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Grain Hardness, Hectolitre Weight, Nitrogen and Phosphorus Concentrations of Durum Wheat (*Triticum turgidum* L.var. *Durum*) as Influenced by Nitrogen and Phosphorus Fertilisation

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Abstract: Nitrogen and phosphorus fertilizers are the major limiting factors in most soils. The highland vertisols of Ethiopia are prone to nutrient deficiency especially of N and P as the result of monocropping and leaching losses. An experiment was conducted at Bale highlands, South-eastern Ethiopia to investigate the effect of nitrogen and phosphorus fertilisers on grain hardness, hectolitre weight and nitrogen and phosphorus concentrations of durum wheat (Triticum turgidum L. var. *durum*). No interaction was observed between N and P rates on all of the parameters. Grain hardness was higher at Robe while hectolitre weight was higher at Agarfa sites. Grain hardness was not significantly affected by phosphorus while hectolitre weight was not influenced by nitrogen rates. Flour and tissue N concentrations and flour P concentration were higher at the highest rate of N (92 kg N ha^{-1}). N concentrations of the flour and tissue were higher at the lowest phosphorus rate and flour P concentration was higher at the highest P rate (69 kg P_2O_5 ha^{-1}). Grain hardness was correlated positively with flour N concentration and NHI whereas hectolitre weight was negatively correlated with thousand kernels weight, harvest index, flour P, flour N and tissue N concentrations.

Key words: Hectolitre weight · Nitrogen · Phosphorus · Grain hardness · Durum wheat

INTRODUCTION

Durum wheat (*Triticum turgidum* L.var. *durum*) is the second most cultivated wheat species in the world next to common wheat [1]. Recently, wheat in general has become one of the most important cereal crops in Ethiopia ranking 2nd in total grain production next to maize. Of the different wheat species grown in Ethiopia, durum wheat is the most important one. The crop is one of the major cereals grown on vertisols. It is consumed in Ethiopia largely in the form of whole wheat, fermented or leavened local bread, or as flat breads [2].

Wheat is grown in a wide range of environments that affect overall performance, particularly grain yield and end-use quality; wheat yield and end-use quality depend upon the environment, genotype and their interaction [3]. Productivity is limited, among other factors, by low soil fertility because of which fertilizers are becoming important inputs to maximize crop yield and end-use quality. Nitrogen is a macronutrient required by plants in comparatively larger amounts than other elements [4]. Soil nitrogen depletion, poor crop productivity and the ensuing human misery are serious problems in East African highlands. The use of commercial nitrogen fertilizer for cereal production in subsistence farms is generally low because of cost and climatic risks [5]. The generally poor food situation in Africa is related to the low soil fertility of nitrogen (N) and the low soil availability of phosphorus [6]. Ethiopian highland vertisols tend to exhibit low total N and organic, matter content and application of N fertilizer is considered essential to improve cereal production; however, peasant farmers commonly apply sub-optimal rates of fertilizer to crops due to limited access to credit and relow availability of fertilizers during the planting season [7]. Phosphorus (P) deficiency is limiting crop production in many agricultural soils worldwide where conventional fertilizers are inaccessible. Of total soil P, only 1 to 5% is in a soluble, plant-available form. In sub-Saharan Africa and in similar tropical soils, P deficiency is considered to be one of the main biophysical constraints to food production. This deficiency is a result of low inherent P fertility due to weathering, in combination with intensive, nutrient-extracting agricultural practices [8].

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Crops experience periods during the growing cycle when yield is mainly limited by the source strength, the sink capacity or co-limited by both [9]. Nitrogen and phosphorus are the most important nutrients which affect the assimilate production and distribution and affecting directly or indirectly the source-sink relation [10]. High hectolitre weight and kernel size, influenced by environmental factors such as nitrogen fertilisation, are associated to the milling quality. Nitrogen had significant influence on tillering, number of grains and grain weight [11]. Durum wheat showed a poor response to phosphate fertilisation: small amounts were sufficient, additional amounts increased the phosphorus content of products and by-products only [12]. Among the complex factors affecting wheat grain nutritional quality, the N and P contents are highly important. The mineral contents of wheat grains may be affected by a number of factors including soil, climate and cultural practices. A comparison of grain from organic and conventional wheat production in South Australia found higher P in conventional grain, along with higher grain phytic acid concentrations. Phytic acid is a compound found in most cereal seeds and it is present in wheat as a mixed insoluble salt of Mg, Ca and K, with phytate-P constituting 49-80% of the total P. Phytic acid is a strong chelator of mineral nutrient elements. The complex of phytic acid and mineral elements, in the form of phytate, leads to a marked reduction in bioavailability of these nutrient elements and thus a consequent public health problem of iron and zinc deficiency for the populations whose diets are mainly cereals and legumes [13].

Physical properties of the endosperm, such as hardness, are closely related to the milling process affecting the starch damage, particle size, distribution of semolina and flour size and total milling score. Grain hardness is therefore one of the important distinguishing factors in the wheat evaluation for commercial purposes and plays an important role with regard to the suitability of grinding on a commercial mill. Hardness and softness are the milling characteristics related to the way of the endosperm breaks down. One view is that hardness is related to the degree of adhesion between starch and protein. Another one is that hardness depends upon the protein matrix continuity. According to various researches, the wheat hardness is transmitted by breeding [14]. The environmental factors affecting grain hardness are summarised as: the growing location (soil type, elevation, planting type, irrigation, fertiliser and cultivation practice), growing season (precipitation and temperature during maturation and post-ripening), storage condition, protein content, moisture, kernel size and other factors. Environmental conditions can modify the manner in which the available protein is arranged by sufficient planting regime [15].

The wheat industry has used grain hardness for decades to differentiate grain quality and market classes. Hard wheat kernels require more force to fracture while soft wheat grains require less energy, caused by differences in the endosperm starch-protein matrix. Grain hardness has also been described as the extent of endosperm packing. Soft wheat fractures easily into flour with small particle size and limited starch damage, while hard wheat produces larger flour particles with increased starch damage [16]. The purpose of this study is to see the effect of nitrogen and phosphorus fertilisers on grain hardness, hectolitre weight, grain and tissue nitrogen concentration, grain phosphorus concentration and nitrogen harvest index of durum wheat.

MATERIALS AND METHODS

Description of the Study Area: The experiment was conducted at Sinana Agricultural Research Centre, at latitude of 7°7'N and longitude of 40°10' E, with altitude of 2400 meter above sea level, located at highlands of Bale, South-eastern Ethiopia. The major soils of the area are cambisols and vertisols with clayey to sandy loam structure and a pH of 7.5 (1: 2.5 Soil: H_2O ratio). Most of the soils are poor in total nitrogen, medium in available phosphorus and high in potassium. The highland of Bale is characterized by bimodal rainfall pattern receiving peak amounts in April and September. Days are hotter in February and nights are cooler in December. The average temperature is 9.5 °c, maximum mean temperature of 21 °c and the average total annual rainfall of the experimental years is 960 mm.

Experimental Setup and Statistical Procedures: The treatments were combined in factorial arrangements of nitrogen (0, 23, 46 69 and 92 kg N ha^{-1}) and phosphorus (0, 23, 46 and 69 kg P_2O_5 ha^{-1}) in randomized complete block design with three replications on a plot size of 4m x 5m. Urea and Diammonium phosphate were used in the study as sources of nitrogen and phosphorus, respectively. Cultural operations like weeding and pest control were applied uniformly to all plots. Soil samples were taken prior to planting for analysis of total nitrogen by digestion method of Kjeldahl [16] and phosphorus by Olsen method [17]. Organic carbon was determined by volumetric method [18].

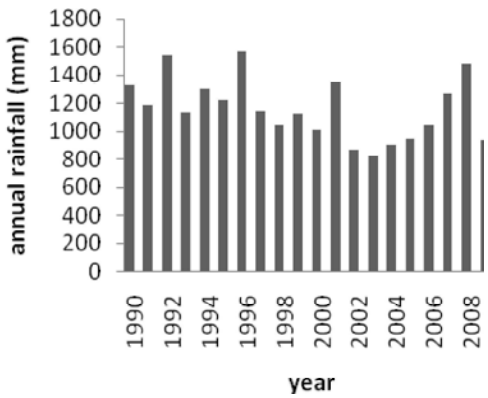

Fig. 1: Annual rainfall (mm) of 20 years

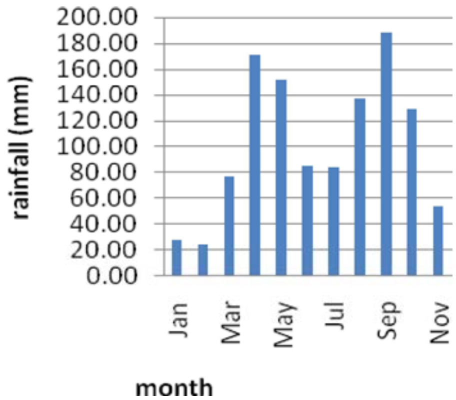

Fig. 2: Average monthly rainfall of 20 years

Table 1: soil characteristics of the experimental site

Parameters	Robe	Agarfa	Gassera	Adaba
Available P	6.38	2.39	11.90	5.53
Total N	0.12	0.17	0.22	0.24
Organic C.	2.75	2.05	1.52	-
Soil type	Cambisol	Vertisol	Vertisol	Vertisol

Samples were taken at maturity for tissue and grain nitrogen and phosphorus concentration. Samples were oven-dried at 80 °c for 24 hrs to determine the dry matter yield. Nitrogen and phosphorus concentrations of the flour and tissue were expressed in gram per kilogram of grain on dry weight basis. Grain hardness was determined by particle size index by application of milling with rotary mill and determining percentage of grains left on the mill to those passed through the mill. Hectolitre weight was determined by hectolitre instrument and expressed in kilogram per hectolitre. Data were subjected to Analysis of Variance with General Linear Model of SAS [19] and means were separated by fisher's least significant difference (LSD) test.

RESULT AND DISCUSSION

Grain Hardness and Hectolitre Weight: Analysis of variance showed a significant variation of Grain Hardness and Hectolitre Weight parameters between the test sites (Table 2). Hectolitre weight is higher at Agarfa and lower at Gassera whereas grain hardness is higher at Robe and lower at Adaba sites. Grain hardness was not significantly affected by phosphorus fertilizations whereas it had significantly responded to nitrogen fertilisers where the highest rates (46, 69 and 92 kg N ha^{-1}) were statistically responsive similarly to result in better grain hardness than the lower rate (23 kg N ha^{-1}) and the control treatment (Table 3). Hectolitre weight was not significantly affected by nitrogen rates but was responsive to phosphorus fertilizers where the highest rates (46 and 69 kg P_2O_5 ha^{-1}) showed statistically similar and higher values than the control treatment.

Hard wheat exhibits increased flour yield, increased starch damage, increased protein content, increased flour ash content and larger mean particle size compared to soft wheat [20].

There may be advantages if grain phosphorus is increased. Although it has been suggested that a higher phosphorus content in grain may provide safer or healthier products for humans, due to the ability of phytate to inhibit aflotoxin production and impart other benefits, this advantage of high phosphorus is unlikely to be of great importance in human nutrition. An increase in grain phosphorus may also be associated with more vigorous seedlings and a higher grain yield if the seed is used to grow the following year. Each of these affects of high grain phosphorus requires additional study [21].

Nitrogen and P Concentrations and NHI: Analysis of variance also showed a significant difference in experimental sites for the parameters of flour nitrogen concentration, tissue N concentration, nitrogen harvest index and flour phosphorus concentrations (Table 3). The Robe site had highest response in tissue and flour N concentration, tissue P concentration and NHI than the other sites. Nitrogen had significant influence on tissue and flour N concentrations and nitrogen harvest index. However, nitrogen fertilization did not affect flour P concentration. Nitrogen concentration in the grain and plant tissue as well as nitrogen harvest index increased with the increasing nitrogen levels. On the contrary, flour and plant tissue N concentration and NHI decreased with increasing phosphorus levels indicating apparently antagonistic effects of higher levels of phosphorus on N uptake and translocation to the grain. This is in contrast with [22] who reported the decreasing N concentration of the total plant and of the different plant organs with decreasing P supply rate.

Table 2: Response of quality parameters at different experimental locations

Locations	GH	HLW	FNC	TNC	FPC	NHI
Gassera	68.35b	81.36c	15.97b	11.29b	1.09c	0.58a
Robe	75.53a	81.81b	19.40a	12.70a	1.46a	0.61a
Agarfa	65.97b	83.45a	15.47b	10.91b	0.94d	0.48b
Adaba	57.85c	81.69b	14.48c	11.08b	1.31b	0.49b
Mean	66.93	82.08	16.33	11.49	1.19	0.54
$LSD_{0.05}$	2.74	0.32	0.78	0.77	0.079	0.035

ns= non-significant; GH= grain hardness; HLW= hectolitre weight (kg/hl); FNC= flour N concentration (gm/kg); TNC= tissue N concentration (gm/kg); FPC= flour phosphorus concentration (gm/kg); NHI= nitrogen harvest index

Table 3: Response of quality parameters to nitrogen and phosphorus fertilisation

Treatments	GH	HLW	FNC	TNC	FPC	NHI
			Nitrogen (kg N ha^{-1})			
0	63.39b	81.92a	14.48c	11.63ab	1.25a	0.48d
23	63.27b	82.26a	15.06c	11.23b	1.19a	0.51dc
46	67.52a	82.09a	16.11b	11.28b	1.19a	0.54bc
69	70.46a	82.13a	17.59a	11.19b	1.17a	0.59a
92	69.98a	81.99a	18.41a	12.14a	1.18a	0.57ab
LSD	3.068	ns	0.88	0.85	ns	0.039
			Phosphorus (kg P_2O_5 ha^{-1})			
0	67.57a	81.81b	17.12a	12.21a	1.19ab	0.55a
23	67.43a	82.11ab	16.46ab	11.34bc	1.15b	0.55a
46	66.25a	82.15a	16.04b	10.59c	1.22ab	0.55a
69	66.45a	82.25a	15.69b	11.85ab	1.24a	0.51b
Mean	66.93	82.08	16.33	11.49	1.19	0.54
LSD	ns	0.32	0.79	0.77	0.08	0.04

ns= non-significant; GH= grain hardness; HLW= hectolitre weight; FNC= Flour N concentration; TNC= tissue N concentration; FPC= Flour phosphorus concentration; NHI= nitrogen harvest index;

Table 4: Pearson's correlation analysis between yield and quality parameters

	HLW	FNC	TNC	FPC	NHI	TKW	HI	GY	BM	SPS
GH	0.05ns	0.81***	0.14*	0.01ns	0.64***	0.30**	0.28**	-0.11ns	-0.16*	0.28**
HLW		-0.14*	-0.13*	-0.31**	-0.17*	-0.39**	-0.28**	-0.01ns	0.11ns	0.12ns
FNC			0.24*	0.09ns	0.75***	0.23**	0.32**	-0.21**	-0.26**	0.33**
TNC				0.25**	-0.06 ns	0.09ns	0.02ns	-0.19**	-0.19**	0.05ns
FPC					-0.02ns	0.20**	0.16*	-0.33**	-0.34**	0.21**
NHI						0.38**	0.55**	0.02ns	-0.19**	0.16*

*= significant at P ≤ 0.05; **= significant at P ≤ 0.01; ***= significant at P ≤ 0.001; ns= non-significant; GH= grain hardness; HLW= hectolitre weight; FNC= Flour N concentration; TNC= tissue N concentration; FPC= Flour phosphorus concentration; NHI= nitrogen harvest index; TKW= thousand kernel weight; HI= harvest index; GY= grain yield, BM= biomass yield; SPS= seeds per spike

Correlation Analysis among Parameters: Grain hardness is positively and strongly associated (Table 4) with flour N concentration and N harvest index (NHI). It is also related positively but weakly with thousand kernels weight, harvest index, seeds per spike and tissue N concentration, while associated negatively but weakly with biomass yield. Grain hardness did not show significant correlation with hectolitre weight, flour P concentration and grain yield. This indicates that grain hardness is not affected significantly by flour P concentration and the increase in grain yield is also not related with increase in grain hardness. Grain hardness increases with the increase in N concentration of the flour and NHI.

Hectolitre weight had negative associations with thousand kernels weight, harvest index and flour P concentration. Similar associations were also observed with flour N and tissue N concentrations although the associations were not strong. However, hectolitre weight did not have significant association with grain yield, biomass yield and seeds per spike. Number of seeds per spike does not either increase or decrease the hectolitre weight of the grains. The analysis shows that hectolitre weight will decrease with the increase in thousand kernels weight, harvest index, flour P concentration and flour and plant tissue N concentrations.

Nitrogen concentration of the flour was most influenced by grain hardness and N harvest index while less powerful and positive influence exists from thousand kernels weight, tissue N concentration, harvest index and seeds per spike. Flour N concentration is reduced by increasing values of biomass yield, grain yield and hectolitre weight. However, the increase or decrease in flour P concentration does not have any influence on flour N concentration at least for the rates of P applied in the experiment. Tissue N concentration was also negatively correlated with grain yield, biomass yield and hectolitre weight although the correlation was not strong. No association was observed for tissue N concentration with thousand kernels weight, harvest index, NHI and seeds per spike.

CONCLUSION

Nitrogen and phosphorus are the most limiting nutrients in crop production especially in the tropics where applications of these fertilisers definitely bring about significant improvement in yield and quality especially of those highly responsive commercial crops. Durum wheat is produced in highland vertisols of Ethiopia mainly for food and industrial purposes. The soils of Ethiopian highlands are mainly deficient in organic matter, nitrogen and phosphorus because of nutrient mining by cereal monocropping and leaching losses where deficiency of these elements reduces yield and quality of crops.

Grain hardness and hectolitre weight are quality parameters considered by the processing industry for which they set specific standards for milling and end-use. Hardness is related to milling properties and the degree of adhesion between starch and protein. Hectolitre weight is related to the flour volume obtained from a specific weight of grain. These parameters have different responses across test sites and fertiliser rates. Grain hardness is higher at Robe site while hectolitre weight is higher at Agarfa site. The Robe site also had higher values of tissue and flour N concentrations and flour P concentration whereas these parameters are lower at the Gassera site. Once a rate is determined for maximum index, increase in nitrogen rate does not result in a change of grain hardness whereas phosphorus rate has no effect on grain hardness. Hectolitre weight is not influenced by nitrogen application while it is affected by phosphorus rates compared to no phosphorus application.

Correlation analysis shows the degree of association between parameters and it indicates how one variable is changing with the change in the other variable. Grain yield and biomass yield are negatively correlated with tissue and flour N concentrations and flour P concentration indicating that as grain yield and biomass yield increases, these parameters decrease. Increasing biomass yield is related with decreasing grain hardness and NHI. Higher harvest index will result in higher NHI, flour N concentration, grain hardness and flour P concentration. More information should be obtained by conducting extra experiments in the highlands of Bale to draw conclusions of the effect of nitrogen and phosphorus fertiliser rates on grain texture and hectolitre weight as well as grain and tissue nitrogen and phosphorus concentrations.

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