In this regard, there are limited research results that focus on identification of best-performing bread wheat varieties under irrigated production systems in the lowland areas of Ethiopia. On the other hand, the performance of crop varieties including bread wheat depends on the prevailing climatic conditions, soil types and other biotic factors (Li and Troy, 2018). Thus, the objective of this research was to select the appropriate bread varieties along with their optimum seeding rates for the production of bread wheat in lowland areas using an irrigation production system.

2. Materials and Methods

2.1. Description of the study area

The experiment was carried out in the low-land areas of Jawi district, Northwestern Ethiopia. The global positioning of the experimental site is 11°00′7″ N (longitude) and 36°02′0″ E (latitude) with an altitude of 1254 m.a.s.l (Direct GPS reading). The climate alternates with long summer rain fall (June-September) and a winter dry season (October-May) with a mean annual rainfall of 1569.4 mm (Mihretu *et al.*, 2022). The district is warm and humid lowland. The mean maximum temperature during the experimental year was 38.1 °C (April) while the mean minimum temperature was recorded in January (11.6 °C) as indicated in Figure 1. Generally, during the experimental months (November - April), the temperature was higher compared to other months and there was no rainfall. The soil types of the experimental area were vertisols with the textural class of clay to clay loam (unpublished). The land is covered by different vegetation types namely savanna grassland, forest, riverine and bush lands with major agricultural products like sorghum, maize, sesame and cotton (Abay and Tilaye , 2018).

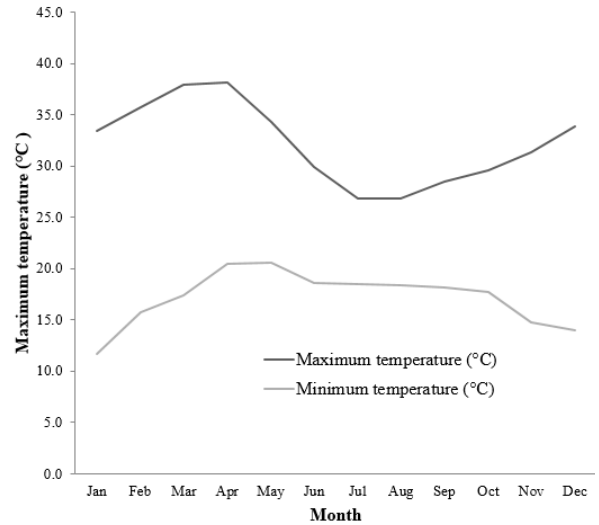


Figure 1: Average monthly maximum and minimum temperature of the study area during the experimental year (2020/2021)

2.2. Experimental materials

Three wheat varieties namely *Fentale-2, Kakaba (Picaflor) and Ogelcho* were used for the experiment (Table 1). *Kakaba* (Picaflor#1) wheat variety was developed for low, mid and high altitudes while the *Ogolcho* variety was developed and released for lowland to mid-altitude areas of the country in 2010 and 2012, respectively. Both two varieties were developed by EIAR at Kulumsa Agricultural Research Centre (Table 1). *Fentale-2* variety is recommended for lowland irrigated areas of Awash Valley by the Ethiopian Institute of Agricultural Research (EIAR). The seeds of these varieties together with their full production package were collected from the Ethiopian Institute of Agricultural Research.

2.3. Experimental treatments and designs

The treatments consisted five levels of seeding rates (100, 125, 150, 175 and 200 kg ha^{-1}) and three wheat varieties released for the irrigation production system (*Fentale-2, Kakaba and Ogolcho*). The experiment was laid out in a randomized complete block design (RCBD) with three replications. Wheat was planted with an inter-row spacing of 0.20 m. The gross plot size was 3.2 m x 3.00 m (9.6 m^2). The net plot area was 1.20 m x 2.50 m (3.00 m^2). The distance between adjacent plots and blocks was 0.50 m and 1.00 m wide, respectively.

Table 1: Description of Agronomic and morphological Characteristics of bread wheat varieties used for the study

SN	Description	Bread wheat varieties registered/released by EIAR		
		Kakaba	Ogelcho	Fentale-2
1	Adaptation area	Low Mid High altitude	Lowland- Mid altitude	From lower to upper awash
1.1	Altitude (m.a.s.l.)	1500-2200	1600-2100	300-1200
1.2	Rain fall (mm)	500-800	400-500	
2	Seed rate (Kg ha^{-1})	150-175	125 row,150 broadcast	80-100
3	Days to heading	50-70	60	45
3	Days to maturity	90-120	102	81
4	Spike length(cm)	--	--	8
5	Number of kernel/spike	--	--	39
6	1000 seed weight (gram)	39	26	40
7	Plant height (cm)	85-100	70	72
8	Seed color	White	white	white
9	Crop yield (t ha^{-1})			
9.1	Research field	3.3-5.2	2.8-4.0	5.0-6.0
9.2	Farmer field	2.5-4.7	2.2-3.5	4.0-4.5
10	Year of release	2010	2012	2017
11	Breeder/Maintainer	KARC/EIAR	KARC/EIAR	WARC/EIAR

Source: MoA (2021)

2.4. Experimental procedures

The experiment was conducted under irrigation conditions. Experimental plots were ploughed three times using an oxen-plough. The first and the second plow was done in October, the third plough was done in November (2020). Smoothing and levelling of the experimental plots were done mechanically on the same date of sowing. Seeds of each wheat variety were drilled in rows at its recommended inter-row spacing of 20 cm. Wheat plants received N and P_2O_5 fertilizers at the rates of 46 kg ha^{-1} P_2O_5 in the form of NPS and 69 kg ha^{-1} N in the form of urea. All the recommended quantities of P_2O_5 and 2/3 of N were applied at the time of planting, while the remaining 1/3 N was applied at the tillering stage (35 days after emergence) (Worku, 2008). Fertilizers were applied in a band with a depth of 2 cm. Irrigation was done in furrow (40 cm wide) using surface irrigation technique at the frequency of 10 day intervals. Weeding was done at the early tillering, maximum tillering and booting stages of the wheat plant (Worku, 2008).

2.5. Data collection

Average plant height was measured from ten randomly taken plants of the net plot at 90% physiological maturity. Spike length (SL in cm) was taken as the average spike length of 10 randomly taken plant samples grown in the harvestable rows, by measuring the spike length from its base to the tip by excluding the awns. The number of total and effective tillers per meter square was counted from $1m^2$ quadrant in each net plot. Number of kernels per spike (NKPS) was recorded from randomly take 10 plants grown in net plots. The total above ground-biomass from the net plot area was harvested and sun-dried for two weeks with an average air temperature of 25–27 °C.

Grain yield was separated and determined from the total biomass yield. The grain yield was separated, dried, threshed, cleaned and adjusted to the 12.5% moisture level. The moisture correction factor was done using the formula described by Birru (1979) as indicated below.

$$\text{Adjusted Yield} = \frac{100 - \text{Measured moisture content (\%)}}{100 - 12.5\%} \quad [1]$$

The 12.5% moisture-adjusted grain yield was then obtained by multiplying the grain yield obtained from each plot multiplied with the moisture correction factors.

Thousand-kernel weight (TKW g) was determined by counting 1000 grains harvested from the net plot area using an electronic automatic seed counter and weighing them with a sensitive balance of precision + 0.001g. The TKW weight was recorded after the grain was adjusted to 12.5% moisture content by using the Draminski Gmm mini quick moisture tester instrument. Harvest index (HI) values of each treatment were computed as the percent ratio of grain (economic) yield to the total biomass (straw and grain) yield per plant from the respective treatments and expressed in percentile using the following formula (Donald, 1963).

$$\text{Harvest index } (\%) = \frac{\text{Economice yield(t per ha)}}{\text{Total biological yield (t per ha)}} * 100 \quad [2]$$

Straw yield (SY t ha^{-1}) was obtained by subtracting the grain yield from the corresponding total biomass yield.

2.6. Data analysis

2.6.1. Statistical analysis

Quantitative data from the experimental field were entered to Microsoft Office Excel. The same software was used for data edition and management. Data ware subjected to analysis of variance (ANOVA) using statistical procedures as described by Gomez and Gomez (1984) with the help of SAS statistical analysis software version 9.4 (2008). Before ANOVA analysis, data were checked for normal distribution following the scatter plot technique. Data were analyzed with seeding rates and crop varieties as fixed effects and replication as random effects. When crop characteristics showed significant differences at any probability level, mean separation was conducted using the Least Significance Difference (LSD). Regression analysis was conducted to determine the relationship between (a) NETPMS and seed rate and (b) grain yield and number of effective tillers per meter square.

2.6.2. Partial budget analysis

Partial budget analysis was conducted to explore the economic feasibility of the treatments being tested following the procedure of CIMMYT (1988). The cost of improved seeds was the only variable cost that varied with the cultivars (total variable cost), while the labor cost for land preparation, planting, weeding, harvesting, trashing, cleaning and other crop management practices were fixed costs. Grain yield was the only output yield and the cost is the output cost, since straw yield of the varieties were not significantly varied across seeding rates. Costs of the improved seeds were 33, 31 and 31 Ethiopian birr per kilo gram (ETB kg^{-1}) for *Fentale-2, Ogelcho and Kakaba*, respectively. Price of wheat grain yield was 24.20 ETB kg^{-1}. All costs were calculated as the average value of June to February during 2021/2022. The mean grain yield was adjusted downward by 10% so as to reduce the yield gabs between experimental plots and farmers' fields. The gross field benefits for each treatment were calculated by multiplying the field price by the adjusted yield. Total costs that vary for each treatment are the sum of the individual costs that vary. Net benefit was calculated by subtracting cost of production (TVC) from gross benefit. Dominance analysis was performed before calculating the Marginal rate of return (MRR). MRR was calculated as a change of net benefit divided by a change of total variable cost as indicated by CIMMYT (1988). A treatment which is non-dominated and has the highest net benefit is said to be economically profitable (CIMMYT, 1988).

$$\text{MRR } (\%) = \left(\frac{\mathbf{NBT1-NBT2}}{\mathbf{TVCT2-TVCT1}}\right) * 100 \quad [3]$$

Where; T2 and T1 are consecutive treatments arranged in ascending order based on their TVC after excluding treatments with low net benefit and high total variable cost**.**

3. Results and Discussion

3.1. Agronomic attributes

The analysis of variance for plant height (PH), spike length (SL), total number of tillers per meter square (TNTPMS), number of kernels per spike (NKPS), biomass yield (BY), straw yield (SY), harvest index (HI) showed significant *($P < 0.05$)* differences among main effects of variety and seeding rate. However, their interaction effect had no significant *($P > 0.05$)* effect on these agronomic attributes. On the other hand, number of effective tillers per square (NETPMS), grain yield (GY) and thousand kernel weight (TKW) were significantly *($P < 0.05$)* affected by the main effects and their interaction effect.

Results revealed that variety Kakaba had produced the tallest plant height (88.11 cm), while variety Fentale-2 produced the shortest plant height (79.12 cm) (Figure 2). The difference in plant height among varieties could be ascribed to the difference in their genetic makeup. In agreement with the current results, Bayisa *et al.* (2019) reported that the height of the crop is mainly controlled by the genetic makeup of a genotype and it can also be affected by the agronomic practice and environmental factors.

On the other hand, the mean values of the data indicated that increasing the seeding rate of wheat from 100 kg ha^{-1} to 200 kg ha^{-1} increased the plant height of plant from 81.51 cm to 85.89 cm (Figure 3). The tallest plant (85.90 cm) was observed at a seeding rate of 200 kg ha^{-1} but statistically similar with a seed rate of 175 kg ha^{-1}, while the shortest plant (81.51 cm) was recorded when wheat was planted at the seeding rate of 100 kg ha^{-1}. The increase in plant height due to increased seed rate might be due to the presence of intense light competition as the plant population becomes denser. Tewodros *et al.* (2017) also remarked that increased plant density resulted in increased height of the plants, since high plant density resulted in minimum space for horizontal expansion of the plant and increase the competition for light interception between plants that in turn caused upward growth of the plant. In addition, Abiot (2017) also stated that longest and shortest plant heights were observed when wheat was planted at the highest and lowest seed rate, respectively. Contrary to the current results, researchers reported that plant height is significantly decreased as seed rate increased perhaps due to high competition among wheat plants for common resources in contradiction of phototropic computation of plants (Rahel and Fekadu, 2016; Amare and Mulatu, 2017).

Regardless of seed rate, *Ogelcho* (9.41cm) and *Fentale-2* (8.54cm) varieties gave the longest spike length, whereas *Kakaba* variety gave the shortest spike length (Figure 4). The result revealed that the spike length can be affected by agronomic practices like seeding rate in addition to its inherent characteristics and environment. This result is similar to the results of Amare and Mulatu (2017) who concluded that due to the inherent characteristics, individual genotypes responded differently to the spike length. Regardless of the varieties, planting irrigated wheat at various seeding rates showed differences in spike length (Figure 5). The tallest spike length was observed when wheat was planted at the seeding rate of 100 kg ha^{-1} (9.59 cm) but it was statistically similar with the seeding rate of 125 kg ha^{-1} (9.34 cm). The shortest spike length (8.3 cm) was observed when wheat was planted at the seeding rate of 200 kg ha^{-1}.

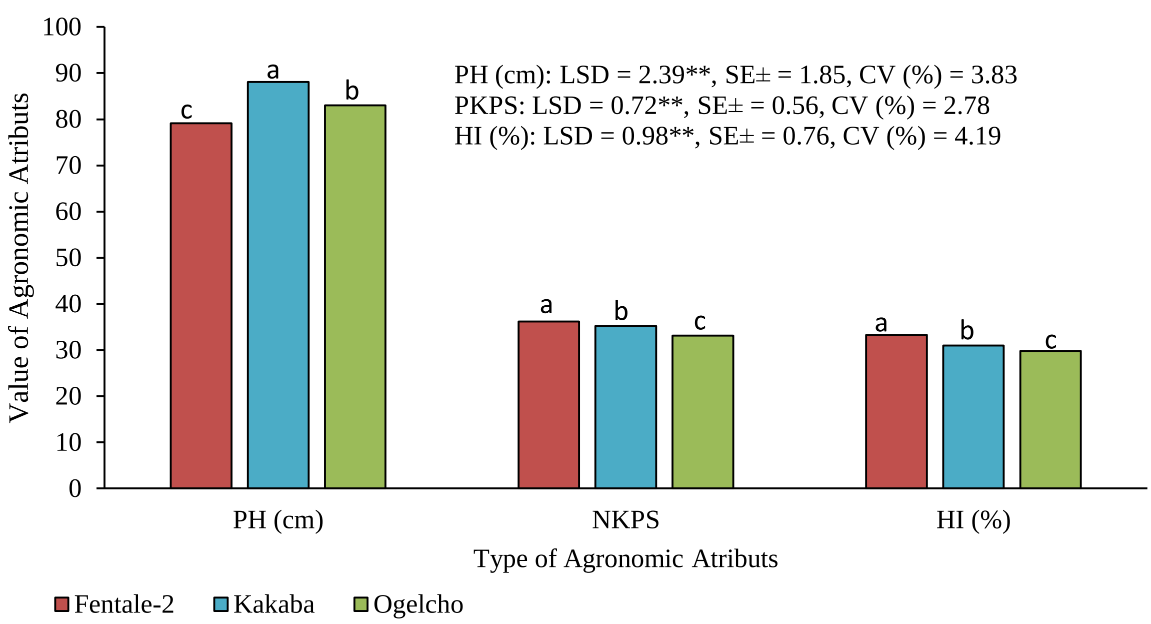
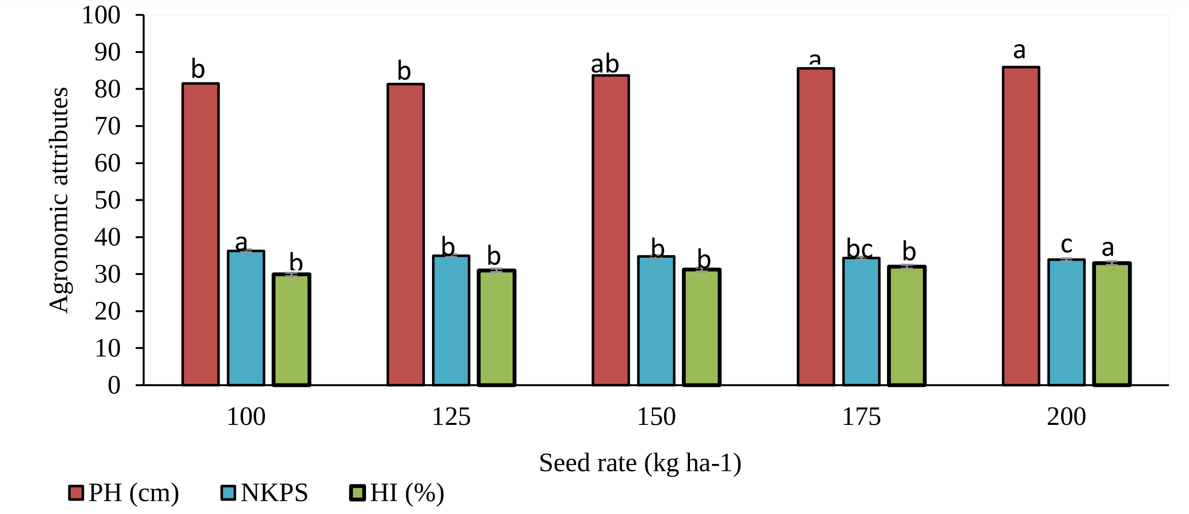


Figure 2: Plant height (PH), number of kernels per spike (NKPS) and harvest index (HI) difference among the various irrigated bread wheat varieties

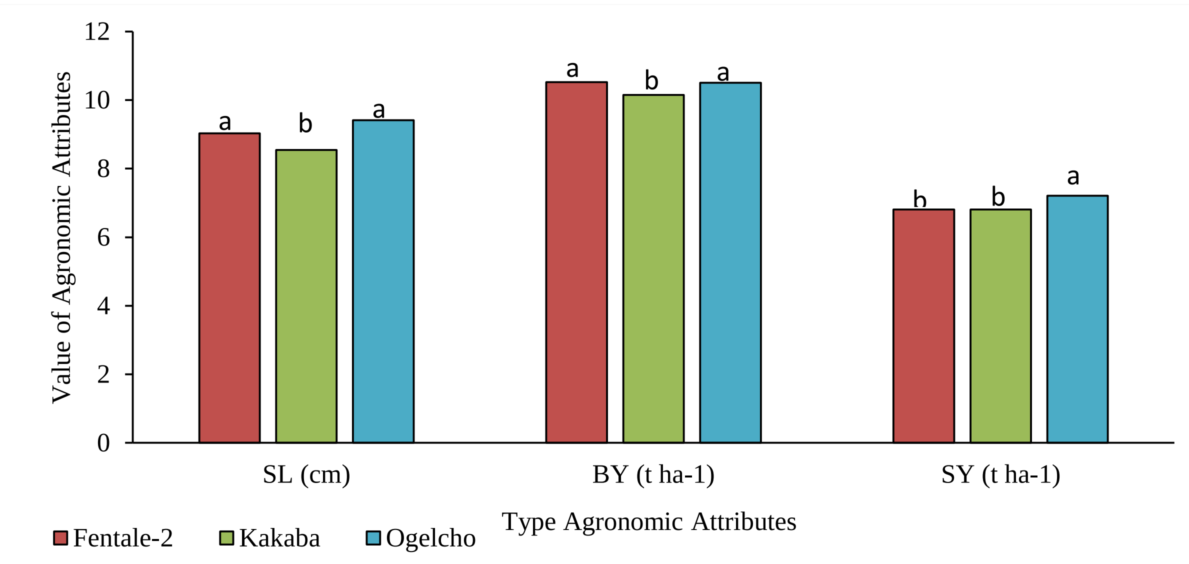
** and ** indicates significant and highly significant difference at 5% and 1% probability level, respectively. LSD = Least significant difference, CV (%) = coefficient of variation, SE+= standard error. Means followed by the same letter are not significantly difference among treatments*



PH: LSD = 93.1*, SE± = 1.43; NKPS: LSD = 0.93**, SE± = 0.43; HI: LSD = 1.27*, SE± = 0.59

Figure 3: Response of plant height (PH), number of kernels per spike (NKPS) and HI (%) to seed rates of irrigated bread wheat

** and ** indicate significant and highly significant differences at 5% and 1% probability level, respectively. LSD = Least significant difference, CV (%) = coefficient of variation, SE+= standard error. Means followed by the same letter are not significantly different among treatments.*



SL: LSD = 0.47**, SE± = 0.37, CV (%) = 7; BY: LSD = 0.277**, SE± = 0.22, CV (%) = 3.57; SY: LSD = 0.2895**, SE± = 0.223, CV (%) = 5.58

Figure 4: Spike length (SL), biomass yield (BY) and straw yield (SY) difference among the various irrigated bread wheat varieties

, ** and * indicate significant, highly significant and very highly significant difference at 5%, 1% and 0.1% probability level, respectively. LSD = Least significant difference, CV (%) = coefficient of variation, SE+= standard error. Means followed by the same letter are not significantly different among treatments.*

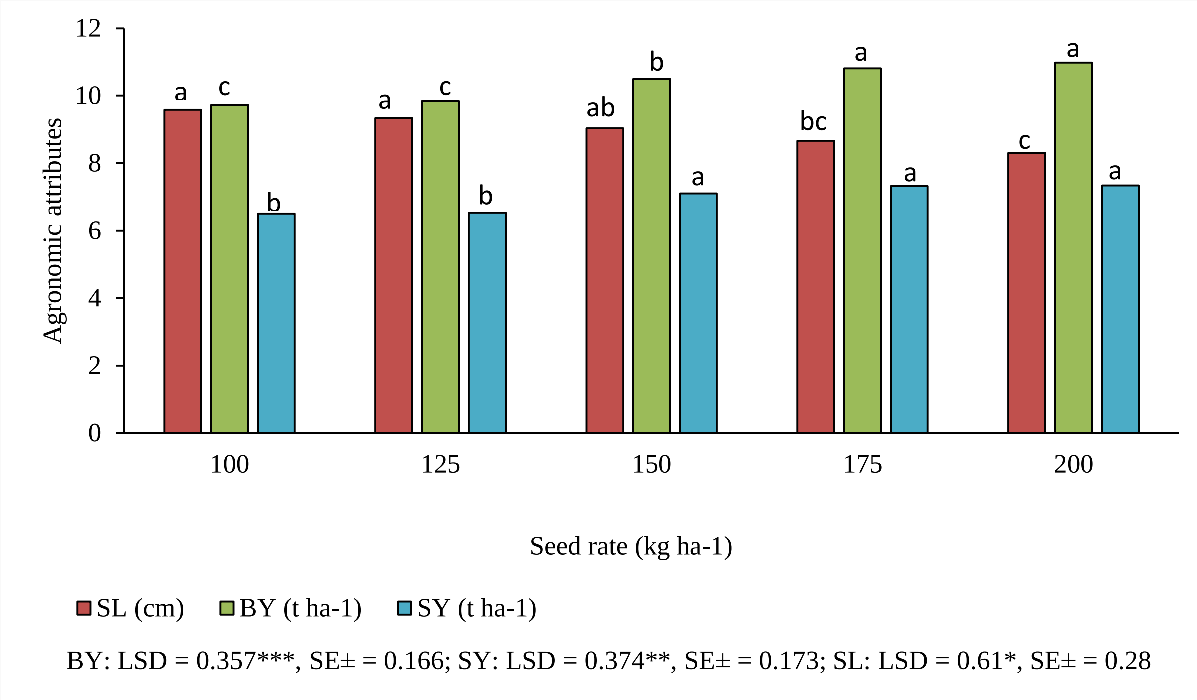


Figure 5: Response of spike length (SL), biomass yield (BY) and straw yield (SY) to various seed rates of irrigated bread wheat

, ** and * indicate significant, highly significant and very highly significant difference at 5%, 1% and 0.1% probability level, respectively. LSD = Least significant difference, CV (%) = coefficient of variation, SE+= standard error. Means followed by the same letter are not significantly different among treatments.*

The spike of wheat acts as a major sink for dry matter accumulation (Demotes *et al.*, 2001). Due to lower growth resource competition, wheat planted at a lower seeding rate showed longer spike length as compared to those planted at a higher seeding rate. The present findings are similar to the various works of the research that increased sowing density significantly decreased the spike length of bread wheat (Gafaar, 2007; Abiot, 2017).

The highest number of total tillers per m^{-2} was observed at the seeding rate of 200 kg ha^{-1} (361.60) followed by the seeding rate of 175 kg ha^{-1} (334.29) while less number of total tillers per m^{-2} was recorded at 100 kg ha^{-1} seeding rate (279.33) of wheat (Table 2). Increasing the seeding rate from 100 to 200 kg ha^{-1} increased the number of total tiller m^{-2} by 23 %. The highest number of total tillers per m^{-2} at the highest seed rate could be due to the high nutrient use efficiency of crops at the higher soil fertility status (Jamal *et al.*, 2015). The present findings are in conformity with the findings of Matsuyama and Ookawa (2020) who reported the highest tiller number m^{-2} decreased as the seeding rate reduced. On the other hand, the highest number of total tiller per m^{-2} was recorded from *Fentale-2* (330.58) and *Ogelcho* (325.11) varieties, which were statistically similar, while the lowest number of total tiller per m^{-2} was recorded from the *Kakaba* variety (301.17) as indicated in Table 2.

Sowing variety *Fentale-2* (306.63) and *Ogelcho* (302.43) at the seeding rate of 200 kg ha^{-1} showed greater effective tillers m^{-2} (statistically similar effect) (Table 2) while sowing all varieties at a seeding rate of 100 kg ha^{-1} showed statistically similar and lowest number of effective tillers per m^{-2}.

Table 2: Total number of tillers per meter square as affected by seed rates and bread wheat varieties

Treatments	Total number of tillers
Seeding rate (kg ha^{-1})	
100	279.33^{d}
125	312.93^{bc}
150	306.63^{c}
175	334.29^{b}
200	361.59^{a}
LSD	23.23**
SE±	1.83
Variety	
Fentale-2	330.58^{a}
Kakaba	301.17^{b}
Ogelcho	325.11^{a}
LSD	17.93*
SE±	2.37
CV (%)	7.54

LSD = Least significant difference, CV (%) = coefficient of variation, SE+= standard error. Means followed by the same letter are not significantly different among treatments

Regression analysis results showed that the number of effective tillers per m^2 increased linearly with the increasing seeding rate in all the tested varieties (Figure 6). The increase in the effective tillers in line with sowing density is due to the increase in the number of plants per unit area and the highest number of effective tillers or spikes per m^2. Similarly, several research results showed that the highest and lowest number of effective tillers was recorded when variety *Danda'a* was planted at the highest and lowest seeding rate, respectively (Jamal *et al.,* 2015; Khan et al., 2020, Nuru and Taminaw, 2021).

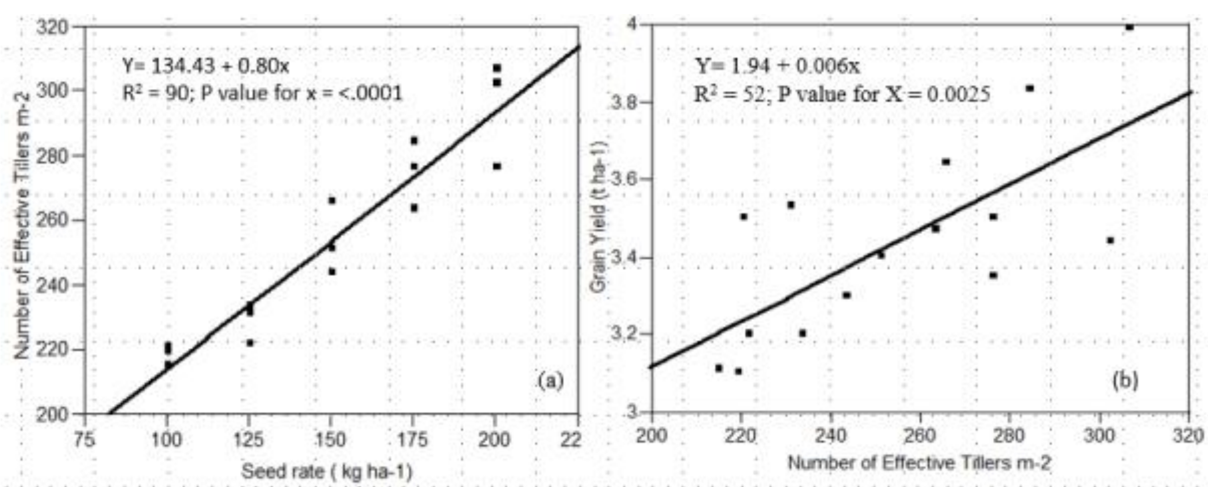


Figure 6: The relationship between (a) number of effective tiller per square meter (NETPMS) and seed rate and (b) between grain yield and number of effective tillers per meter square

Among the three tested wheat varieties, the variety *Fentale*-2 (10.52 t ha^{-1}) and *Ogelcho* (10.50 t ha^{-1}) produced the highest biomass yield. The remaining variety *Kakaba* produced the lowest biomass yield (10.15 t ha^{-1}) (Figure 4). The reason for the highest biomass yield from the former varieties might be related to its high number of total and effective tillers per m^{-2} resulting from the varietal adaptability to the area. Wheat sown at various seeding rates differed in biomass yield (Figure 5). Accordingly, the highest biomass yield was obtained when wheat was planted at a seeding rate of 200 kg ha^{-1} (10.98 t ha^{-1}) and 175 kg ha^{-1} (10.87 t ha^{-1}), which were statistically similar. The lowest biomass yield was obtained at 100 kg ha^{-1} seeding rate (9.73 t ha^{-1}). Results of the present study depicted that as the seeding rate increased from 100 to 200 kg ha^{-1}, the biomass yield of irrigated wheat become increased. The highest biomass production at the highest seed rate might be due to the increased plant population of wheat. These results are in agreement with the findings of Gafaar (2007) and Worku (2008) who claimed that the highest biological yield of wheat was obtained at the highest seeding rate as compared to the lower seeding rate.

The highest grain yield was obtained when the *Fentale*-2 variety was planted with the seeding rates of 200 kg ha^{-1} (3.99 t ha^{-1}) and 175 kg ha^{-1} (3.83 t ha^{-1}) (Table 3). On average, this variety gave a 10.50% yield advantage when the seeding rate increased from 100 to 200 kg ha^{-1}. The lowest grain yield was recorded when *Kakaba* (3.11 t ha^{-1}) and *Ogelcho* (3.10 t ha^{-1}) varieties were planted at the seeding rate of 100 kg ha^{-1} (Table 3).

Regression analysis results showed that grain yield increased linearly with the increasing seeding rate in all the tested varieties (Figure 6). The difference in the grain yield of wheat varieties might be due to the difference in genetic makeup and their different response to crop management practices. These results are in agreement with the findings of Dalia (2016) who reported that different varieties responded differently to varying seed rates.

The highest thousand kernel weight was recorded when *Fentale*-2 was planted with a seed rate of 100 (42.54g), 125 (41.31g) and 150 (41.13g) kg ha^{-1}, which are statistically similar when compared to each other (Table 3). The lowest thousand kernel weight was measured when *Kakaba* (34.77g) and Ogelcho (36.16) varieties were planted at the seed rate of 200 kg ha^{-1}. Regardless of the variety, the lowest thousand kernel weight was produced from the highest seeding rate, which might be due to the high plant population that resulted from intense growth resource competition. Research findings showed that thousand kernel weights of various bread wheat varieties respond differently as affected by different seed rates (Veselinka *et al.*, 2014; Khan *et al.*, 2020).

The ability of a cultivar to convert the dry matter into economic yield is indicated by its harvest index. The tested varieties (*Fentale-2, Kakaba and Ogelcho*) were significantly different from each other (Figure 2). Variety *Fentale-2* gave the highest harvest index (33.26%) followed by *Kakaba* (31.01%) while *Ogelcho* gave the lowest (29.81%) harvest index (Figure 2). The higher the harvest index value the greater the physiological potential of the crop in converting the dry matter to grain yield, which may be associated with the genetic makeup of the varieties. The current results are in line with the results of El-Lattief (2014) who found that one of the tested varieties *'Giza 168'* gave a significantly higher harvest index compared to the other tested variety *'Sohag 3'* over two consecutive years. Jamal *et al.* (2015) also noted significant differences between cultivars in the bread wheat harvest index.

Planting irrigated wheat at the seeding rates of 200 kg ha^{-1} and 100 kg ha^{-1} exhibited the highest (32.63%) and the lowest harvest index (29.9%), respectively (Figure 3). However, the 100 kg ha^{-1} seeding rate had a statistically similar effect with the remaining seeding rates. The highest harvest index along with increased seeding rate could be due to an increase in biological yield with a simultaneous increase in grain yield at the highest seeding rate. The results are in line with Abiot (2017) who found the highest harvest index (38.15%) at the relatively highest seeding rate of 150 kg ha^{-1} and the lowest harvest index (31.69%) at the seeding rate of 100 kg ha^{-1} of the tested bread wheat. Contrary to the present study Jamal et al. (2015) found that the lowest harvest index was observed when wheat was planted at the highest seeding rate. Moreover, Mollah *et al.* (2009) reported that seeding rate has a non-significant effect on the harvest index of wheat.

3.2. Partial budget analysis

The results of the partial budget analysis showed that the highest net benefit (65,778.8 ETB ha^{-1}) with an acceptable marginal rate of return (224%) was obtained when variety *Fentale*-2 was planted with the seeding rate of 200 kg ha^{-1} followed by 175 kg ha^{-1} (NB = 63,402.4 ETB ha^{-1} and MRR = 297% (Table 4). The former gave a net benefit advantage of

22.21% over when the variety *Ogelcho* was planted at a seed rate of 100 kg ha^{-1}. The highest profitability could be due to the highest grain and straw yield as compared to the others, which is affected by genotype and seeding rate.

Table 3: Response of number of effective tillers per meter square, grain yield and thousand kernel weight of bread wheat varieties to different seeding rates

Treatment combination		Mean		
Seed rate (kg ha^{-1})	Variety	Effective tiller	Grain yield (t ha^{-1})	Thousand kernel weigh (g)
100	*Fentale-2*	220.53[h]	3.50[de]	42.54[a]
125		231.10[g]	3.53[cd]	41.31[ab]
150		265.67[d]	3.64[c]	41.13[ab]
175		284.47[b]	3.83[b]	40.20[bc]
200		306.63[a]	3.99[a]	40.13[bc]
100	*Kakaba*	215.07[h]	3.11[i]	38.73[cd]
125		233.77[g]	3.20[hi]	36.76[ef]
150		251.10[e]	3.40[efg]	37.77[def]
175		263.13[d]	3.47[de]	38.40[cde]
200		276.17[c]	3.50[de]	34.77[g]
100	*Ogelcho*	219.27[h]	3.10[i]	41.53[ab]
125		221.60[h]	3.20[hi]	39.64[bcd]
150		243.40[f]	3.30[gh]	36.53[efg]
175		276.17[c]	3.35[fg]	36.57[efg]
200		302.43[a]	3.44[def]	36.16[fg]
LSD		6.86**	0.109*	1.93*
SE±		1.06	2.07	0.39
Main effects				
Variety		**	**	**
Seed rate		**	**	**
CV		1.61	0.065	2.99

LSD = Least significant difference, CV (%) = coefficient of variation, SE+= standard error. Means followed by the same letter are not significantly different

Table 4: Partial budget analysis of bread wheat crop produced during the 2021 irrigation season in low land area of Jawi District, North west Ethiopia

Treatments	GB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
Ogelcho/100 kg ha^{-1}	67,589.2	16,423	51,166.2	
Kakaba/100 kg ha^{-1}	67,648.0	16,424	51,224.3	5810
Fentale-2/100 kg ha^{-1}	76,126.1	16,714	59,411.7	2816
Ogelcho/125 kg ha^{-1}	69,704.7	17,621	52,084.0	D
Kakaba/125 kg ha^{-1}	69,754.8	17,621	52,133.6	D
Fentale-2/125 kg ha^{-1}	76,853.6	17,947	58,906.4	D
Ogelcho/150 kg ha^{-1}	71,781.0	18,618	53,163.1	D
Kakaba/150 kg ha^{-1}	74,128.2	18,643	55,485.2	D
Fentale-2/150 kg ha^{-1}	79,221.9	18,998	60,224.4	36
Ogelcho/175 kg ha^{-1}	73,025.5	19,606	53,419.3	D
Kakaba/175 kg ha^{-1}	75,588.1	19,634	55,954.5	D
Fentale-2/175 kg ha^{-1}	83,470.3	20,068	63,402.4	297
Kakaba/200 kg ha^{-1}	76,226.3	20,615	55,610.8	D
Ogelcho/200 kg ha^{-1}	74,914.5	20,601	54,313.1	D
Fentale-2/200 kg ha^{-1}	86,908.5	21,130	65,778.8	224

GB, TVC, NB, D and MRR indicate: Gross benefit, Total variable cost, Net benefit, Dominance and Marginal rate of return, respectively.

4. Conclusion

The study showed that the highest plant height, number of total and effective tillers per unit area; and biomass and grain yield were recorded when the varieties *Fentale-2*, *Kakaba and Ogelcho* were planted at the seed rates of 200 kg ha^{-1}, 175 kg ha^{-1} and 200 kg ha^{-1}, respectively. On the other hand, the highest net benefit was obtained when variety *Fentale-2* was planted at the seeding rate of 200 kg ha^{-1} (NB = 65,778.8 ETB ha^{-1} and MRR = 224 %) followed by the same variety at a seed rate of 175 kg ha^{-1} (NB = 63,402.4 ETB ha^{-1} and MRR = 297 %). Accordingly, planting the variety *Fentale-2* with the seeding rate of 200 kg ha^{-1} can be recommended for the economical production of bread wheat under irrigation condition in the low land agro-ecology of the Jawi area. Further research on the effect of planting time, irrigation water requirement and irrigation frequency for lowland wheat production under irrigation condition is also recommended.

Data availability statement

Data will be made available on request.

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Conflicts of interest

The authors declared that there is no conflict of interest.

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