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Boosting the Productivity of Bread Wheat (*Triticum aestivum L.*) Varieties through Optimal Seed Rates and Appropriate Systems for Irrigation Production System of Northwestern Ethiopia

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ABSTRACT

The availability of high-yielding varieties adapted to diverse agro-ecologies and production systems, preferred by farmers and consumers, is the key factor limiting productivity. Farmers access seeds of different quality levels from various seed systems. Studies on seed systems and rates in relation to yield and yield traits of bread wheat varieties under irrigation are limited. Therefore, an experiment was conducted in 2021 in Northwestern Ethiopia to improve the productivity of bread wheat (Triticum aestivum L.) varieties through suitable seed rates and systems under irrigation. The experiment was conducted using a randomized complete block design in a factorial arrangement of two varieties (Kakaba and Ogolcho), three seed systems (formal, intermediate and informal), and three seed rates (125, 150, and 175 kg ha^{-1}) in three replications. SAS software was used for analysis. The results showed that the seed system and variety interaction had a significant effect ($P < 0.05$) on productive tiller numbers, days to 50% heading, kernel numbers per spike, and plant height. Additionally, the productive tiller numbers and days to 50% heading were significantly ($P < 0.05$) influenced by the interaction of variety with seed rate. However, the main effects of seed system, seed rate, and variety alone had a significant ($P < 0.05$) impact on physiological maturity, 1000-seed weight, kernel length, grain yield, biomass yield, and harvest index. The highest grain yields were obtained from the following main factors: seed system (intermediate (4.52 t ha^{-1}); seed rate (150 kg ha^{-1} (4.71 t ha^{-1})); and variety (Kakaba (4.47 t ha^{-1})), which exceeded the average yield in irrigation (4.4 t ha^{-1}). It is necessary to conduct experiments involving a greater number of seed rates and varieties over multiple cropping seasons and locations and sowing dates to strengthen the results.

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Introduction

In Ethiopia, wheat is one of the most vital cereal crops in terms of production and consumption. It significantly contributes to food security, poverty reduction, the supply of raw materials for industries, and the creation of employment opportunities. The national demand for wheat and wheat products is growing at an average rate of 9% per year (Khan et al., 2020), which is higher than the growth rate of local production (7.8%). This is partly due to high population growth, increased urbanization, and changing trends in food consumption patterns and preferences (Tolessa et al., 2019). To bridge the production gaps and meet these demands, Ethiopia has been importing an average of 1.5 million tons of wheat annually at a cost of 700 million dollars in the last five years (Wuletaw et al., 2022). Therefore, achieving self-sufficiency in wheat production is crucial for Ethiopia by enhancing its production and productivity.

Ethiopia is the second largest wheat producer in Africa after Egypt (USDA, 2024). The total production in Ethiopia is 5.2 million metric tons on 1.86 million hectares with a yield of 2.80 metric tons per hectare in the 2023/2024 production season, which is lower than other wheat-producing countries with average yields of 3.54 metric tons per hectare. World wheat production area and total production in the 2023/2024 season were 222.72 million hectares and 787.36 million metric tons, respectively (USDA, 2024). Low yields per hectare in Ethiopia are influenced by environmental factors affecting crop production like temperature, rainfall, wind, and light, which influence flowering, pollination, seed setting, ripening, and disease infection. Inadequate crop management practices such as planting, fertilization, irrigation, and weed control also contribute to low yields. Factors like inappropriate fertilizer and seed rates, lack of quality seeds for high-yielding varieties adapted to different agro-ecologies, and the use of poor-quality farm-saved seeds are key reasons for low productivity (Yohannes & Mulugeta, 2022). However, using quality seeds from known sources, adopting irrigation and mechanization (Mihratu et al., 2018), and expanding land (EIAR, 2020) are factors that can enhance wheat production and productivity.

Bread wheat (*Triticum aestivum L.)* is a staple crop in Ethiopia, and enhancing its yield and quality is crucial to meet the food requirements of the growing population. The seeding rate is a critical agronomic management practice that significantly affects the growth, yield, and yield components of bread wheat, ultimately influencing crop productivity (Iqbal et al., 2020). High seeding rates can lead to low yields and poor-quality crops due to increased competition for limited resources such as water, nutrients, and sunlight (Jemal et al., 2015). Optimizing the seed rate can help increase production potential, improve crop establishment, and counteract soil fertility decline. This optimization is crucial for ensuring food security, sustaining agricultural productivity, and addressing soil degradation challenges in Ethiopia (Kelemu et al., 2024). It also promotes nutrient availability, sunlight penetration for photosynthesis, appropriate soil conditions for nutrient uptake, and water use efficiency, all crucial for crop vigor, increased yield, and productivity (Amare & Mulatu, 2017).

In Ethiopia, several bread wheat varieties with varying seed size, height, tillering capacity, and maturity have been developed, along with recommended seed rates. However, farmers in the region often use inappropriate seed rates, ranging from 100 kg ha^{-1} to 288 kg ha^{-1}, for both small and large-sized bread wheat varieties (Dawit, 2012). Identifying the best-performing and well-adapted bread wheat varieties, along with implementing proper agronomic management practices such as seed rate, is essential for boosting productivity. Varieties and seed rates significantly affect the phenology, growth, yield, and yield-related traits of bread wheat (Shigedib & Bitew, 2023).

Farmers access seeds through different seed systems, including formal, informal, and intermediate systems (Dawit et al., 2017). The formal seed system in Ethiopia is mainly government-supported, involving public and private sector institutions (ATA, 2015; Djen, 2021). The informal system enables farmers to select, reproduce, store, utilize, and distribute seeds through social networks and local marketplaces. The intermediate system comprises seed-producing cooperatives (SPCs) and local seed businesses (ATA, 2015). Government offices, development projects, universities, research institutes, ATA, and NGOs are partners that support these systems. The choice of bread wheat varieties, seed sources, and seed rates significantly affects phenology, growth, yield, and yield components (Alemayehu & Mohammed, 2019). Seed systems, both intermediate and informal, have a significant influence on the phenology of barley (Abraha et al., 2020).

Ethiopia has significant potential for irrigated water availability, but only 1.1% of cultivated land is under irrigation (Girmay, 2018). Wheat yield under irrigation in Ethiopia averages 4.4 tons per ha, lower than the attainable yield of 6.5 tons per ha (EIAR, 2020). This is mainly due to crop management practices for irrigation systems being based on recommendations for rain-fed systems. The scarcity of high-quality certified seeds from reliable sources also affects bread wheat yield. To enhance wheat yield in irrigated systems, it is essential to optimize agronomic practices such as seeding rate and utilize improved varieties from reliable sources. The Ethiopian government is prioritizing the expansion of wheat production in lowland irrigated areas to attain self-sufficiency and enhance productivity in rain-fed agro-ecologies (Tolessa et al., 2019). Understanding the impact of different seeding rates and seed systems on bread wheat growth and yield can provide valuable insights for farmers, researchers, and policymakers. However, many farmers lack information on how inappropriate seed rates and unreliable seed systems affect the productivity of bread wheat varieties in irrigation systems. We hypothesize that high-quality certified seeds and optimal seed rates can significantly influence the quality and productivity of bread wheat varieties. This research aims to investigate the effect of seed systems and seed rates on the phenology, growth, yield, and yield traits of bread wheat varieties. The study also aims to determine the optimum seed rates for optimizing productivity in irrigation production systems in North Western Ethiopia.

Materials and Methods

Description of the Study Area

The research was conducted at Koga Irrigation Schemes, Ambomesk Kebele, in North Western Ethiopia during the 2020/2021 irrigation production season. It is located between 12° 20′ and 12° 31′ N latitude and 37° 02′ and 37° 08′ E longitude, with an elevation ranging from 1807 to 2300 meters above sea level (masl). It has a unimodal rainfall distribution pattern, and the total annual rainfall is 3043.9 mm. The rain usually starts in May and gradually increases in frequency, reaching its peak values in July or August (Desale et al., 2021). The highest and lowest recorded temperatures were 28.01°C and 10.57°C, respectively. The predominant soil type is red nitosol (Likawunt et al., 2012), and the primary production system is crop-livestock mixed farming, where livestock provides the draught power needed for the farming operation. The Koga irrigation dam has a capacity to retain 83 million cubic meters of water on 1,800 ha of land and is designed to irrigate 7,200 ha of land. Wheat, maize, and vegetables are grown under irrigated conditions (Desale et al., 2021).

Experimental Materials

Two bread wheat varieties, Kakaba and Ogolcho, were used for the experiment. Kakaba was released in 2012, and Ogolcho was released in 2010 by the Kulumsa Agricultural Research Center, Ethiopian Institute of Agricultural Research. Kakaba is adapted to lowland to highland areas, while Ogolcho is adapted to lowland to midland areas. The seeds for all varieties were collected from the 2019/2020 harvest.

Experimental Treatment and Design

The experiment consisted of three seed systems (formal, intermediate, and informal), three seed rates (125, 150, and 175 kg ha^{-1}), and two bread wheat varieties. It was conducted in a Randomized Complete Block Design (RCBD) in a 3×3×2 factorial arrangement with three replications, resulting in eighteen treatment combinations to demonstrate the main and interaction effects of seed systems, rates, and bread wheat varieties. Each treatment combination was randomly applied to fixed experimental units. The gross and net harvestable plot areas were 6 m² (3 m x 2 m) and 4.16 m² (2.6 m x 1.6 m), respectively. The experiment was planted with 10 rows in 0.2 m row spacing. Data collection was done from the middle rows, leaving the outermost two rows on both sides uncollected.

Experiment Management and Procedures

The experimental field was plowed and prepared using a tractor, oxen, and hand tools. It was then manually subdivided into blocks and plots based on the design and treatments. Sowing took place on January 8, 2020, by hand drilling in rows and lightly covering the seeds at a depth of 3-5 cm in the soil. All plots were uniformly fertilized with 100 kg ha^{-1} NPS (19% N, 38%P, and 7% S) at sowing and 75 kg urea (46% N) at sowing and 75 kg urea at full tillering. Weeding was done manually as needed, and irrigation water was applied at eight-day intervals using the furrow irrigation method, a common practice in Koga irrigation schemes (Schmitter et al., 2017).

Data Analysis Methods

Analyzing data was used by SAS software version 9.0. Data normality was tested using Levene's test before subjecting it to ANOVA. Three way ANOVA was used to determine the interaction and main effect of seed system, seed rate and variety. Mean comparisons between treatments were done using Duncan's Multiple Range Test at a 5% level of significance.

Results and Discussion

Days to 50% Heading

The main effects of seed rate ($P < 0.0001$), seed system ($P < 0.0001$), variety ($P < 0.0001$), the seed system with variety interaction ($P = 0.0087$), and variety with seed rate interaction ($P = 0.0139$) had significant ($P < 0.05$) effects on days to 50% heading. Nevertheless, other potential interactions were not statistically significant ($P > 0.05$). The Ogolcho variety with a seed rate of 125 kg ha^{-1} showed delayed days to 50% heading (71.44 days), whereas the Kakaba variety with a seed rate of 175 kg ha^{-1} exhibited earliness (58.11 days) (Table 1). The Ogolcho variety with the informal system interaction also showed delayed days to 50% heading (71.44 days), while the Kakaba variety with the formal system interaction exhibited earliness (58.78 days) (Table 3). These early days to 50% heading may be attributed to variations in genetic makeup, seed size and weight, and increased competition for resources at higher seed rates (175 kg ha^{-1}), prompting a shift in phenology from the vegetative to the reproductive stage. This has the advantage of escaping terminal moisture stress and adapting well to moisture variability in the growing area. Therefore, varieties with different seed systems and rates that show early heading days may have an advantage in regions where terminal moisture stress is prevalent. These delays in reaching 50% heading may be attributed to reduced plant competition resulting from lower seed rates. In agreement with this, (Abraha et al., 2020) revealed that seeds obtained from the intermediate system (seed-producing cooperatives) and the informal system (farmer-saved seeds) had a significant effect on the days to heading of food barley. This finding is consistent with (Amare & Mulatu, 2017) reported that the Tay bread wheat variety showed a delay in days to 50% heading (73.67 days) when interacted with a seed rate of 100 kg ha^{-1}, while the Dinkinesh variety at a seed rate of 150 kg ha^{-1} exhibited early heading (50 days). The findings presented in this paper demonstrate that as the seed rate increased from 125 to 175 kg ha^{-1}, the days to 50% heading decreased, and vice versa. Similarly, (Kelemu et al., 2024) stated that in bread wheat, as the seed rate increased from 100 to 200 kg ha^{-1}, the days to 50% heading decreased from 63.08 to 60.68. This study is also supported by (Wolde et al., 2024), who revealed that as the tef seeding rate increased from 2.5 to 12.5 kg ha^{-1}, the days to 50% heading decreased from 56.1 to 51.41, and vice versa.

Days to Reach 90% Physiological Maturity

The main effects of seed system ($P = 0.0005$), seed rate ($P < 0.0001$), and variety ($P < 0.0001$) had a highly significant impact on reaching 90% physiological maturity ($P < 0.05$). However, all possible interactions had a non-significant effect on it ($P > 0.05$). The informal system delayed days to 90% physiological maturity (106.89 days), followed by the intermediate system (105.11 days), and earliness was observed in the formal system (104.67 days). The seed rate of 125 kg ha^{-1} resulted in delayed days to reach 90% physiological maturity (107.78 days), while the seed rate of 175 kg ha^{-1} led to the earliest maturity (103.50 days). Additionally, the Ogolcho variety took longer to reach 90% physiological maturity (109.48 days), while Kakaba had a shorter maturity period (101.63 days) (Table 2).

Table 1. Interaction of variety with seed rate on productive tiller numbers and days to 50% heading

Variety	*Seed rate (kg ha^{-1})*	*Parameters* Productive tiller numbers	 50% heading days
Kakaba	125	109.67^{a}	63.11^{c}
	150	95.33^{b}	60.78^{d}
	175	84.11^{c}	58.11^{e}
Ogolcho	125	82.78^{c}	71.44^{a}
	150	74.44^{d}	70.11^{a}
	175	65.44^{e}	68.22^{b}
P value (0.05)		0.0347	0.0139
LSD (0.05)		6.5423	1.4607
CV (%)		8.09	2.36

Means with the same letter in the columns were not significantly different at 5%. SL- significance level, CV- coefficient of variation

Table 2. The effect of seed system, variety and rate on physiological maturity (PM), spike length (SL) and thousand kernels weight (TKW) of bread wheat

Factors	*Parameters*		
Seed system	PM	SL(cm)	TSW (gm)
Formal	104.67^{b}	8.16^{b}	34.94^{b}
Intermediate	105.11^{b}	9.08^{a}	36.18^{a}
Informal	106.89^{a}	7.89^{b}	34.12^{b}
P value (0.05)	< 0.0001	0.0181	0.0006
Seed rate kg ha^{-1}			
125	107.78^{a}	9.59^{a}	37.49a
150	105.39^{b}	8.13^{b}	34.96^{b}
175	103.50^{c}	7.40^{b}	32.79^{c}
P value (0.05)	0.0005	<0.0001	<0.0001
Variety			
Kakaba	101.63^{b}	8.84^{a}	36.63^{a}
Ogolcho	109.48^{a}	7.91^{b}	33.53^{b}
P value (0.05)	< 0.0001	0.0099	< 0.0001
LSD (0.05)	1.0885	0.844	0.9853
CV (%)	1.53	14.91	4.20

Means with the same letters in the columns are not significantly different, CV- coefficient of variation

Table 3. Interaction of seed system and variety on productive tiller numbers (PTN), days to 50% heading (HD), plant height (PH) and number of seeds per spike (NSPS)

Interaction		*Parameters*			
Variety ×seed system		PTN	HD	PH	NSPS
Kakaba	Formal	95.56^{ab}	58.78^{d}	82.70^{c}	50.33^{b}
	Intermediate	104.89^{a}	61.00^{c}	83.72^{c}	57.89^{a}
	Informal	88.67^{b}	62.22^{c}	84.13^{c}	44.56^{c}
Ogolcho	Formal	74.89^{c}	69.00^{b}	92.61^{b}	42.44^{c}
	Intermediate	77.89^{c}	69.33^{b}	93.91^{ab}	45.56^{c}
	Informal	69.89^{c}	71.44^{a}	96.20^{a}	40.56^{c}
P value (0.05)		3.79	5.42	4.11	3.35
LSD (0.05)		9.7755	1.87	3.05	4.67
CV (%)		12.09	3.03	3.62	10.55

Means with the same letter in the columns are not significantly different. SL- significance level, CV- coefficient of variation

The early days leading to maturity may be attributed to physiological maturity, which happens when the kernel has accumulated its highest dry matter content, lost its water content, changed color from green to yellowish, and exhibited genetic makeup variability. This early emergence could also be attributed to an increased plant population, leading to plants utilizing growth resources more rapidly through intra-specific competition, which results in earlier maturation. Bread wheat sourced from the informal system (farmer-saved) matured later, while wheat grown from seeds sourced from the formal system (Haramaya University Wheat Research Program) matured earlier (Alemayehu & Mohammed, 2019). This is in agreement with (Bereket, 2022), who revealed that different food barley varieties significantly influenced the days to physiological maturity. Shedho (3381-01) variety took the longest to reach maturity (115.67 days), while the HB 1307 variety matured faster (99.44 days). This study also aligns with (Anbessie et al., 2020 & Birhanu et al., 2020), who reported that the days to reach 90% physiological maturity of bread wheat were significantly influenced by varieties. Increasing the seeding rate from 125-175 kg ha^{-1} decreased the number of days to reach 90% physiological maturity of bread wheat, and vice versa (Table 2). This may be due to a higher seed rate contributing the grain-filling period reduction because at a higher seed rate heading and maturity were hastened compared to a lower seed rate (Alemayehu & Mohammed, 2019). Furthermore, (Kelemu et al., 2024) reported that the number of days to reach physiological maturity was significantly influenced by the seed rate. They noted that as the seed rate increased from 100 to 200 kg ha^{-1}, the days to physiological maturity decreased from 110.75 to 107.33, and vice versa. The studies are also supported by (Wolde et al., 2024), who revealed that the seed rate had a significant effect on tef physiological maturity. They reported that as the seed rate increased from 2.5 to 12.5 kg ha^{-1}, the days to physiological maturity decreased from 86.75 to 82.92, and vice versa.

Plant Height

The main effects of seed system ($P < 0.0001$), seed rate ($P < 0.0001$), variety ($P < 0.0001$), and the interaction between variety and seed system ($P = 0.0248$) had a significant impact on plant height. However, other potential interactions had a non-significant effect ($P > 0.05$). The informal system with the Ogolcho variety interaction had the highest plant height (96.20 cm), while the formal system with the Kakaba variety interaction had the shortest (82.7 cm) (Table 3). This might be associated with varietal genetic makeup and species differences. This is in accordance with the findings of (Alemayehu & Mohammed, 2019), who revealed that the tallest plants were observed in the intermediate seed system (Kersa Local Seed Business Program) of the Digalu bread wheat variety. The shortest plant height was obtained from the formal seed system (Haramaya University Wheat Research Program) of the Qulqull variety. Correspondingly, (Chaluma, 2023) reported that soybean height was significantly influenced by varieties, with the highest height obtained from AFGAT (76.22 cm) and the lowest from Davis (38.32 cm).

Spike Length

The main effects of seed rate ($P < 0.0001$), variety ($P = 0.0099$), and seed system ($P = 0.0181$) significantly influenced ($P < 0.05$) spike length. However, not all possible interaction effects significantly affected spike length. The intermediate system (9.08 cm) had the longest spike length, followed by the formal system (8.16 cm), while the informal system had the shortest (7.89 cm). A seed rate of 125 kg ha^{-1} produced the longest spike length (9.59 cm), followed by 150 kg ha^{-1} seed rate (8.13 cm), and the shortest from a 175 kg ha^{-1} seed rate (7.4 cm). Moreover, the Kakaba variety yielded the highest spike length (8.84 cm), while the Ogolcho variety had the lowest spike length (7.91 cm) (Table 2). The shorter spike length could be attributed to variations in seed quality used for sowing, differences in plant height, genetic makeup variations among varieties, and reduced spacing between plants at higher seed rates (175 kg ha^{-1}), leading to shorter spike length and taller plants. Plant height and spike length have an inverse relationship as reported by (Zewdie et al. 2014), shorter plants produce longer spike lengths, while longer plants produce shorter spikes and higher biomass production. This is in agreement with (Khan et al., 2015), who reported that the formal system (Bangladesh Agricultural Research Institute) had the longest spike length (17.5 cm), while the informal system (farmer-saved seed) had the shortest (15.6 cm). Increasing the seed rate of bread wheat from 125 to 175 kg ha^{-1} resulted in a decrease in spike length, and vice versa (Table 2). The spike length of bread wheat decreased as the seed rate increased from 100 to 150 kg ha^{-1}, and vice versa (Abiot, 2017; Amare & Mulatu, 2017; Bereket, 2022). Furthermore, (Kelemu et al., 2014) revealed that the seed rate had a significant effect on bread wheat spike length. They reported that as the seed rate increased from 100 to 200 kg ha^{-1}, spike length decreased from 7.87 to 7.45 cm, and vice versa. In this study, different bread wheat varieties exhibited varying responses to spike length. This is also in agreement with (Bereket, 2022), who reported that the HB 1307 food barley variety produced the longest spike length (8.933 cm), while the Shagee variety produced the shortest spike length (7.289 cm). Similarly, (Abraha et al., 2020) revealed that the variety of food barley significantly influenced spike length. They found that the highest spike length was obtained from Fetina (7.33 cm), while the lowest was from Felamit (6.38 cm).

Productive Tiller Numbers

The main effects of seed system ($P < 0.0001$), seed rate ($P < 0.0001$), and variety ($P < 0.0001$), as well as the interaction between seed system and variety ($P = 0.0322$) and variety and seed rate ($P = 0.0347$), significantly influenced ($P < 0.05$) the number of productive tillers. However, other potential interactions were not statistically significant ($P > 0.05$). The Kakaba variety with a seed rate of 125 kg ha^{-1} had the highest number of productive tillers (109.66), while the lowest number was observed for Ogolcho with a seed rate of 175 kg ha^{-1} (65.44) (Table 1). In addition, the intermediate system with the Kakaba variety interaction had the highest productive tiller number (104.89), whereas the lowest was obtained from the informal system with the Ogolcho variety (69.89) (Table 3). The variability in productive tiller production per unit area may be attributed to genetic makeup variation, population density, and spacing. These factors allow plants to utilize more water, light, air, and nutrients, leading to increased photosynthetic activity and ultimately influencing the number of effective tillers. As the seed rate decreased from 175 to 125 kg ha^{-1}, the number of productive tillers increased, and vice versa. This might be because a higher seed rate produces many tillers, but it may not result in a high number of productive tillers per unit area. This could be due to competition among tillers for growth factors, leading to the production of fewer productive tillers per unit area. Similarly, (Wolde et al., 2024) revealed that as the tef seeding rate increased from 2.5 to 12.5 kg ha^{-1}, effective tillers per plant decreased from 7.16 to 4.00, and vice versa. Similar to the current study, bread wheat varieties sown at lower seed rates (Wondimu et al., 2022) and food barley varieties planted at lower seed rates (Bereket, 2022) exhibited a higher number of productive tillers, and vice versa. Similarly, Alemayehu & Mohammed (2019) reported that the highest productive tiller number of bread wheat was recorded in the intermediate system (Kersa Local Seed Business Program) for the Quluquluu variety (54.56), while the lowest was recorded in the informal system (farmer-saved seed) for the Digalu variety (45.56).

Number of Kernels per Spike

The main effects of seed system ($P < 0.0001$), variety ($P < 0.0001$), seed rate ($P = 0.0028$), and the interaction between seed system and variety ($P = 0.0463$) had a significant impact ($P < 0.05$) on the number of kernels per spike. Other potential interactions did not have a significant effect ($P > 0.05$) on the number of kernels per spike. The intermediate system of the Kakaba variety produced the most kernels per spike (57.89), whereas the informal system of the Ogolcho variety produced the fewest kernels per spike (40.56) (Table 3). The low number of kernels per spike in farmer seeds of the Ogolcho variety may be attributed to its poor quality, limited adaptability, and inadequate management practices during its growth and development. The high number of kernels per spike in the intermediate system of Kakaba may be attributed to the adaptability of the variety to the study area, genetic composition of the variety, high-quality seeds such as thousand seed weight, and other physiological quality parameters including spike length. Similarly, (Alemayehu & Mohammed, 2019) reported that the interaction between seed system and variety had a significant effect on the number of kernels per spike. The Qulqulluu variety seed from the intermediate system (Kersa Local Seed Business Project) yielded the maximum number of kernels per spike at 68.24. Seeds of the Digalu variety from the informal system (farmers saved) yielded the minimum number of kernels per spike (53.31).

Table 4. The effect of seed system, seed rate and varieties on grain yield, biomass yield and harvest index of bread wheat

Factors	*Parameters*		
Seed system	Grain yield (t ha^{-1})	Biomass yield (t ha^{-1})	HI (%)
P value (0.05)	0.0493	0.0461	<0.0001
Formal	4.31^{ab}	11.87^{b}	36.35^{a}
Intermediate	4.52^{a}	12.32^{ab}	36.74^{a}
Informal	4.21^{b}	12.59^{a}	33.42^{b}
Seed rate kg ha^{-1}	P < 0.0001	P < 0.0001	P < 0.0001
125	3.90^{c}	11.15^{c}	35.01^{b}
150	4.71^{a}	12.46^{b}	37.89^{a}
175	4.43^{b}	13.17^{a}	33.62^{c}
Variety			
Kakaba	4.47^{a}	$12.021.70^{b}$	37.20^{a}
Ogolcho	4.22^{b}	$12.491.60^{a}$	33.81^{b}
P value (0.05)	0.0194	0.0489	< 0.0001
LSD (0.05)	251.41	572.72	0.8517
CV (%)	8.56	6.91	3.55

Means with the same letters in the column are not significant. HI (%) - harvest index (%), CV- coefficient of variation.

Thousand Kernel Weight (TKW)

The main effects of seed rate (P < 0.0001), seed system (P = 0.0006), and variety (P < 0.0001) had a highly significant impact (P < 0.05) on TKW. However, the remaining potential interactions did not significantly affect TKW (P > 0.05). The highest thousand kernel weight (TKW) mean was obtained from the intermediate system (36.18 g), followed by the formal system (34.94 g), and the lowest from the informal system (34.12 g). The highest thousand kernel weight (TKW) was also obtained from the lowest seed rate of 125 kg ha^{-1} (37.49 g), followed by 150 kg h^{-1} a seed rate (34.96 g), and the lowest from 175 kg ha^{-1} seed rate (32.79 g). Additionally, Kakaba (36.63 g) had the greatest thousand kernel weight (TKW) compared to Ogolcho (33.53 g) (Table 2). The higher thousand kernel weight (TKW) record might be due to the high adaptation to agro-ecology, high-quality seeds, genetic variability of the variety, and longer spike length. Moreover, at a low seed rate, there were fewer plants per unit area. This allowed plants to utilize more light and nutrients from the available space, resulting in the highest thousand kernel weight (TKW) at a reduced seed rate. This might lead to adequate grain filling. Lower seed rates (125 kg ha^{-1}) increase the availability of photosynthetic matter and facilitate the transformation of photosynthetic matter into grains, resulting in an increase in thousand kernel weight (TKW). The lowest thousand kernel weight (TKW) produced from the highest seed rate (175 kg ha^{-1}) might be due to the higher seed rate resulting in a greater number of spikes per row, which in turn leads to fewer kernels per spike and smaller-sized kernels. This is likely caused by inter-plant competition for limited soil resources. Insufficient photosynthetic matter during the grain filling stage at the higher seed rate (175 kg ha^{-1}) could be a contributing factor to the decrease in thousand kernel weight (TKW) due to intense competition. Increasing the seeding rate of bread wheat significantly decreased thousand kernels weight (TKW), and vice versa (Amare & Mulatu, 2017; Eldey et al., 2019; Kelemu et al., 2024). Similarly, (Wolde et al., 2024) reported that the tef seed rate significantly affected the thousand kernel weight (TKW). They observed that as the seed rate increased from 2.5 to 12.5 kg ha^{-1}, TKW decreased from 0.37 to 0.32 grams, and vice versa. Similar to the current findings, (Amare & Mulatu, 2017) and (Anbessie et al. (2020) affirmed that different varieties of bread wheat significantly influenced the thousand seed weight. Food barley varieties had a significant effect on TKW (Bereket, 2022). Similar to these findings, (Khan et al., 2015) reported that the formal system (Bangladesh Agricultural Research Institute) had the highest thousand-grain weight (42.3 g), while the informal system (farmer seed) had the lowest (37.9 g).

Grain Yield

The main effects of seed rate (P < 0.0001), seed system (P = 0.0493), and variety (P = 0.0194) significantly influenced grain yield (P < 0.05). However, other possible interaction effects did not significantly affect it (P > 0.05). The intermediate system had the highest grain yield (4.52 t ha^{-1}), followed by the formal system (4.31 t ha^{-1}), and the informal system had the lowest yield (4.21 t ha^{-1}). A seed rate of 150 kg ha^{-1} resulted in the highest grain yield (4.71 t ha^{-1}), followed by 175 kg ha^{-1} (4.43 t ha^{-1}), while 125 kg ha^{-1} had the lowest yield (3.89 t ha^{-1}). Additionally, the Kakaba variety had a higher grain yield (4.47 t ha^{-1}) compared to Ogolcho, which yielded 4.22 t ha^{-1}) (Table 4). This result indicated a higher grain yield than the average yield (4.4 t ha^{-1}) under irrigation in Ethiopia. The highest grain yield might be due to good adaptation to agro-ecology, high seed quality, genetic variability, longer spike length, increased productive tiller number, thousand kernel weight (TKW), and number of kernels per spike. Furthermore, the higher number of primary spikes per unit area reversed the effect of an increase in grain yield per spike obtained at decreased sowing density. This finding is consistent with (Khan et al., 2015), who reported that the highest grain yield was obtained from the formal system (Bangladesh Agricultural Research Institute) (3.5 t ha^{-1}), whereas the minimum was from informal system (farmer seed) (2.4 t ha^{-1}). Moreover, the highest grain yield was obtained from the intermediate system (Kersa Local Seed Business Project) (5.65 t ha^{-1}), while the lowest grain yield was from informal farmers (4.59 t ha^{-1}) (Alemayehu & Mohammed, 2019). The current finding is in agreement with (Bereket, 2022) revealing that the highest grain yield was obtained from the HB 1307 food barley variety (4.42 t ha^{-1}) while the lowest yield was from Shagee (2.8 t ha^{-1}).

This study describes that as the seed rate increased from 125 to 150 kg ha^{-1}, grain yield also increased and then decreased (Table 4). This finding is consistent with (Kelemu et al. (2024), who reported that a seed rate of 150 kg ha^{-1} for bread wheat resulted in the highest grain yield (3125 kg ha^{-1}), whereas 100 kg ha^{-1} led to the lowest yield (2674.3 kg ha^{-1}). This finding is consistent with the study by Betwoded et al. (2022), which also reported that the seed rate of bread wheat significantly influenced its yield. The study recorded the highest yield of 4.4 t ha^{-1} from a seed rate of 150 kg ha^{-1}. As the seed rate increased beyond 150 kg ha^{-1}, bread wheat grain yield decreased.

Biomass Yield

The main effects of seed rate ($P < 0.0001$), seed system ($P = 0.0461$), and variety ($P = 0.0489$) had a significant impact on biomass yield ($P < 0.05$). However, other possible interaction effects did not significantly affect it ($P > 0.05$). The informal system had the highest biomass yield (12.59 t ha^{-1}), followed by the intermediate system (12.32 t ha^{-1}), and the formal system had the lowest yield (11.86 t ha^{-1}). A seed rate of 175 kg ha^{-1} resulted in the highest biomass yield (13.17 t ha^{-1}), whereas 125 kg ha^{-1} led to the lowest yield (11.15 t ha^{-1}). Additionally, the Kakaba variety had the lowest biomass yield (12.02 t ha^{-1}), while Ogolcho had the highest (12.49 t ha^{-1}) (Table 4). The highest biomass yield recorded might be due to the plant's height, genetic makeup variability, a greater number of primary stems, and an increase in straw yield per hectare as the seed rate increased. Biomass yield and plant height had a direct association; thus, taller plants resulted in higher biomass yield (Zewdie et al., 2014). Wheat seed sources had a significant effect on aboveground dry biomass yield (Alemayehu & Mohammed, 2019, and Khan et al., 2015). Similarly, (Alemayehu & Mohammed, 2019, Birhanu, 2021), and Nwry et al., 2021) reported that as the seed rate increased, bread wheat biomass yield also increased, and vice versa. Food barley varieties (Bereket, 2022) and malt barley varieties (Senait et al., 2020) had a significant effect on biomass yield.

Harvest Index Percentage

The main effects of seed rate ($P < 0.0001$), variety ($P < 0.0001$), and seed system ($P < 0.0001$) had a very highly significant effect on the harvest index. However, other possible interaction effects had a non-significant effect on it ($P > 0.05$). The intermediate system (36.74%) and formal system (36.35%) had the highest harvest index, while the informal system had the lowest (33.42%). A seed rate of 150 kg ha^{-1} had the highest harvest index (37.89%), followed by 125 kg ha^{-1} (35.01%), and 175 kg ha^{-1} had the lowest (33.62%). Additionally, the Kakaba variety had the highest harvest index (37.20%), followed by Ogolcho (33.81%) (Table 4). The highest harvest index percentage might be due to higher grain yield, lower biomass yield and plant height, and population density, and an increase in biological yield accompanied by an increase in grain yield at a higher seed rate. This indicates that the harvest index had an interrelationship with grain yield and biomass yield. The harvest index was significantly affected by the seed source of bread wheat (Alemayehu & Mohammed, 2019; Khan et al., 2015). Seed rate had a significant effect on the harvest index by recording the highest yield from 150 kg ha^{-1}. Different authors reported the highest harvest index obtained at high plant population densities. Bread wheat seed rate (Abiot, 2017; Anbessie et al., 2020), and maize plant density (Ion et al., 2015) had a significant effect on the harvest index. Similarly, several researchers stated that the harvest index significantly influenced by bread wheat varieties. Bread wheat varieties had a significant effect on the harvest index (Jemal et al., 2015; Nwry et al., 2021).

Conclusions and Recommendations

The field experiment showed that seed systems, varieties, and seed rates of bread wheat significantly influenced grain yield and yield traits. The informal seed system had lower grain yield compared to formal and intermediate seed systems. Similarly, Ogolcho bread wheat varieties also had lower grain yield than Kakaba. As the seed rate increased from 125-175 kg ha^{-1}, thousand kernel weights, spike length, and the number of kernels per spike significantly decreased. Meanwhile, plant height and biomass yield significantly increased as the seed rate increased from 125-175 kg ha^{-1}. Even though grain yield was significantly affected by the main effects of seed rate, seed system, and variety, the highest grain yield was recorded from the intermediate system (4.52 t ha^{-1}), Kakaba variety (4.47 t ha^{-1}), and 150 kg ha (4.71 t ha^{-1}), which are higher than the average bread wheat grain yield in irrigation production systems (4.4 t ha^{-1}). Therefore, bread wheat producers and farmers benefit from using seeds from reliable sources, well-adapted varieties, and proper agronomic practices. These experiments were conducted based on some varieties and seed rates at one location and growing season. However, further studies are necessary to conduct experiments considering the number of seed rates and varieties at multiple locations of major bread wheat growing areas for multiple cropping season and year to make a conclusive recommendation for bread wheat producers and farmers. Studies on other bread wheat agronomic management practices such as sowing date and depth, row spacing, nutrient requirements, irrigation water requirement, irrigation scheduling, wheat irrigation critical stages, and partial budget analysis under irrigation are also recommended.

Declarations

Competing Interest

The author declares that they have no competing interest.

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