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Research Article

Grain Quality Responses of Durum Wheat (*Triticum turgium* L. var. durum) to N Fertilizer and Seed Rates

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Abstract

In Ethiopia, knowledge about integrated seed and N fertilizer rates aimed at increasing the nutritional quality of durum wheat is limited. To full fill this gap, four levels of seed rate (i.e. 100, 125, 150, and 175 kg ha^{-1}) and four levels of N rate (i.e. 0, 46, 92, and 138 kg ha^{-1}) were arranged in randomized complete block design under two growing locations (environments). Results showed that the sole effects of the N fertilizer rate were a linear increment in hectoliter weight, gluten index (), and grain hardness under a high N rate. However sole effect of seed rate as well as the interaction effects of seed by N fertilizer rates did not have significant effects in all the tested grain nutritional qualities. On the other hand, interaction between the N rate and growing environment was found to be significant effects observed on the grain quality traits; grain protein content, wet, dry gluten, and gluten index were higher in Memirhager (low damp environment) combined with N application of 92 kg ha than Chefe Donsa site (high damp environment) even under higher N rate. The results of this research indicated that the aforementioned quality traits would be appreciably modified by N fertilizer, durum wheat should be grown in a low-damp environment. However, hectoliter weight, 1000-KW, and grain hardness were higher at the Chefe Donsa site. Therefore, an agronomist must consider the effects of nitrogen fertilizer, the environment, along their interaction, when aiming to optimize quality traits.

Keywords

Protein Content, Wet Gluten, Dry Gluten, Durum Wheat

1. Introduction

Durum wheat (*Triticum turdidum* L. var. durum) is Ethiopia's second most important cultivated wheat species after bread wheat [3, 40]. Ethiopia is considered the center of genetic diversity for durum wheat (*Triticum turgidum* L.) [4] and it has been cultivated for thousands of years [20, 37]. It has a wealth of genetic diversity and has contributed significantly to global durum wheat improvement programs [41, 28, 33]. In Ethiopia, the crop is used to prepare several traditional foods such as injera (fermented pancake-like flathead), kinche (boiled coarse-ground wheat), and nifro (boiled whole grain). Moreover, with the current emergence of the pasta processing industry in Ethiopia [26] there is an increasing demand for durum wheat grains as raw materials for processors.

Although durum wheat is considered the center of genetic diversity, it has been cultivated for thousands of years and has a wealth of genetic diversity, low volumes, and poor grain

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quality. The low volume and poor grain quality of durum wheat leads pasta processor industries to import the required raw material from abroad [7]. Unbalanced or underrated application of chemical fertilizers and improper use of seed rates are found to be the key factors that lead to a significant reduction in the end-use quality of durum wheat [2, 7]. The technological properties of wheat depend heavily on the protein content of wheat grains. Although grain protein content is a genotypic characteristic of wheat, it is greatly affected by variations in the availability of N nutrients to the crop [9]. Improper seeding rates have been estimated to cause a reduction in yield by approximately 24% and grain protein content by approximately 8.7%.

Crop management practices play an important role in increasing the yield and improving the end-use quality of wheat [34]. For instance, proper management of N fertilizer is essential to enhance yield and ensure quality crop production, while reducing nitrogen losses to the environment [38, 11]. In particular, grain protein content is a function of the total N uptake and partitioning of N and dry matter to the grain [32, 31]. Nitrogen fertilizer significantly contributes to increases in protein content, especially when fertilizer rates satisfy the requirements of both yield and protein synthesis [18, 22]. Several studies have documented that adding N at the post-flag-leaf stage may directly increase grain protein content without reducing yield [12, 10, 5]. As reported in some studies, an increase in the N fertilizer rate has a favorable effect on end-use quality and improves alveograph indices [14, 13]. It has been reported that the N fertilizer levels necessary to maximize the quality parameters are higher than those necessary to optimize yield parameters in both bread wheat [8, 18] and durum wheat cultivated [16, 29, 42, 7]. Fuertes-Mendizábal, T. et al. [13] reported an increase in glutenin and high-molecular-weight glutenin subunits with increasing N fertilization, which is associated with an increase in gluten strength. Nitrogen is a key input for the end-use quality of wheat.

Another important agronomic practice that determines and enhances grain yield and end-use quality is the seed rate. Both low and high seed rates have been found to have negative effects on the end-use quality and grain yield of durum wheat [35, 25]. Overgrowing plants can suffer from disease pressure and lodging of crops [23]. In the central highlands of Ethiopia, where durum wheat is predominantly cultivated, rainfall is abundant early in the season but lacking during the second half of the crop ages, and high seeding rates can result in higher biomass production but low grain yield and grain quality [6]. On the other hand, a low seed rate could also affect technological properties: under a low seed rate, the formation of ineffective tillers increases, and these ineffective tillers produce shriveled seeds and small seed sizes, leading to a reduction in technological properties [21]. Optimization of nitrogen fertilizer rate and seeding rate management are priorities and endless topics to enhance durum wheat production and grain quality to meet the domestic demand of the country. Therefore, the objective of the experiment was to examine the response of durum wheat to N rate and seed rate application, and to determine the optimal rate of N and seed rate associated with the technological properties of durum wheat.

2. Material and Methods

2.1. Description of the Study Areas

The experiments were conducted at Memirhager in Minjar Shenkora and Chefe Donsa in Ginbichu districts on farmers' fields during the 2018 and 2019 main cropping seasons. Memirhager is located at 8°46'33.5'' latitude and 39°16'40.7'' longitude with an altitude ranging from to 1950-2220 m.a.s.l. Chefe Donsa is located at 08.85 °latitude and 39.12 °longitude and resides at an elevation of 2450-2700 m.a.s.l. The rainfall patterns of the study areas were unimodal, with approximately 76% of the Memirhager and 78% of the Chefe Donsa rainfall received from June to October. The Memirhagre site received rainfall of 824.6 mm in 2018 and 817 mm in 2019 during the cropping season (June to October). The Chefe Donsa site rainfall was 1090 mm in 2018 and 1049 mm in 2019 during the cropping season (June to October). During these months, the mean minimum and maximum temperatures ranged from (13 ℃) to (26 ℃) Memirhager and (11 ℃) to (22 ℃) Chefe Donsa. Most farmers in the study areas used cereal-based rotation, and experimental sites with tef precursors were selected for this study. The soil at the experimental sites was slightly Vertsol and heavy Vertisol in Memirhager and Chefe Donsa, respectively. The analysis of some of the selected soil physicochemical properties for the composite surface soil (0-20 cm depth) is presented in Table 1.

Table 1. *Soil physio-chemical property analysis before planting at Memirhager and Chefe Donsa in 2018 and 2019 cropping seasons.*

Soil property	Memirhager site		Chefe Donsa site	
Textural class	2018	2019	2018	2019
Clay (%)	54.4	50.2	57.4	56.2
Silt (%)	30.4	32.2	28.4	30.2
Sand (%)	15.2	17.6	14.2	13.6
pH (1: 2.5 H_2O)	6.23	6.58	5.34	5.87
CEC[Cmol(+)kg^{-1} soil]	36.0	45.0	28.0	31.0
Organic matter (%)	0.64	0.71	0.21	0.23
Total N (%)	0.07	0.06	0.02	0.03
Ava. P_2O_5 (mg/kg)	9.23	11.01	7.23	6.01

2.2. Treatments, Experimental Design, and Procedures

The factorial combination of the four N rates (0, 46, 92, and 138 kg ha^{-1}) and four seed rates (100, 125, 150, and 175 kg ha^{-1}) were evaluated in randomized complete block design (RCBD) with three replications in a gross plot size of 3 m in length and 3 m in width, while the net plot size was 3 m × 2.8m. For phosphorus (di-ammonium phosphate), 18% N and 46% P_2O_5) and urea (46% N) as the N source were used for this study. All phosphorus and 1/3 of N were applied at planting based on the treatment specification, while the remaining 2/3N was applied during the pre-tillering stage of durum wheat. The experimental fields were prepared according to local farming practices. Thus, the experimental land was plowed three times using oxen before sowing to pulverize the soil and control and/or reduce early emerging weeds. Seeds of durum wheat variety Utuba were uniformly hand-drilled for each treatment specification with 20 cm row spaced and covered. The spaces between the blocks and plots were 1 m and 0.5 m, respectively. Before the second stage, N fertilizer was applied, and hand weeding was carried out to keep the plots free from weeds and to provide better aeration. The remaining weeding activities were performed at the mid-tillering and flag-leaf stages of the crop.

2.3. Data Collection

Data on technological properties, such as grain protein content (GPC), hectoliter weight (HLW), wet gluten content (WGC), dry gluten content (DGC), gluten index (GI), thousand kernel weight (1000-KW), grain hardness (GH) and seed diameter (SD) were collected. Approximately 250 g of grain sample was taken to measure GPC using an Infratech 1241 Grain Analyzer (Foss, Hilleroed) at the Kulumsa Agricultural Research Center grain quality laboratory. Infratech 1241 is a whole-grain analyzer that uses infrared transmittance technology to test multiple parameters (grain moisture, starch, oils, protein, etc.) in a broad range of oilseed and cereal grains. The GH was evaluated by the particle size index by applying milling with a rotary mill and determining the percentage of grains left on the mill to those through the mill. The HLW was determined for the dockage-free grain samples using a Seed Burro Hectoliter mass device and an electronic balance. The wet (g) and dry (g) gluten contents were determined using hand-washing techniques according to [1]. The gluten index (%) was determined using an automatic system [36]. Grain protein content, HLW, 1000-KW were analyzed at the Debre Zeit Agricultural Research Center quality analysis laboratory, whereas wet, dry, gluten index, seed diameter, and GH were analyzed at the Kulumsa Agricultural Research Center quality analysis laboratory.

2.4. Methods of Data Analysis

The data were subjected to a combined mean analysis of variance (ANOVA) across locations and years after confirmation of homogeneity of error variance to test the impacts of N fertilizer, seed rate, and environmental grain quality traits of durum wheat.

The homogeneity of the variance was computed by the F test:

$$\text{F calculated} = \frac{\text{Lager mean erroe square}}{\text{Small erroe mean square}}$$

If the F calculation of the tested parameter is <1, the error variances are homogenous and a combined analysis of the data is used. When significant treatment effects occurred, the means were compared using the least significant difference (LSD) test at a 5% significance level.

3. Result and Discussion

Grain Quality Parameters

The technological properties of durum wheat are expressed in terms of grain protein content, HLW, wet gluten content, dry gluten content, gluten index, thousand kernel weight, and seed diameter. The analysis revealed that the sole effect of N application rate had a significant ($p<0.05$) impact on HLW, GH, and GI (Table 2). The highest (138 kg ha^{-1}) N rate resulted in improved HLW, GH, and GI of 81.52 kg hl^{-1}, 86.23 (%), and 77.62 (%), respectively (Table 2). The sole effect of seed rate was significant ($p< 0.05$) only on the SD. An increase in seed rate from 100 kg ha^{-1} to 175 kg ha^{-1} led to a reduction in seed diameter (Table 2).

Table 2. *A sole effect of N rate and seed rate (kg ha^{-1}) on grain end-use functional properties of durum wheat.*

Treatments	**Grain quality traits**			
N rate (kg ha^{-1})	**HLW (kg hl^{-1})**	**GI (%)**	**GH**	**SD (mm)**
0	80.74b	82.68b	71.74b	3.21
46	81.03b	84.83ab	71.68b	3.21
92	81.03b	86.38a	72.18b	3.19

Treatments	Grain quality traits			
N rate (kg ha^{-1})	HLW (kg hl^{-1})	GI (%)	GH	SD (mm)
138	81.52a	86.23a	77.62a	3.18
$LSD_{0.05}$	0.49	2.59	3.22	0.03
Seed rate (kg ha^{-1})				
100	81.00	84.90	74.17	3.22a
125	81.14	84.71	73.51	3.21ab
150	81.12	85.50	72.86	3.19ab
175	81.05	85.00	72.67	3.18b
$LSD_{0.05}$	0.48	2.54	3.15	0.03
CV (%)	1.47	7.43	10.68	2.27

CV%: Coefficient of variation; LS: least significant at p= 0.05%; ns = non-significant. Key observations: HLW, GI, gluten index, GH, GH, SD, seed diameter

Additionally, the growing environment was found to have significant (p<0.05) effects on most grain quality traits studied: PC, HLW, DG, 1000 KW, GH, and SD Figures 1 & 2). The highest GPC (11.79%) and DG (10.79%) occurred in Memirhager, and the lowest PC (10.14%) and DG (9.83%) occurred in Chefe Donsa (Figure 1). On the other hand, higher HLW (81.89 g hl^{-1}), GH (86.7%) and SD (3.48 mm) were obtained from Chefe Donsa (Figure 2), and the lower HLW (78.26 g hl^{-1}), GH (78.89%) and SD (3.15 mm) occurred at Memirhager (Figure 2).

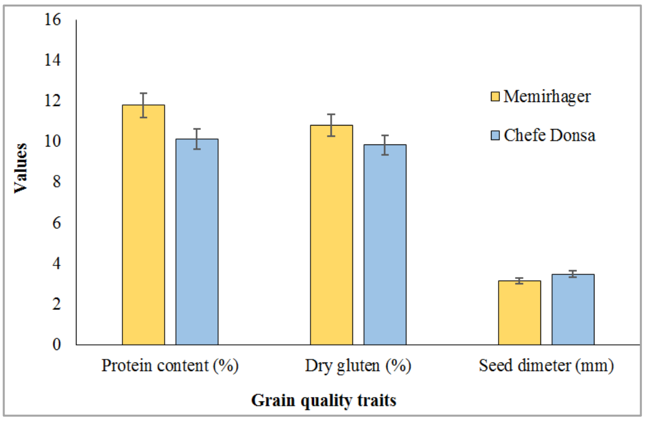

Figure 1*. Protein content, dry gluten content and seed dimeter as influenced by growing environment.*

The interaction between the N rate and growing environment was found to be significant (p<0.05) for PC, WG, DG, and 1000 KW of durum wheat (Table 3). The highest WG, DG, and 1000 KW were noted in plots treated with the highest N rate (138 kg ha^{-1}) in both growing environments (Table 3); however, the effect was more profound in the Memirhager environment than in the Chefe Donsa environment (Table 3). The maximum GPC was attained at the higher N rate of 138 kg ha^{-1} in the Memirhager environment. However, in the Chefe Donsa environment, the GPC was not appreciably modified by the N rate (Table 3). This suggests that the interaction between N fertilizer management practices and the environmental conditions of the growing location played a crucial role in determining grain quality traits.

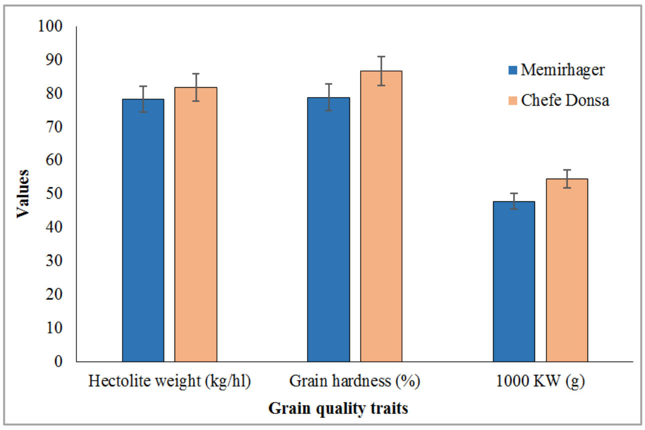

Figure 2*. HLW, GH and 1000-KW as influenced by growing environment.*

Table 3. Nitrogen fertilizer rate by location effect on grain quality of durum wheat.

Locations	N rate (kg ha^{-1})	Grain quality traits			
		PC (%)	WG (%)	DG (%)	1000-KW(g)
Memirhager	0	10.86b	30.96c	9.89bcd	47.04d
	46	12.13a	33.19ab	10.82ab	48.37ab
	92	12.11a	33.99a	11.29a	47.28cd
	138	12.07a	33.43a	11.20a	48.80ab
Chefe Donsa	0	9.84d	32.85ab	9.30d	47.77bcd
	46	10.03d	31.49bc	9.36cd	48.60ab
	92	10.45c	32.72ab	10.30a-d	48.54abc
	138	10.22cd	33.76a	10.36a-c	49.26a
$LSD_{0.05}$		0.39	1.71	1.05	1.32
CV (%)		6.23	9.12	17.4	4.81

CV%: Coefficient of variation; LS: least significant at p= 0.05%; ns = non-significant. Key observations; PC: protein content; WG: wet gluten content; DR: dry gluten content, 1000-KW: 1000 kernel weight

The sole effect of seed rate, the two-way interaction between N rate × seed rate, and the three-way interaction, N rate × seed rate × growing environment, did not have a statistically significant influence on the durum wheat grain quality traits studied, except for the sole effect of seed rate on SD.

4. Discussion

Crop management practices, such as plant density and nitrogen fertilizer research for durum wheat in Ethiopia, began in the late 1960s in the central highlands [20]. The recommendations of those practices that are effective under normal climatic conditions may not be suitable under the current agro-climatic variability and change. Thus, continuous monitoring and revisiting of basic agronomic practices are very important to enhance durum wheat production and grain quality to meet the domestic demand of the country. The current research results indicated that across different N rates, the growing environment and interaction effects of N rate × growing environment had significant impacts on the end-use quality traits studied (Table 3). As the N rate increased, there was a notable improvement in some grain quality traits such as HLW, gluten index, and GH (Table 2). This means that, as the N rate increases, the aforementioned quality traits tend to increase. In agreement with these results, additional N application significantly increased the grain quality traits of HLW, dry glute, and GH in durum wheat [16, 19, 42]. The acceptable Ethiopian standard grain protein content for durum wheat semolina is 11.5% [24]. In the present study, GPC showed considerable variation, as would be expected from the application of different N rates and acceptable range of GPC in the Memirhager site, while the lowest value was recorded in Chefe Don's site and was not appreciably modified by N fertilization, which did not fit the acceptable standard range.

This finding further highlights that the growing environment significantly affects the grain quality of durum wheat (Figure 1 and Figure 2). However, the extent to which qualitative grain traits are influenced by the growing environment varies according to a given set of growing environments. This means that grain quality traits, such as GPC and DG, are superior at Memirhager compared to the Chefe Donsa site (Figure 1). The differences in rainfall and temperature in the two growing locations are probable reasons for this variation. It is commonly observed that grain protein increases in areas experiencing low rainfall and dry cool seasons during the grain-filling stages [15, 27]. This can be attributed to a higher accumulation of nitrogen in the grain and a lower concentration of carbohydrates [43]. As carbohydrate and protein contents are inversely related, a decrease in carbohydrate content caused by low rainfall and dry and cool conditions may increase the grain protein content [43]. On the other hand, the lower GPC observed in the Chefe Donsa environment was probably due to the higher and prolonged rainfall during the crop growing period, which increased N mineralization and leaching [32] compared to Memirhager. Rainfall and damp conditions during grain filling can result in the loss of kernel vitreousness due to moisture absorption into the grain, causing the endosperm to fracture and an increase in preharvest sprouting. An increase in carbohydrate content caused by high rainfall and damp conditions may result in a decrease in the grain protein content [30]. In addition, [39] reported that excessive rainfall during the vegetative stage can leach nitrogen and other nutrients from the soil root zone and reduce their availability for uptake by the plant and the formation of phytochemicals. In agreement with these results, additional N fertilization did not significantly increase GPC of durum wheat in Chefe Donsa, Ethiopia [16]. Nevertheless, Chefe Donsa favored a better expression of seed diameter, 1000-KW, HLW, and GH. Several researchers have previously reported that the environment has a profound effect on the indicated quality traits compared with fertilizer and genotypes [17, 30]. Weather factors such as air temperature, rainfall, and relative humidity during grain filling are important factors affecting grain quality [30]. Higher SD, HLW, GH, and 1000-KW were favored by growing locations with cool air temperatures, which is why at Chefe Donsa the aforementioned grain quality traits were not appreciably modified by N fertilization rather than by the environment. The results of this research indicated that GPC, WG, DG, and GI would be appreciably modified by N fertilizer, and durum wheat should be grown in a dry environment with high temperatures during the day and low temperatures during the night. In contrast, seed diameter, HLW, GH, and 1000-KW were favored in cool and damp growing locations.

5. Conclusion

The findings of the present study indicate that nitrogen fertilizer rate, growing environment, and the interaction effects of N rate and environment significantly enhanced the tested quality traits. On the other hand, the sole effects of seed rate and interaction effects of N rate by seed rate did not have a significant effect on most grain quality traits. In conclusion, the results indicated that GPC, WG, DG, and GI would be appreciably modified by N fertilizer, and durum wheat should be grown in a dry environment with high temperatures during the day and low temperatures during the night. SD, HLW, GH, and 1000-KW were favored by prolonged rainfall and damp conditions rather than the N rate. This means that the quality traits of SD, HLW, GH, and 1000-KW were not appreciably modified by N fertilization, but rather by the environment. Therefore, an agronomist must consider the effects of nitrogen fertilizer application, the environment, and their interactions to optimize quality traits.

Author Contributions

Bizuwork Tafes Desta: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Supervision, Writing – original draft

Sisay Eshetu: Data curation, Investigation, Software, Writing – review & editing

Almaz Meseret: Validation, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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