ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 13 No. 3
June 2013
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

SEEDING RATE AND GENOTYPE EFFECTS ON AGRONOMIC PERFORMANCE AND GRAIN PROTEIN CONTENT OF DURUM WHEAT (*Triticum turgidum* L. var. *durum*) IN SOUTH-EASTERN ETHIOPIA

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Published by African Scholarly Science Communications Trust
Josem Trust Place, Bunyala Road, Upper Hill, Nairobi
P.O. Box 29086-00625 Tel: +254-20-2351785 Fax: +254-20-4444030, Nairobi, KENYA
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ABSTRACT

The use of optimum seeding rate for the genotype may enhance productivity and grain protein content of durum wheat. Therefore, an experiment was conducted at two locations in south-eastern Ethiopia during the main cropping season of 2008 with the objective of elucidating the effects of seeding rate and genotype on agronomic performance and grain protein content of the crop. The experiment consisted of factorial arrangements of four improved durum wheat genotypes and five seeding rates, which were laid out as a randomized complete block design with three replicates. Seeding rates significantly influenced agronomic performances including number of fertile spikes m^{-2}, plant height, number of seeds $spike^{-1}$, and grain yield. Number of fertile spikes m^{-2} was increased proportionally with the seeding rate and the highest number (382 spikes m^{-2}) was recorded in the highest seeding rate of 200 kg ha^{-1}. Inversely, the highest number of kernels $spike^{-1}$ (29.8) was at the seeding rate of 100 kg ha^{-1}. The highest grain yield (4341 kg ha^{-1}) was obtained in response to seeding rate of 175 kg ha^{-1}, which was in statistical parity with the yield obtained at the seeding rate of 150 kg ha^{-1}. However, grain protein content was not influenced by the seeding rates. There were significant ($P \leq 0.05$) variations among the genotypes for all the agronomic traits measured. The largest number of fertile spikes m^{-2} was recorded for the genotypes Oda (360 spikes m^{-2}) and Bakalcha (345 spikes m^{-2}). Genotype Illani produced the longest spike (6.9 cm). Oda and Illani produced the highest numbers of seeds $spike^{-1}$, 38.8 and 36.9, respectively. The number of fertile spikes m^{-2}, number of seeds $spike^{-2}$ and kernels weight significantly contributed grain yield. The genotypes had exhibited less variation for grain protein content. Except for grain yield and harvest index, seeding rate x genotype interaction had no significant effect on other agronomic traits. Highest grain yields of 4938 kg ha^{-1} and 4774 kg ha^{-1} were obtained from genotypes Ejersa and Bakalcha when sown at the seeding rate of 150 kg ha^{-1} and 175 kg $ha^{-1,}$ respectively. Grain protein response was significantly influenced by the interaction effect in which genotype Oda had the highest (12.9%) and lowest (10.5%) protein contents at the highest (200 kg ha^{-1}) and lowest (100 kg ha^{-1}) seeding rates, respectively.

Key words: Genotype, seeding rate, protein, wheat

INTRODUCTION

Wheat is one of the most important cereal crops of the world and is a staple food for about one third of the world's population [1]. In Ethiopia, it is grown annually on 1.47 million ha with a total production of 2.2 million tons [2] and the country is considered as the largest wheat producer in sub-Saharan Africa. Of the total wheat production area, 75.5% is located in Bale, Arsi and Shewa regions [3]. Wheat is primarily used as a staple food providing more protein than any other cereal crop [4]. However, one challenge for global nutrition is to increase grain yield per unit area while maintaining its end use value [5, 6]. Wheat yield and protein quality depend upon the environment and management practices (climatic factors, soil types, fertilizers, pesticides, seeding density, and irrigation), genotype, and their interaction [7, 8, 9].

In Ethiopia, both durum wheat (*Triticum turgidum* L. *var durum*) and bread wheat (*Triticum aestivum* L.) species are widely cultivated. From an estimated total area under wheat production in the country, durum wheat covers about 40%. While bread wheat is an introduced crop, durum wheat is indigenous to the country [3]. As a result, the country has an amazing wealth of durum wheat genetic diversity [10], which could be ascribed to long history of its production in varied agro-ecologies. Despite its long history of cultivation and importance to the Ethiopian agriculture, the average yield of durum wheat is still fairly low (not exceeding 1.5 ton ha^{-1}) [11]. However, compared to bread wheat, durum wheat is an economically important crop because of its unique end product making characteristics [12].

In Ethiopia, durum wheat is currently considered a potential crop by the government for food industry as an import substitution and one means of income diversification for peasant farmers [11]. Aligned to this, several research and extension efforts have been have been exerted by Sinana Agricultural Research Center, different NGOs and cooperatives to extend improved durum wheat varieties in extensive wheat growing areas of south-eastern Ethiopia. Consequently, several high yielding varieties of durum wheat have been developed and released for use by smallholder farmers, farmers' organizations, private investors, and state farm enterprises. This indicates the potential to be tapped for increasing production and productivity of durum wheat in the area.

Despite these facts, the overall agronomic performance and grain protein content of modern high yielding genotypes as influenced by growing conditions is unknown in the study area. Depending on the management, environment and genotype, seeding rate can impact on wheat tillering, grain yield and protein quality [13, 14]. Hence, achieving higher agronomic performance and better end-use quality requires optimizing and periodically reviewing management practices such as seeding rates [15].

It was reported that, in a dense wheat population, grain yield was decreased due to competition between plants that induced self-regulation [16]. However, in cultivars that produce fewer tillers, higher seeding rates compensated for reduced tiller and promoted more main stem spikes [13, 14]. Wheat quality was not reduced at higher seeding rates as protein content, kernel weight and test weight were unaffected [16, 17]. On the other hand, it was stated that protein concentration declined as seeding rates and yields increased [18, 19].

In general, seeding densities play an important role in determining the yield and protein content of wheat genotypes. Although the effect of seeding densities on agronomic performance of wheat has been studied for a long time, little information is available regarding the effect on protein content of improved genotypes. Thus, the objective of this study was to evaluate the influence of seeding rate and genotype on agronomic performance and protein content of durum wheat.

MATERIALS AND METHODS

Experimental Sites

The experiment was conducted at two proxy sites; Sinana Agricultural Research Center (SARC) on-station and farmer's field in South Eastern Ethiopia during the 2008 main cropping season. SARC is located at 7°7'N latitude, 40° 10' E longitude and at the altitude of 2400 meters above sea level in Bale Zone of Oromia Regional State. The soil in the area is sandy loam in texture with pH 7.5, low organic carbon content of 0.3%, low total nitrogen content of 0.04%, medium content of available phosphorus (17.7 mg kg^{-1}), and high content of exchangeable potassium (834 mg kg^{-1}). The area is characterized by a bimodal rainfall pattern. Average annual rainfall during the experimental year was 1264.0 mm with minimum and maximum temperatures of 9.2 °C and 18.1 °C, respectively. The average rainfall in the main cropping season of the experiment (August-December) was 550.8 mm.

Treatments and Experimental Design

The treatments consisted of four improved durum wheat genotypes (Oda, Illani, Bakalcha and Ejersa) and five seeding densities (100, 125, 150, 175 and 200 kg ha^{-1}). The experiment was laid out as a randomized complete block design (RCBD) with a factorial arrangement and replicated three times. The seeding rate was considered as management factor environmental condition influencing agronomic performance and protein content of the genotypes. All field activities (land preparation, planting, fertilizer application and weeding) were done according to local production practices.

Seeds were planted by broadcasting on plots of 4 by 5 m^2. Phosphate fertilizer in the form of DAP at the rate of 46 kg P_2O_5 ha^{-1} was applied equally to all plots as a basal application at planting. Nitrogen fertilizer at the locally recommended rate of 41 kg ha^{-1} was broadcast and incorporated into the soil just before planting. All data on agronomic characteristics and protein content were measured from the central areas of each plot.

Data Measurements

Data on yield and yield-related traits consisting of number of fertile spikes, number of grains per spike, plant height, biological yield, grain yield, thousand kernels weight, and harvest index were recorded. The number of fertile spikes (number m^{-2}) was recorded at maturity by counting all the tillers producing seeds in the 1 m^2 quadrate of each plot. Number of kernels per spike was computed based on sample yield, number of spikes per unit area, and thousand kernels weight. 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 main tillers from each plot at physiological maturity. Biological Yield (kg ha^{-1}) was obtained by weighing the total above ground, grain, and non-grain plant parts, in the 1 m^2 unit areas of each plot using sensitive balance and computed on hectare basis. Grain Yield (kg ha^{-1}) was measured from the harvested 3 m^2 central area of each plot and computed on hectare basis. The grain samples were cleaned following harvesting and threshing, weighed using an electronic balance and moisture was adjusted to 12.5% moisture content.`

$$\text{Grain Yield (kg ha}^{-1}\text{) at 12.5\% moisture base} = \text{yield obtained (kg ha}^{-1}\text{)} \times \frac{(100 - \%MC)}{(100 - 12.5)}$$

Where, MC= grain moisture content.

Grain harvest index (%) was calculated as the ratio of grain yield to the total above ground biomass yield. Thousand kernels weight (g) was determined based on the weight of 1000 seeds sampled from the grain yields of each treatment, and counted by an electronic seed counter. Consequently, the kernels weight was determined using an electronic balance.

Furthermore, grain protein content (%) was determined by the digestion method of the Micro-kjeldahl apparatus as stated by American Association of Cereal Chemists (AACC) [20]. Total grain nitrogen concentration was estimated from a 1 g dry flour sample taken from the harvested grain yields of each plot and the grain protein content was calculated as:

$$\%\ \text{protein} = \%\ N \times 5.7$$

Where, 5.7 is wheat factor and

$$\%\ N = \frac{(\text{ml of standard } H_2SO_4 - \text{ml blank})\ (\text{Normality of standard } H_2SO_4)\ (0.014007)}{\text{Sample dry weight (g)}} \times 100$$

0.014007 is milliequivalent of nitrogen.

Statistical Analysis

Analysis of variance for the data recorded was conducted using the SAS GLM procedure [21]. Significant differences between mean values of treatments were computed using the least significant differences (LSD) test at 5% level of significance. Pearson's correlation analysis was done using Minitab software [22] to estimate the association between selected agronomic traits and grain protein content.

RESULTS

The results of the data combined over the two locations indicated significant variations ($P \leq 0.05$) in some agronomic traits in response to the different seeding rates. Among others, the number of fertile spikes, plant height, number of seeds spike^{-1}, and grain yield were the major agronomic traits highly affected by the seeding rate. Increasing the seeding rate increased the number of spikes per unit area with the highest number (382 spikes m^{-2}) obtained at the highest seeding rate of 200 kg ha^{-1}. However, using the highest seeding rate led to the lowest kernel number spike^{-1} (29.8). The lowest value for plant height was recorded at the lowest seeding rate (100 kg ha^{-1}). The height of plants grown at the lowest seeding rate was significantly lower than the heights of plants grown at seeding rates ranging from 125-175 kg ha^{-1}, but was in statistical parity with the heights of plants grown at the highest seeding rate. The maximum response of grain yield was obtained at the seeding rate of 175 kg ha^{-1}, which is comparable with the yield obtained at the seeding rate of 150 kg ha^{-1} (Table 1). In contrast, other agronomic traits such as spike length, biological yield, harvest index, and kernel weight were not significantly affected by the seeding rates. The result also indicated that grain protein concentration was not significantly influenced by the seeding densities.

The genotypes varied significantly in all agronomic traits measured: plant height, number of fertile spikes m^{-2}, spike length, number of seeds spike^{-1}, grain yield, biological yield, kernel weight, and harvest index (Table 1). Genotypes Bakalcha and Ejersa were significantly shorter than Oda and Illani. Number of fertile spikes m^{-2}, counted at maturity, for the genotypes averaged over the five seeding rates considerably varied in which the largest numbers were counted for the genotypes Oda (360 spikes m^{-2}) and Bakalcha (345 spikes m^{-2}). Genotype Illani had the lowest number of fertile spikes m^{-2} (307). The highest numbers of seeds spike^{-1}, 38.8 and 36.9 respectively, were produced by genotypes Oda and Illani. On the other hand, genotypes Bakalcha and Ejersa produced lower numbers of seeds spike^{-1}, 33.2 and 32.3, respectively.

Significant variations among the genotypes were measured for kernel weights. It was shown that genotype Illani, which produced the lowest number of spikes m^{-2}, had the highest kernel weight (54.7 g). Genotypes Oda, Bakalcha, and Ejersa produced statistically similar and higher total above ground biological yields while Illani produced the lowest. Except Illani, the three genotypes (Oda, Bakalcha and Ejersa) were statistically similar in yield performances across the seeding rates and locations.

Grain yield was highest for Bakalcha (4263 kg ha^{-1}), which was closely followed by Oda (4219 kg ha^{-1}), and Ejersa (4169 kg ha^{-1}). There were little variations among the genotypes for grain protein content across all seeding rates.

Seeding rate x genotype interaction had no effect on most of the agronomic traits including plant height, number of spikes m^{-2}, spike length, number of seeds $spike^{-1}$, biomass yield and kernels weight. The effect was significant ($P \leq 0.05$) for grain yield and harvest index indicating the genotypes responded differently to the seeding rates for these traits (Table-3). For genotypes Ejersa and Oda, the highest grain yields, 4938 kg ha^{-1} and 4588 kg ha^{-1} respectively, were obtained when sown at the seeding rate of 150 kg ha^{-1}. However, for Bakalcha and Illani, optimum grain yields, 4774 kg ha^{-1} and 3908 kg ha^{-1} respectively, were obtained when sown at the seeding rate of 175 kg ha^{-1}.

The variation in grain protein content caused by the interaction effect of seeding rate and genotype was much higher than the variation caused by each factor alone. Genotype Oda was highly affected in which case it produced the highest (12.9%) and the lowest (10.5%) protein contents, respectively at the highest and the lowest seeding rates. It had exhibited the highest and lowest grain protein contents at the highest (200 kg ha^{-1}) and lowest (100 kg ha^{-1}) seeding densities, respectively. For genotype Illani, the highest grain protein content was measured at the seeding rate of 125 kg ha^{-1}. At the seeding rates of 150 kg ha^{-1} to 175 kg ha^{-1}, genotype Ejersa had the highest grain protein content.

DISCUSSION

The decrease in plant height in response to lowering the seeding rate to 100 kg ha^{-1} may reflect formation of more secondary tillers in less populated stands, which tend to be shorter in stature. At the highest seeding density, the increased intra-plant competition may have also contributed to the reduction in plant height. Similar results of decreased plant heights at the lowest and highest seeding rates were reported by Nebraska [19]. However, the result contrasts with other findings [23] in which it was suggested that increased competition may have led to weaker and taller stems as the seeding rate was increased.

The highest seeding rate resulted in higher proportion of fertile spikes m^{-2} possibly as a result of increased main culms with lower number of tillers $plant^{-1}$. The results indicated that the number of spikes m^{-2} was not affected by the seeding rates of 100 to 175 kg ha^{-1} suggesting the ability of more fertile tiller production of the individual plants at the lower seeding rates. Reports from other studies conducted in the area also indicated that the highest number of spikes m^{-2} was recorded in the highest seeding rate of 225 kg ha^{-1} [24].

The number of fertile spikes m^{-2} increased linearly with the increasing seeding rates. Conversely, the number of kernels $spike^{-1}$ decreased when the seeding rate was increased from 125 kg ha^{-1} to 200 kg ha^{-1}. At the lower seeding rates of 100-150 kg ha^{-1}, the number of kernels $spike^{-1}$ was higher compared to that obtained at the higher seeding rates. This could be attributed to the availability of more free space at the lower seeding rates, which may have created opportunity to the plants to utilize available resources and produce higher number of kernels spike^{-1}. On the other hand, the lower number of kernels spike^{-1} at the higher seeding rates may also have resulted from the stiff intra-plant competition for resources. In another study [25], it was found that decreased number of kernels at dense wheat plants was ascribed to competition between plants that induced self-regulation.

In this study, grain protein content was less affected by the seeding density. Grain protein response to seeding rates was lower at the rates in which the highest and the lowest grain yields obtained (Figure 1). Comparatively, it was found to be higher in the seeding rates of 125 kg ha^{-1} and 200 kg ha^{-1}. Other investigations on bread wheat under different seeding densities also indicated little variation in grain protein content [17, 26]. There was also no change in the overall grain protein content at the density in which the maximum yield was reached [27].

There was little variation in the response of grain yield to the change in the seeding rate from 125 to 200 kg ha^{-1}. However, the lowest seeding rate resulted in a grain yield of 3851 kg ha^{-1}, which was significantly lower than the yields obtained at the other seeding rates. Seeding rates of 150 and 175 kg ha^{-1} resulted in yield advantages of 12.6% and 12.7%, respectively over the lowest seeding rate. Increasing the seeding rate from 150 kg ha^{-1} to 175 kg ha^{-1} did not affect grain yield as the yield was insignificantly increased by only 0.1%.

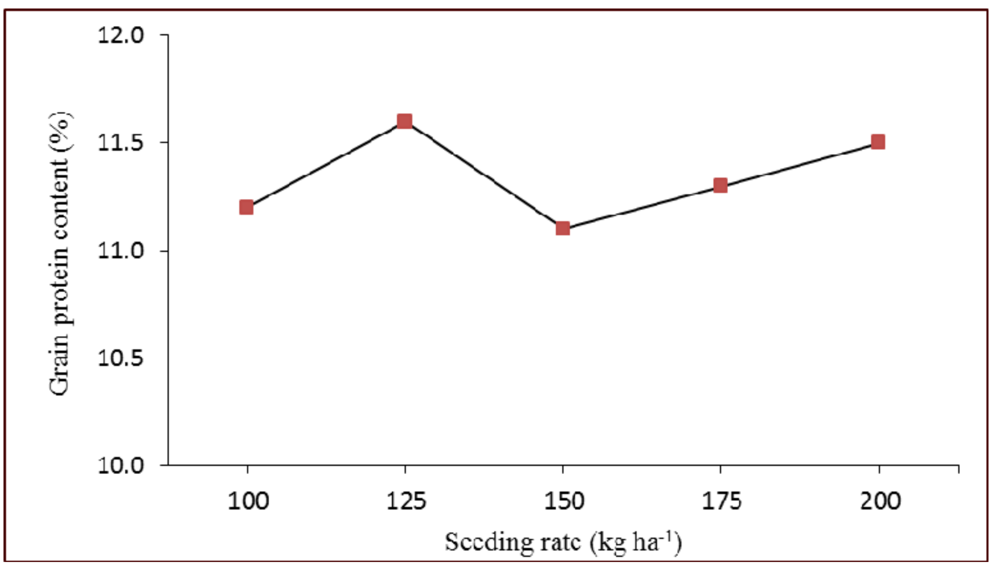

Figure 1: Grain protein response of durum wheat to seeding rates across the genotypes

ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 13 No. 3
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PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Genotype Oda produced the tallest plants with the average height of 120 cm, which was 19.7 cm taller than the average height recorded for genotype Illani. On average, the mean height of plants recorded for genotype Illani was 29.0 cm taller than the mean height of plants measured for genotype Bakalcha. Bakalcha and Ejersa had comparable height with only 1.6 cm difference. The result indicated that genotypes Oda and Bakalcha produced larger numbers of fertile tillers plant^{-1} while Illani had lower capacity of tiller production. Genotype Oda produced about 17% more fertile spike m^{-2} than Illani. However, despite the lowest spike count, genotype Illani produced the longest spike (6.9 cm) compared to the spike of Oda, which had the length of 6.8 cm. Genotype Bakalcha produced the shortest spike while Ejersa produced spike with intermediate length. The number of kernels spike^{-1} produced by the genotypes Oda and Illani were proportional to the length of their spikes in which the genotype with the longest spike (Illani) produced larger number of seeds. Despite its shorter spike compared to Ejersa, genotype Bakalcha produced higher number of seeds spike^{-1}, indicating its ability to produce higher number of fertile florets per spike. Illani exhibited the highest genotypic response in kernel weight. In contrast, Oda and Ejersa produced statistically lower kernels weight.

Correlation coefficients among the agronomic traits indicated that number of fertile spikes m^{-2} (r = 0.26**), number of seeds spike^{-1} (r = 0.27**) and kernels weight (r = 0.27**) were highly associated with grain yield (Table 2). The grain yield of genotype Bakalcha was higher compared with that of Oda and Ejersa possibly because of its higher kernel weight. On the other hand, the lowest grain yield obtained from genotype Illani, despite its highest kernel weight, may have been due to low contribution from its lower number of fertile spikes per unit area. Genotype Oda had the lowest grain harvest index due to the significant negative correlation between biomass yield and grain harvest index. Conversely, Illani had low biomass production and highest grain harvest index.

The overall range of grain protein content among the genotypes was narrow, 11.2 to 11.5% (Figure 2). Genotype Ejersa had relatively higher response of grain protein content. The highest grain yielding genotype, Bakalcha, had the lowest performance for grain protein composition. However, across the seeding rates and genotypes, there was a significant positive correlation between grain yield and protein content (r = 0.48**).

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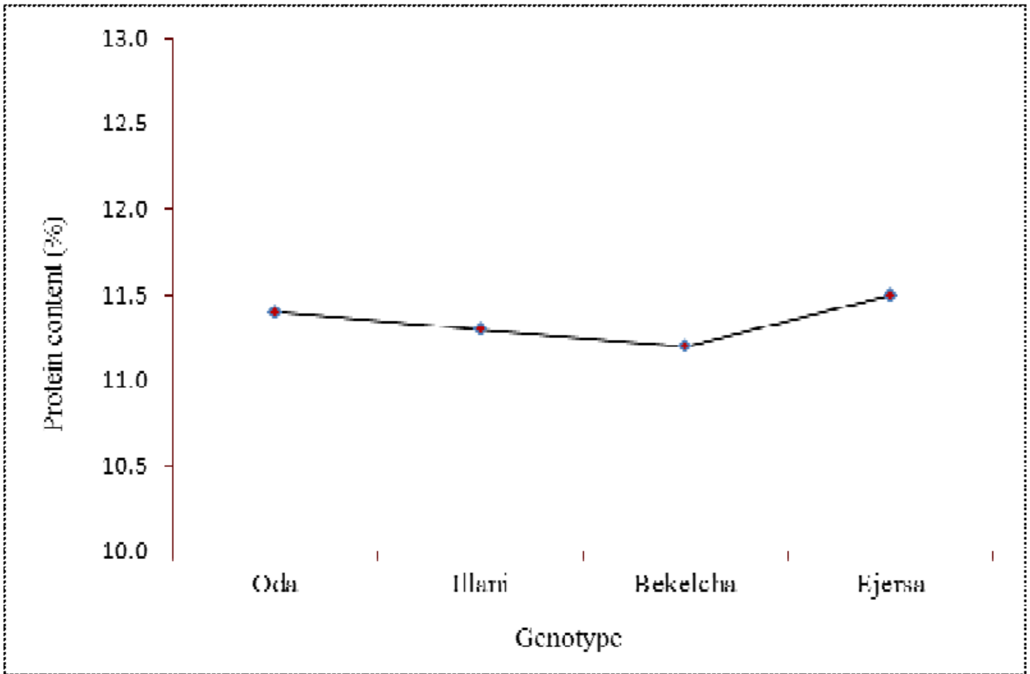

Figure 2: Grain protein response of durum wheat genotypes across the seeding rates

Seeding rate x genotype interaction revealed that the grain yield of genotype Oda increased linearly when the seeding rate was increased from 100 kg ha^{-1} to 150 kg ha^{-1}, but sharply decreased when the seeding rate was increased from 150 kg ha^{-1} to 200 kg ha^{-1}. Grain yields of the genotypes Illani and Ejersa, however, varied slightly especially when the seeding rate changed from 175 kg ha^{-1} to 200 kg ha^{-1}. This result agreed with the findings of other researchers in which significant response of grain yield to seeding rate x genotype interaction for winter wheat genotypes [28]. On the other hand, other researchers [19, 29] found no significant effect of genotype x seeding rate interaction for all agronomic traits including grain yield of winter wheat genotypes.

The interaction effect showed that grain yield and protein content proportionally increased for genotype Oda when the seeding rate was increased from 100 kg ha^{-1} to 125 kg ha^{-1} and then decreased to the lowest content at the seeding rate of 150 kg ha^{-1} where the grain yield was maximum (Figure 3). Grain protein content of the genotype was again increased when the seeding rate increased from 150 kg ha^{-1} to 200 kg ha^{-1} with inverse relationship to the grain yield. For genotype Illani, grain protein content was found to decline inversely to the grain yield increment when the seeding rate increased from 150 kg ha^{-1} to 200 kg ha^{-1}. On the other hand, for genotype Bakalcha, protein content was lowest at the seeding rate of 150 kg ha^{-1} where grain yield was minimum and higher at the seeding rate of 175 kg ha^{-1} where yield was maximum. Genotype Ejersa had also moderately higher grain protein at the seeding rate of 150 kg ha^{-1} which provided the highest grain yield produced.

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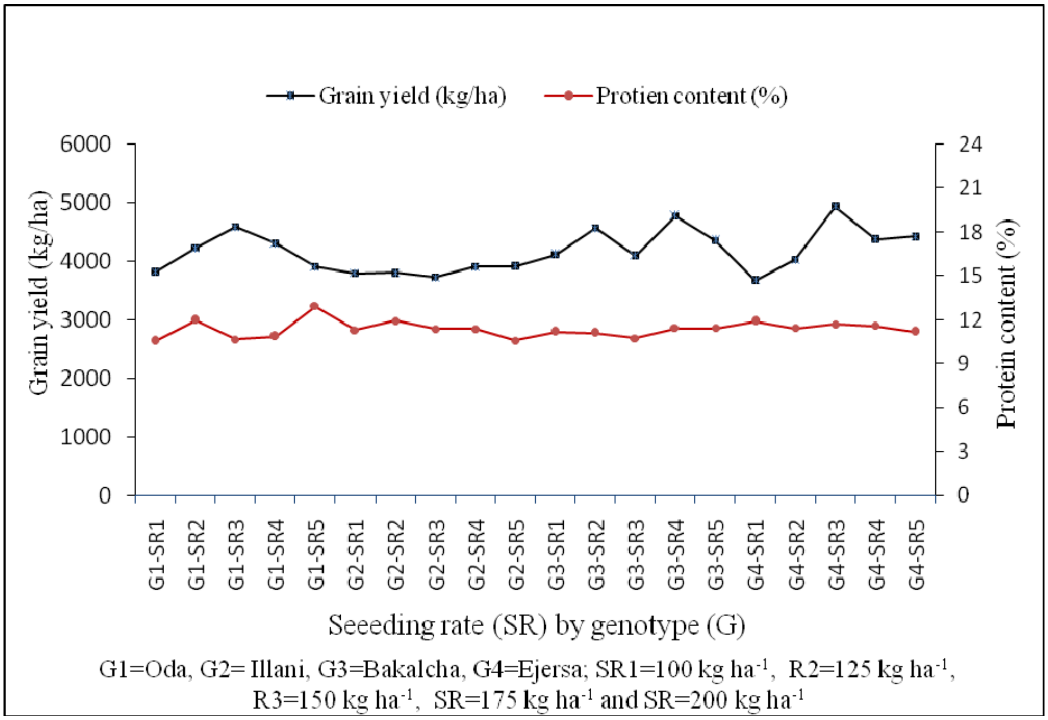

Figure 3: Interaction effect of seeding rate and genotype on grain yield and protein content of durum wheat

CONCLUSION

There were large variations among the improved durum wheat genotypes in all the agronomic performances. Genotype Bakalcha produced the highest grain yield which was, however, in statistical parity with the grain yields of Oda and Ejersa. However, Illani produced the lowest grain yield. The genotypes did not significantly vary in grain protein contents. Grain yield, harvest index, and grain protein content were highly influenced by the interaction effect of seeding rate and genotype. Genotypes Oda and Ejersa produced optimum grain yield at the seeding rate of 150 kg ha^{-1}. On the other hand, Illani and Bakalcha produced optimum grain yield at the seeding rate of 175 kg ha^{-1}. At the seeding rate of 150 kg ha^{-1}, genotype Ejersa provided the highest grain protein content indicating its suitability for end-use quality with optimum grain production. Genotype Bakalcha produced higher grain protein at the seeding rate of 175 kg ha^{-1} where optimum grain yield was obtained. Oda produced lowest protein content at the seeding rate of 150 kg ha^{-1} where grain yield was optimum. Hence, it may not be used for quality industrial products. Illani had intermediate protein content at the seeding rate of 175 kg ha^{-1} where grain yield was optimum. Therefore, Oda and Illani can be used for quality end-use products rather than for optimum production of grain yields when sown at the seeding rate of 125 kg ha^{-1}. This is because the yield potential for the genotypes was intermediate and protein content was higher at this seeding rate.

This study revealed that using appropriate seeding rate which fits specific durum wheat genotypes is necessary to optimize grain yield and enhance grain protein content of the crop. Therefore, durum wheat producing farmers in the region should dispense with the use of the same blanket seeding rate in the cultivation of all genotypes of the crop and adopt appropriately recommended seeding rates for enhanced productivity and human nutrition in the country.

ACKNOWLEDGEMENTS

This research was funded by Oromia Agricultural Research Institute and executed by Sinana Agricultural Research Center. The excellent technical assistance provided by Mengistu Bogale in organizing the data and inquisitive efforts of Habtamu Tadese and Mekonnen Wubetu in data collection and field work are highly appreciated.

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Table 1: Seeding rate effect on selected agronomic performance of durum wheat genotypes combined over two locations

Treatments	Plant height (cm)	Fertile spikes^{-2} (no.)	Spike length (cm)	Kernels spike^{-1} (no.)	Grain yield (kg/ha)	Biomass yield (kg/ha)	Thousand kernels weight (g)	Grain harvest index
Seeding rate (kg/ha)								
100	98^{b}	314^{b}	6.4	37.0^{a}	3851^{b}	9693	50.4	0.43
125	102^{a}	321^{b}	6.6	38.0^{a}	4154^{a}	9475	50.8	0.43
150	101^{a}	327^{b}	6.6	37.0^{a}	4338^{a}	10167	50.2	0.42
175	102^{a}	336^{b}	6.4	34.9^{ab}	4341^{a}	10778	50.6	0.39
200	100^{ab}	382^{a}	6.3	29.8^{b}	4150^{a}	9030	49.2	0.43
Mean	100.6	336	6.5	35.4	4167	9829	50.2	0.42
LSD	2.42	40.9	ns	5.6	271.8	Ns	Ns	ns
Genotype								
Oda	120^{a}	360^{a}	6.8^{a}	38.8^{a}	4219^{a}	10712^{a}	47.7^{c}	0.39^{b}
Illani	100^{b}	307^{b}	6.9^{a}	36.9^{a}	3830^{b}	8519^{b}	54.7^{a}	0.45^{a}
Bakalcha	91^{c}	345^{a}	5.9^{c}	33.2^{b}	4263^{a}	10269^{a}	51.8^{b}	0.42^{ab}
Ejersa	92^{c}	333^{ab}	6.2^{b}	32.3^{b}	4169^{a}	9815^{a}	46.8^{c}	0.43^{ab}
Mean	101	336	6.5	35.4	4120	9829	50.3	0.42
LSD	2.2	36.6	0.2	3.0	275.7	1103.9	1.8	0.04
CV (%)	4.2	21.2	7.25	16.4	13.02	21.83	6.84	20.73

Table 2: Estimates of correlation coefficients among selected agronomic traits of durum wheat genotypes across the seeding rates combined over two locations

Trait	NFS	PH	SL	NSPS	TKW	HI	GY	BM
NFS	1.00	0.24**	0.01	-0.32**	0.01	-0.04	0.26**	0.29**
PH		1.00	0.49**	0.25**	-0.05	-0.13	0.07	0.20*
SL			1.00	0.16	0.14	0.15	0.05	0.04
NSPS				1.00	-0.02	-0.12	0.27**	0.34**
TKW					1.00	0.21*	0.27**	0.15
HI						1.00	0.14	-0.47**
GY							1.00	0.55**
BM								1.00

**= significant at 0.05 probability levels, **= significant at 0.01 probability levels, NFS= number of fertile spikes m^{-2}, PH= plant height (cm), SL= spike length (cm), NSPS= number of seeds $spike^{-1}$, TKW= thousand kernels weight, HI= harvest index, GY= grain yield (kg ha^{-1}) and BM= biomass yield (kg ha^{-1})*

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Table 3: Interaction effect of genotype and seeding rate on selected agronomic traits of improved durum wheat genotypes in southeastern Ethiopia

Genotype	Seeding rate (kg ha^{-1})	Plant height (cm)	Fertile spike m^{-2} (no.)	Spike length (cm)	Seeds spike^{-1} (no.)	Grain yield (kg/ha)	Biomass yield (kg/ha)	Thousand kernels weight (g)	Harvest index
Oda	100	114	317	7.0	41.2	3819^{f-i}	12204	48.2	0.33^{d}
	125	122	339	6.8	42.3	4227^{c-h}	10153	49.3	0.42^{bcd}
	150	119	358	6.8	39.1	4588^{abc}	11562	47.2	0.39^{bcd}
	175	122	389	6.7	37.5	4305^{b-g}	11394	46.8	0.35^{cd}
	200	121	395	6.8	33.9	3906^{e-i}	8246	46.8	0.46^{b}
Illani	100	97	271	6.7	32.2	3796^{ghi}	7344	55.3	0.58^{a}
	125	102	321	7.4	35.5	3801^{ghi}	9200	54.1	0.41^{bcd}
	150	100	303	6.9	32.2	3726^{hi}	8478	55.2	0.44^{bc}
	175	101	308	6.6	35.0	3908^{e-i}	9686	55.3	0.40^{bcd}
	200	99	331	6.7	31.1	3919^{e-i}	7886	53.4	0.42^{bcd}
Bakalcha	100	90	319	5.9	35.2	4112^{c-i}	9535	53.6	0.43^{bcd}
	125	90	346	5.9	31.6	4566^{a-d}	9932	52.3	0.43^{bcd}
	150	91	338	5.9	34.8	4099^{c-i}	10635	51.7	0.42^{bcd}
	175	92	330	5.8	31.1	4774^{ab}	11740	52.6	0.38^{bcd}
	200	90	391	5.9	29.0	4352^{b-f}	9503	49.0	0.42^{bcd}
Ejersa	100	92	348	6.1	33.6	3677^{i}	9690	44.4	0.39^{bcd}
	125	93	277	6.3	40.2	4025^{d-i}	8616	47.4	0.47^{b}
	150	93	308	6.7	42.1	4938^{a}	9993	46.8	0.43^{bcd}
	175	92	316	6.3	37.6	4378^{b-e}	10294	47.8	0.43^{bcd}
	200	91	412	5.8	30.7	4421^{a-e}	10485	47.6	0.42^{bcd}
LSD									
	SR	2.4	40.9	ns	5.6	271.8	ns	ns	ns
	G	2.2	36.6	0.2	3.0	275.7	1103.9	1.8	0.04
	SR x G	ns	ns	ns	ns	543.7	ns	ns	0.10
CV (%)		4.2	21.2	7.3	16.4	13.0	21.8	6.8	20.7

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