Heliyon 9 (2023) e18733

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Sustainable management practices for durum wheat production: Analyzing specific agronomic interventions on productivity, grain micronutrient content, and quality

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ARTICLE INFO

Keywords:
Durum wheat
Grain micronutrient concentration
Nutrient management
Protein content
Yield

ABSTRACT

As compared with single agronomic crop management practices during grain formation, knowledge about integrated agronomic management practices on grain mineral composition and grain technological properties in durum wheat is limited. This knowledge is important for determining management strategies aimed at increasing grain yield without affecting grain nutritional quality. Integrated agronomic practices such as foliar nutrient application × seeding rate × varieties combined with growing locations were investigated to evaluate the dynamics of yield and grain quality traits. Two durum wheat varieties, three-level of micronutrients (i.e. control, $FeSO_4$, and $ZnSO_4$), and four levels of seeding rate (i.e. 100, 125, 150, and 175 kg ha^{-1}) were arranged in split-split plot design under two different growing locations (environments). The main plots were assigned to the varieties, subplots to micronutrients, and sub-sub plots to the seeding rate treatments. Zinc and iron were applied in a form of $ZnSO_4$ and $FeSO_4$ at the early flowering stage, both at a rate of 25 kg ha^{-1}. Results showed a linear increment in biomass (21.5%) and grain yield (23.5%) under a high seeding rate, even though the 1000-grain weight, the number of grains $spike^{-1}$, spike length, and the number of grains $spike^{-1}$ were decreased. Higher varietal and environmental response of seeding rate was observed between varieties. The grain protein content, gluten, and zeleyn index decreased as the seeding rate increased. Grain micronutrient content was significantly influenced by seeding rate and varietal difference. The grain protein content was higher in a dryland environment than in a wet environment. A combined use of density-tolerant varieties, high seeding rate, and foliar-based iron application can improve the grain yield from 2.01 to 3.20 t ha^{-1} under a potential environment. Hence, all stakeholders should consider the genotype (G), environment (E), management (M), and their synergies, as far as grain yield and quality are considered simultaneously.

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https://doi.org/10.1016/j.heliyon.2023.e18733
Received 6 March 2022; Received in revised form 14 July 2023; Accepted 25 July 2023
Available online 1 August 2023

1. Introduction

Ethiopia is considered a primary center of genetic diversity for durum wheat *(Triticum turgidum* L.*)*, with diverse agro-climatic zones suitable for wheat production [1,2]. Improving durum wheat yield, commercial grain quality, and mineral content are an endless topic in agricultural research, due to an increase in market demand for acceptable grain quality traits. However, this aim is susceptible to challenges stemming from agronomic crop management practices, crop genetic variation, and their intricate interaction with the environment [3,4]. The interaction between agronomic management practices, such as seeding rate and nutrient supply with the growing environment, is a widely accepted yield and grain quality limiting factor [5,6]. Both low and high seeding rates have been found to have negative impacts on the technological properties and grain yield of durum wheat [7], through the fact that higher seeding rate increase disease pressure, insect and decrease lodging resistance of the crop [8]. Improper seeding rate have been estimated to cause a reduction in yield by about 24% and a decrease in grain protein content by 8.7% [3]. However, it is important to note that the specific effect can vary depending on the cultivation environment and response of different varieties to these factor but this effect is varied with [3]. Therefore, having a comprehensive comprehension of the dynamics associated with durum wheat production becomes essential for improving both qualitative and quantitative characteristics. This becomes particularly crucial when cultivating superior durum wheat varieties in marginal environments that demand specific management strategies to ensure sustainable production of high-quality durum wheat [9]. Hence, it is important to adopt integrated crop management practices, as relying solely on agronomic approaches may not yield the desired outcomes. This integrated approach allows for the regulation of interactions between genotype (G), environment (E), and management (M), thereby maximizing the potential of durum wheat production in adverse conditions.

Interventions such as integrated management strategies have been developed with the primary aim of bettering grain yield and qualitative traits, simultaneously. Integrated crop management strategies are combinations of agronomic practices applied to attain maximum grain yield with adequate quality, and long-term sustainability based on analyses of productivity and quality limiting factors under a set of environmental circumstances [10,11]. Thus, fostering and planting suitable varieties, an adequate planting population, and sufficient plant nutrition are among the desired practices to achieve maximum yield and grain quality in durum wheat [4,10]. Integrated use of micronutrients coupled with optimum seeding rate and density-tolerant varieties has paramount importance to improve grain yield, protein content and grain micronutrient concentration, simultaneously [3]. This has been verified that the application of foliar-based zinc containing fertilizers (aka agronomic biofortification) during the crop growth period increases the grain mineral content [12], by about 3.04 mg kg^{-1} to 56.73 mg kg^{-1} of zinc [13]. Similarly, foliar application of iron containing fertilizers can be a practical approach to improving iron concentration, and quality in wheat grains [14]. This can lead to an increase in the iron concentration in durum wheat grains, improving their nutritional and market values as well.

Wheat grain quality and mineral composition can be enhanced by agronomic biofortification through the application of micronutrient-containing fertilizers, which enable to reduce malnutrition and associated human health problems [15]. A diet based on cereals such as wheat grain may lack essential micronutrients, since wheat is naturally low in grain zinc concentration and high in phytate content, which further limits the bioavailability of zinc in the grain [11]. It has been estimated that over 1.5 billion of the world's population are troubled by one or more forms of micronutrient deficiency [16]. Hence, there is a need to improve essential micronutrients in the edible part of food crops. This could be reduced directly through nutrition-specific strategies, and indirectly through nutrition-sensitive interventions, including fertilizer strategies [17]. However, it has been observed that different varieties of the same species respond differently to the applied inputs, suggesting that appropriate varietal selection with a specific set of agronomic management practices is required [3,18,19]. Therefore, incognizant of the aforementioned facts, combined application of selected agronomic practices such as foliar based micronutrients, durum wheat genotype (i.e. improved and landrace) with a range of seeding rates were employed in this study for evaluation of their synergetic effect on grain yield, grain quality, and grain micronutrient concentration, under divergent growing environment. The hypothesis of this study postulates that the combined application of crop micronutrients and adjustments in seeding rate will have an impact on the grain micronutrient content, grain quality, and overall productivity of durum wheat.

2. Materials and Methods

2.1. Description of the study areas

The study was performed to determine the effect of varieties × location × seeding rate × micronutrients on various aspects of durum wheat production, including yield, agronomic traits, grain protein, and mineral content. The research was conducted at two locations: Mekelle University (MU) research station and Hagere-Selam (HS) in Northern Ethiopia. Mekelle University research station is situated at coordinates 13°30′N 39°29′E, with an elevation of 2210 m above sea level (m.a.s.l). Throughout the growing season, the mean maximum temperature recorded was 33.1 °C, while the mean minimum temperature was 8.6 °C. The site received a total rainfall of 412.25 mm during the cropping season. Hagere-Selam, the second site, is located at coordinates 13°39′N and 39°10′E, with an altitude of 2560 m. a.s.l. This location experiences relatively cooler temperatures, with a seasonal range of 4 °C–22 °C. The average annual precipitation in Hagere-Selam was 762 mm [3]. The soil composition at the experimental sites differed, with Mekelle University research station having sandy clay loam soil and Hagere-Selam having clay loam soil. There were variations in total nitrogen, organic matter content, and available phosphorus between the two sites, as indicated in Table 1. Both experimental sites exhibited deficient levels of zinc and iron nutrients in their soil fertility statuses [20].

2.2. Experimental design and treatments

The treatments comprised a factorial combination of two durum wheat varieties (i.e. Asassa and Acc.208,304), four levels of seeding rates (i.e. 100, 125, 150, and 175 kg ha^{-1}), and three-levels of foliar based micronutrient (i.e. control, zinc, and iron) were arranged in a split-split plot design with two replications, under two growing locations. The variety Asassa represents an older improved variety while acc. 208,304 is a newly registered durum wheat variety specifically developed for commercial production. Both varieties have been selected based on their ability to deliver high yields, consistent performance, and suitability for cultivation across a wider geographical area within the target region. The two varieties, were assigned into the main plots, the three-levels of micronutrients into the subplots, and the four-level of seeding rate were assigned into sub-sub-plots with two replications. The plot size of sub-plots was 4.4 m × 2.5 m (11 m^2), while the sub-sub-plots were measured at 1.2 m × 2.5 m (3 m^2). The spacing between each sub-plot and sub-sub-plots was 0.5 m and 0.4 m, respectively, and replications were separated by 0.8 m spacing. At early flowering stage, a solution of zinc and iron sulfate was foliarly applied at a rate of 25 kg ha^{-1}. Urea (46% N) and DAP (18% N, 46% P_2O_5) were used as sources of N and P, respectively. These nutrients were uniformly augmented to all plots at a rate of 46 kg ha^{-1} (N) and 20 kg ha^{-1} (P). However, due to the nature of nitrogen fertilizer, a split application method was employed. The first half-dose along with the recommended phosphorus dose, was supplied at planting, while the remaining half dose was provided at the early tillering stage of the durum wheat. Additionally, other agronomic practices, such as weed control, were applied uniformly to all plots as per recommended for wheat at both locations. Harvesting took place when the crop reaches at the physiological maturity.

2.3. Data collection

2.3.1. Phenological and agronomic traits

Data on phenological, yield and agronomic quantitative traits were collected at both experimental locations. The phenological traits included the number of days until 50% booting, 50% flowering, and 90% maturity, which were recorded by counting the number of days from emergency to the respective stages. Agronomic quantitative traits such as plant height, number of effective tillers $plant^{-1}$, spike length, and the number of grains $spike^{-1}$, were measured from five randomly selected representative plants. Plant height was determined by measuring the distance from the soil surface to the top of the spike, taking the average height of the main tiller into account. The spike length was measured as the average length of five sampled spikes, starting from the base of the spike up to the apex, excluding the awns. The effective number of tillers was determined by randomly selecting seed-producing tillers from each plot and counting the number of such tillers per plant base at physiological maturity. The number of grains per spike was counted and averaged to obtain the average number of grains on a single spike.

Thousand-grain weights were determined by weighing a sample of 1000 grains taken from the grain yield of each treatment using an electronic balance. To estimate grain and aboveground biomass yields, the net plot area was delineated by leaving two border rows on both sides of each plot. The total aboveground plant material including spikes, and grains, was weighed to obtain the biomass yield. Manual threshing was performed to separate the grain from the straw. The grain was then adjusted to 12.5% moisture content according to Badu-Apraku et al. [21], and the final grain yield was determined as ton ha^{-1} base [21].

$$\text{Grain yield obtained } (\text{kg ha}^{-1}) = \frac{100 - \%\ \text{AMC}}{100 - \%\ \text{SMC}} \times 100 \tag{1}$$

where, AMC = Actual (obtained) Grain Moisture Content (%); SMC = Standard Moisture Content.

2.3.2. End-use functional properties

After harvest, a sub-sample of 350 g whole grains was taken from each treatment, considering the different varieties, replications, and tested locations. These grain samples were sent to the Sinana Agricultural Research Center (SiARC) Laboratory in Ethiopia. Using a

Table 1
The soils physical and chemical properties of the experimental locations before planting.

Soil Parameters	Unit	Experimental locations	
		HS	MU
Sand contents	%	31.0	45.0
Clay contents	%	32.0	34.0
Silt contents	%	37.0	21.0
Soil Textural class	%	Clay loam	Sandy clay loam
Soil pH		6.9	6.9
Organic carbon	%	0.1	0.7
Total Nitrogen	%	0.1	0.1
Total Iron	%	5.6	4.5
Total Zinc	%	0.01	0.01
Available Phosphorus	ppm	15.7	11.1
Soil organic matter	%	0.2	1.2
Cation Exchange Capacity	Cmol kg^{-1}	4.4	8.8
Electro conductivity	**mS/cm**	**0.2**	**0.2**

machine called Minfra Smart T® wheat grain analyzer, the whole grain protein content, gluten content, and Zeleny index values were measured [3].

2.3.3. Grain mineral content

To analyze the concentrations of zinc and iron in the whole durum wheat grains, the grains were first digested using the Perten Laboratory Mill 120. The digested grains were passed through a standard sieve with a mesh size of 0.8 mm. The quantification of zinc and iron concentrations was then carried out using the Varian AA240FS Fast Sequential Atomic Absorption Photometer. This device is a fully automated *P*C-controlled true double beam atomic absorption spectrophotometer that allows for fast multi-element flame AA determinations. The instrument was operated using SpectrAA Base and PRO software version, following the procedure outlined by Kunda et al. [22,23]. To facilitate the digestion process, an automated digestion chamber was utilized. The resulting samples were analyzed for zinc and iron concentrations, which were expressed as milligrams per kilogram (mg kg^{-1}) in the durum wheat grains.

2.4. Statistical data analysis

The mean data from five randomly selected plants of each variety were used to calculate the range of agronomic traits, and the overall mean of each environment. Prior to statistical data analysis, the collected data including agronomic, phenological, grain protein and mineral content, were tested for normality and homoscedasticity. The statistical analysis of the data was conducted using GenStat (18th ed.) statistical software package [24,25]. When the ANOVA revealed a significant difference, the mean values of the treatment groups were compared using the least significance difference (LSD) at a 5% significance level. These mean values were then used to construct the graphs using excel graphing features. Additionally, paired Spearman's correlation analysis was performed using the same statistical software package to assess the strength of the relationship between pairs of traits under the applied treatments. This analysis helps to determine the degree of association between different traits.

3. Results

3.1. Phenological plasticity under a range of management practices

The analysis revealed that the tested varieties, seeding rate, location, micronutrients, and their interaction had a significant *($p < 0.05$)* impact on the phenological traits studied (S1). An increase in the seeding rate led to a reduction in number of days required for booting and maturity, and this effect was observed consistently across the tested varieties (Table 2). Additionally, there was a significant interaction between seeding rate and locations in relation to flowering period, particularly at 125 kg seeding rate ha^{-1} (Table 2).

The interaction between seeding rate, variety, and growing environment was found to be significant for the physiological maturity of durum wheat (S1, Table 3). At the higher seeding rate (175 kg ha^{-1}), both varieties exhibited a longer maturity period. However, this effect was more profound in the HS environment compare to MU environment (Table 3). These variations in growing location played a significant role in influencing the phenological plasticity of durum wheat varieties (S3). On the other hand, the sole effect of seeding rate and the interaction between seeding rate and location did not have a statistically significant influence on the flowering period (S1).

3.2. G × E × M for grain and biomass yield

The interaction between genotype (G), growing environment (E), management (M) significantly *($p < 0.05$)* influenced plasticity and final harvestable yield of durum wheat (S1). It was observed that higher seeding rate resulted in a maximum biomass yield and grain yield of 7.5 t ha^{-1} (Fig. 1A) and 2.3 t ha^{-1} (Fig. 1B) across the tested varieties than the lower seeding rate. Moreover, the interaction between seeding rate, variety, and growing locations was found to be statistically significant (S1, Fig. 2). The density-intolerant variety acc.208,304 was attained maximum grain yield at a higher seeding rate of 150 kg ha^{-1}. However, when planted

Table 2
Seeding rate × location effect on phenological plasticity of durum wheat.

Locations	Seeding rate (kg ha^{-1})	Selected phenological traits		
		Days to 50% booting	Days to 50% flowering	Days to maturity
HS	100	63.9	72.6	108.4
	125	66.1	74.0	109.2
	150	63.8	73.1	109.2
	175	63.9	73.4	110.2
MU	100	57.0	62.3	91.6
	125	57.1	62.3	93.6
	150	57.5	62.3	92.3
	175	57.1	62.3	92.7
$LSD_{0.05}$		0.82	1.1	1.4
CV (%)		1.90	1.5	1.94

Table 3
Interaction effect of varieties and seeding rate on phenological traits of durum wheat.

Varieties	Seeding Rate (kg ha^{-1})	Selected phenological traits					
		Days to 50% booting		Days to 50% flowering		Days to maturity	
		HS	MU	HS	MU	HS	MU
Acc.208,304	100	65.2	59.0	72.7	64.5	108.2	90.8
	125	66.8	58.7	73.2	64.0	109.7	93.8
	150	64.5	59.0	73.5	63.7	108.7	93.0
	175	63.7	59.0	73.5	64.0	111.5	92.7
Asassa	100	62.7	55.0	72.5	60.2	108.7	92.3
	125	65.3	55.5	74.8	60.5	108.7	93.3
	150	63.2	56.0	72.7	61.0	109.7	91.5
	175	64.2	55.2	73.3	60.5	108.8	92.7
$LSD_{0.05}$		1.6		1.6		2.3	
CV (%)		1.9		2.2		1.9	

the lowest seeding rate (100 kg ha^{-1}) at MU environment, the grain yield of acc.208,304 decreased by about 12% (Table 4).

A seeding rate × growing environment interaction was significant for grain yield (S1). It was observed that grain yield decreased at a seeding rate of 175 kg ha^{-1} at HS, while the opposite trend was observed at MU, across the varieties (Fig. 2). Furthermore, a statistically significant interaction was observed between seeding rate and foliar-based micronutrients for grain yield (S1). The combination of density-tolerant variety (Asassa), higher seeding rate (150 kg ha^{-1}), and foliar-based iron sulfate fertilization improved the grain yield from 2.01 to 3.20 t ha^{-1} in a potential (HS) environment (Table S2). This indicates the potential benefit of using specific or effective combination of agronomic management practices to enhance rain yield in a specific growing environment.

3.3. G × E × M for yield attributed traits

The combined analysis of variance revealed a significant interaction effect of varieties × seeding rate × location on the studied yield components (S1). Within the range of seeding rate tested, there was a consistent decrease in spike length, number of grains spike^{-1}, and 1000-grain weight with increasing seeding rate (Table 5). This suggests that higher seeding rates negatively impacted these yield attributed traits. Contrary to the expected trend, the plant height results did not coincide with the assumption that interplant competition was the sole factor influencing the observed differences among the studied traits (Table 5). It means the factors other than interplant competition may significantly contributed to the variation in plant height. The interaction between seeding rate and varieties was significant on 1000-grain weight, and the number of effective tillers in both growing locations (Table 4) and for the number of productive tillers (S1). This interaction effect was more pronounced in density-tolerant variety (Asassa) compared to density-intolerant variety (acc.208,304).

3.4. G × E × M for grain quality

Important interaction was observed between seeding rate and micronutrients on grain qualitative traits (Table 7). Additionally, the interaction effect between seeding rate and location was also statistically significant *($p < 0.05$)* for the studied qualitative traits (S1, Table 6). The seeding rate effect on protein content was more pronounced under high-rainfall and wet environment (HS) compared to the dryland (MU) environment (Fig. 3, Table 6).

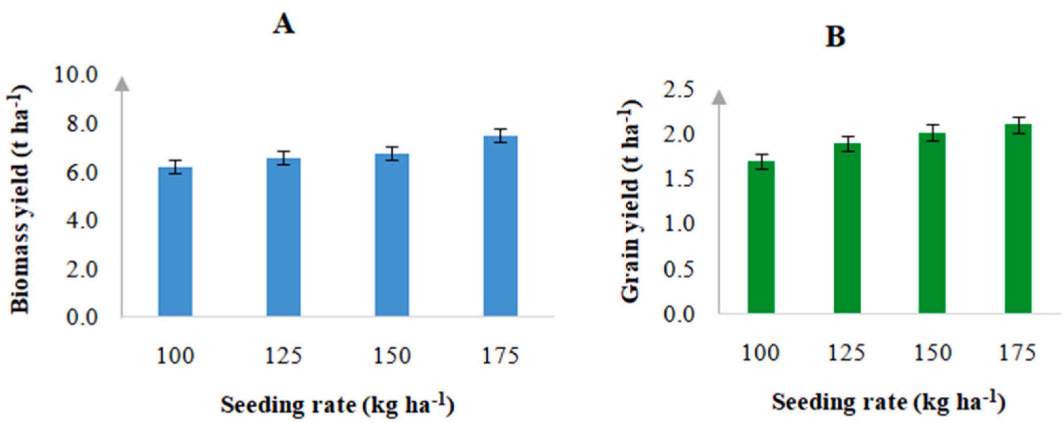

Fig. 1. Illustrates a linear increment in aboveground biomass **(A)** and grain yield **(B)** under high seeding rate, even though fundamental yield attribute traits such as the number of grains spike^{-1} and 1000-grain weight was decreased.

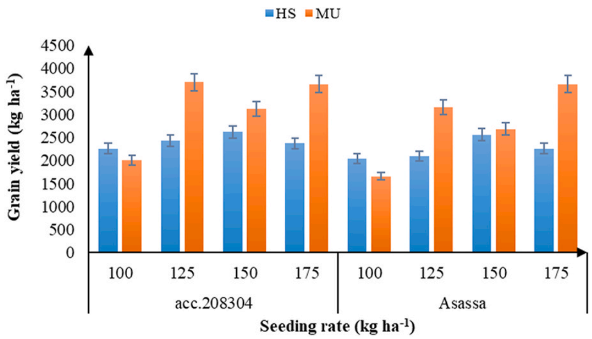

Fig. 2. This figure illustrated that, the positive benefit of increased yield with increasing the seeding rate up to 125 kg ha^{-1} after which there is little apparent reduction in grain yield under wet environment (HS), but this trend is reverse under dryland environment (MU).

Table 4
Interaction effect of varieties, seeding rate and location on selected agronomic traits, biomass and grain yield of durum wheat.

Varieties	Seeding Rate (kg ha^{-1})	SPL (cm)		NET		SPS		BY (t ha^{-1})		GY (t ha^{-1})		TGW (g)	
		HS	MU	HS	MU	HS	MU	HS	MU	HS	MU	HS	MU
Acc.208,304	**100**	5.1	3.8	4.13	3.80	36.9	31.0	6.9	5.4	2.2	1.3	35.2	34.2
	125	4.9	3.7	3.10	3.73	32.1	29.4	7.3	6.1	2.3	1.7	35.8	37.7
	150	5.1	3.8	3.77	3.80	37.0	29.7	8.2	6.2	2.5	1.4	34.4	32.0
	175	4.9	3.6	3.77	3.63	33.2	30.6	7.5	7.6	2.3	1.7	31.5	34.4
Asassa	**100**	5.1	3.5	4.87	3.47	50.1	37.8	8.3	4.4	1.9	1.4	44.2	32.7
	125	5.4	4.3	4.03	4.27	46.1	39.8	6.3	6.7	2.0	1.7	41.4	33.1
	150	5.2	3.7	3.90	3.70	43.4	36.6	6.5	6.3	2.4	1.7	39.9	32.7
	175	5.1	4.1	3.13	4.13	45.5	38.1	6.7	8.2	2.2	2.2	39.3	31.1
$LSD_{0.05}$		0.9				2.8		1.2		0.1		1.0	
CV (%)		4.1				4.7		11.7		5.0		1.7	

Keys to abbreviations: SPL: spike length, **NET:** number of effective tiller, **SPS:** the number of grains spike^{-1}, **BY:** biomass yield, **GY:** grain yield **TGW:** thousand grain weight, **HS:** Hagere-selam, **MU:** Mekelle University, **$LSD_{0.05}$**; least significant difference at 0.05 probability level, **CV (%);** coefficient of variation.

Table 5
A sole effect of adjusting seeding rate on selected agronomic traits, grain end-use functional properties, and grain micronutrient of durum wheat.

Seeding Rate (kg/ha)	Selected agronomic traits					Grain quality traits			Grain Iron content (mg kg^{-1})
	PH (cm)	NET	SPL (cm)	SPS	TGW (g)	Protein content (%)	Dry gluten Content (%)	Zeleyn index (ml)	
100	85.45	4.10	5.56	38.89	36.56	16.18	37.91	79.20	38.89
125	86.00	3.78	5.56	36.78	37.00	15.80	36.74	77.30	49.62
150	86.56	3.80	5.55	36.68	34.67	15.26	35.27	74.00	38.13
175	87.00	3.67	5.31	36.89	34.01	14.93	34.17	72.59	35.83
$LSD_{0.05}$	1.0	0.3	0.2	1.5	0.5	0.3	0.4	0.6	1.78
CV (%)	1.3	0.5	4.1	4.7	1.7	2.6	1.3	0.9	5.10

Table 6
Seeding rate × location interaction on grain quality traits of durum wheat.

Seeding Rate (kg ha^{-1})	Protein Content (%)		Dry gluten Content (%)		Zeleyn Index (ml)	
	HS	MU	HS	MU	HS	MU
100	14.6	17.8	33.9	41.9	72.7	85.7
125	15.1	16.6	34.9	38.6	74.8	79.8
150	13.8	16.7	31.7	38.8	68.3	79.8
175	15.3	14.6	35.5	32.9	76.1	69.0
$LSD_{0.05}$	0.4		0.6			0.7
CV (%)	1.7		2.1			1.0

Table 7
A combined effect of seeding rate and foliar based micronutrient fertilization on grain quality traits, mineral content and grain yield of durum wheat.

Micronutrients	Seeding rate (kg ha^{-1})	Grain quality traits				1000-grain weight (g)	Grain yield (kg ha^{-1})
		Protein content (%)	Dry gluten content (%)	Zeleyn Index (ml)	Iron content (mg kg^{-1})		
Control	**100**	16.64	39.18	82.00	37.18	35.20	1.60
	125	15.70	36.30	76.45	36.30	35.01	1.70
	150	14.98	34.78	72.93	34.78	34.00	2.01
	175	14.63	33.60	71.48	33.60	33.41	2.10
$FeSO_4$	**100**	14.85	34.48	72.78	34.46	37.10	1.90
	125	16.50	38.85	80.35	38.85	38.67	1.80
	150	15.58	36.00	75.20	36.00	35.10	1.90
	175	16.08	37.18	78.08	37.16	34.10	1.80
$ZnSO_4$	**100**	17.08	40.05	82.80	40.05	37.39	1.60
	125	15.20	35.08	75.03	35.06	37.20	2.10
	150	15.28	35.05	73.98	35.05	35.10	2.10
	175	14.10	31.73	68.13	31.73	34.56	2.20
$LSD_{0.05}$		0.52	0.80	0.88	0.78	0.10	1.20
CV (%)		2.60	1.30	0.90	2.1	5.00	1.70

Indeed, the growing location, either as the sole factor or in interaction with the other factors, had a significant effect on all the studied grain quality traits (Table S2, Table 6, Fig. 2). Furthermore the combined effect of all the management practices with the growing environment was found to be statistically significant ($p < 0.05$) (S1). This suggest that the interaction between crop management practices and environmental conditions of the growing location played a crucial role in determining the grain qualitative traits. There was also a significant effect of varieties on the grain quality traits, which suggest the genetic variability between durum wheat varieties in terms of their grain quality characteristics (Fig. 4).

3.5. *Agronomic biofortification and its implication to reduce the hidden hunger*

The concentrations of mineral elements in durum wheat grain varied among different varieties and the imposed treatments (Table 8). When considering the sole effect of seeding rate, it was found that the grain zinc and iron concentration were higher in durum wheat grown under the lowest seeding rate (125 kg ha^{-1}) compared to the higher seeding rate (Table 4). Additionally, the variety acc.208,304 planted at an optimum seeding rate of 125 kg ha^{-1} exhibited higher grain zinc and iron concentration (Fig. 5). These findings suggested that both seeding rate and varietal selection can influence the mineral element concentrations in durum wheat grains.

3.6. *Relationships between grain yield and its components*

3.6.1. *Phenological traits*

A correlation analysis between different agronomic traits and grain yield of durum wheat varieties is presented in Table 9. Most of the yield component parameters showed a statistically significant positive relationship with phenological traits, although there were few exceptions. Days to maturity was positive and significantly correlated with the number of days to booting and flowering ($r = 0.46$, 0.89, DB, and DF, respectively). However, the relationship of days to booting, days to flowering and aboveground biomass was positive but not statistically significant. Furthermore, all selected phenological traits exhibited a positive but non-significant correlation with the number of effective tillers ($r = 0.19^{ns}$, 0.06^{ns}, and 0.10^{ns} for DB, DF, and DM, respectively).

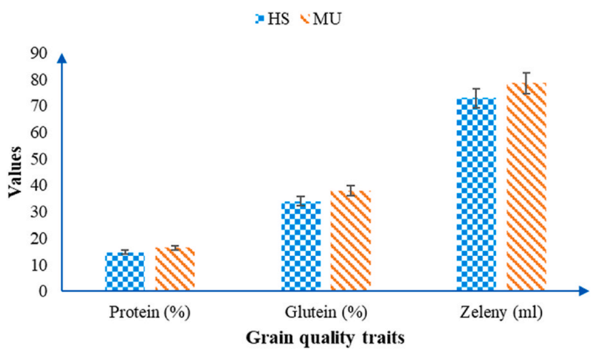

Fig. 3. Grain end-use functional properties as influenced by divergence in growing locations.

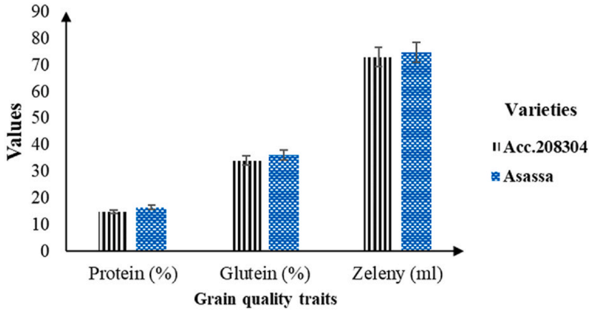

Fig. 4. Variation in genetic landscape influences the grain qualitative of durum wheat.

Table 8
Interaction effect of varietal difference and foliar based micronutrient supply.

Variety	Foliar application of micronutrients	Seeding rate (kg ha^{-1})			
		100	125	150	175
Acc.208,304	Control	33.04	42.65	33.98	35.72
	FeSO4	30.98	50.66	32.46	23.95
	ZnSO4	56.13	57.83	56.52	59.27
Asassa	Control	33.18	32.50	26.48	26.80
	FeSO4	31.0	29.61	31.46	26.54
	ZnSO4	49.0	45.48	47.90	42.68
LSD0.05					5.60
CV (%)					2.10

Additionally, it has been observed that combined use of nutrient efficient varieties (acc.208,304) and foliar-based zinc fertilization with a higher seeding rate (175 kg ha^{-1}) was improved grain zinc concentration (Table 8).

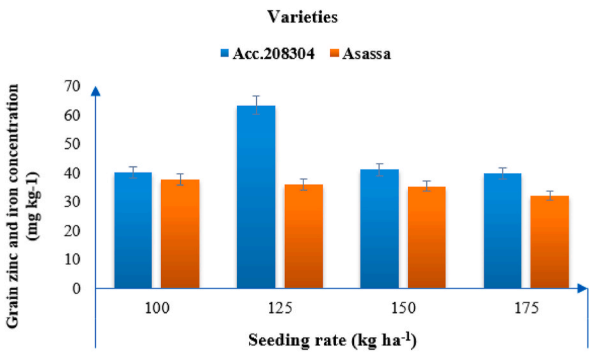

Fig. 5. Corresponding changes in grain micronutrient (zinc, iron) concentration in durum wheat in response to foliar feeding of micronutrients and varieties.

3.6.2. Associations among yield components traits

The correlation analysis revealed several significant associations between agronomic traits, and grain quality in durum wheat (Table 9). Plant height showed a positive and highly significant association with aboveground biomass (r = 0.45, $p < 0.01$) and grain yield (r = 0.53, $p < 0.01$). Additionally, plant height was strongly and positively associated with the number of tillers plant^{-1} (r = 0.40, $p < 0.01$). However, the number of effective tillers was not show a statistically significant with aboveground biomass, but exhibited a positive and significant association with grain yield. The number of grains per spike and spike length were positively and highly significantly correlated (r = 0.47, $p < 0.01$). Spike length also showed a positive and strong association with grain yield (r = 0.42, $p < 0.01$). Furthermore, 1000-grain weights showed a positive and highly significant association with grain yield (r = 0.45, $p < 0.01$). The correlation among the studied traits highlight the importance of agronomic traits in determining grain yield in durum wheat, emphasizing their potential as selection criteria for improving yield potential in future breeding programs of management practices.

Table 9
The correlation coefficient between agronomic traits and yield of durum wheat varieties tasted at four seeding rates and grown under two divergent growing locations (environments).

Selected agronomic traits of durum wheat									
	BY	DB	DF	DM	GY	NET	PH	SPL	SPS
BY	–								
DB	0.06^{ns}	–							
DF	0.22^{ns}	0.48**	–						
DM	0.28*	0.46**	0.89**	–					
GY	0.53**	0.14^{ns}	0.35**	0.50**	–				
NET	0.18^{ns}	0.19^{ns}	0.06^{ns}	0.10^{ns}	0.33*	–			
PH	0.45**	0.30*	0.59**	0.64**	0.68**	0.40**	–		
SPL	0.20^{ns}	0.37**	0.68**	0.67**	0.41**	0.33**	0.57**	–	
SPS	0.21*	0.17^{ns}	0.31*	0.40**	0.42**	0.36**	0.31**	0.57**	–
TGW	0.08^{ns}	0.24*	0.34**	0.39**	0.45**	0.21*	0.24*	0.31**	0.47**

Keys to abbreviations: ** correlation is significant at 0.01 level of probability, * correlation is significant at 0.05 level, **ns:** no significant, **DB:** day to booting, **DF:** days to flowering **DM:** days to maturity **SPL:** spike length, **NET:** number of effective tiller, **SPS:** the number of grains spike^{-1}, **BY:** biomass yield, **GY:** grain yield, **TGW:** thousand grain weight, **PH:** plant height.

4. Discussions

4.1. Phenological plasticity under a range of management practices

The continual monitoring and reevaluation of basic agronomic management practices is very important to enhance performance and sustainability of durum wheat production. This is particularly important in the face of changing climatic condition s and variation in genetic makeup of durum wheat. The recommendations for practices such as seeding rate, variety, and nutrient application that were previously effective under normal climatic conditions may not be suitable under the current production season due to climate variability. The study revealed statistically significant results across different varieties, growing locations and the applied inputs, indicating the influence of these factors on the phenological plasticity of durum wheat. It could be due to the fact that, lowest seeding rate can regulate crop uniformity, and variation in crop uniformity is observed to contribute for prolong the flowering period and associated traits [26]. This finding is in contrast to Geleta et al. [6], which reported that increasing the seeding rate could shorten the flowering time in winter wheat. These discrepancies suggest that the relationship between seeding rate and flowering time in durum wheat varies depending on various factors such as the specific durum wheat variety, growing conditions, and experimental setup. It highlights the importance of considering multiple studies and factors when evaluating the impact of seeding rate on flowering time in wheat. These highlights the need for adaptive agronomic management strategies that take into account the specific genetic characteristics of durum wheat varieties, the local growing condition and dynamic nature of the climate. Hence, regularly assessing and adjusting agronomic practices could optimize the performance and sustainability of wheat production [27].

The observed interaction effects between the imposed factors and seeding rate, particularly on the days of physiological maturity, can contributed to the impact of canopy density and soil water retention. A denser canopy resulting from higher plant stand establishment under increased seeding rate can lead to improved water retention in the soil, which may contribute to longer maturity period. Additionally, the prolonged maturity period under higher seeding rates could be linked to a longer flowering period, as indicated by the positive and significant correlation between flowering and maturity periods (Table 9). This correlation aligns with findings from previous studies [23]. The response of durum wheat to changes in seeding rate, particularly in terms of adjusting reproductive phases is modulated by the specific characteristics of durum wheat varieties and the prevailing growing conditions (S3, Table 2, Table 3). The specific extent of this response can vary depending on the genetic characteristics of different durum wheat varieties and the environmental conditions in which crops are grown. The variation in growing locations has been also found to be significant for both the booting stage and flowering period of durum wheat. Under potential environment (HS), the booting stage and flowering period were delayed by a few days compared to the moderate stress (MU) condition (S3). The observed delays in the HS condition highlight the sensitivity of durum wheat to environmental stress, which can have implications for its overall growth and development. This also clearly indicates that the environmental conditions play a crucial role in shaping the timing and progression of reproductive phases of durum wheat varieties. The variation is likely attributed to differences in climatic conditions, leading to MU experiencing end season moisture stress, thus early maturing is characteristics in such condition. Hence, early maturing durum wheat varieties could have advantage of escaping or minimizing the impact of end season moisture stress by completing their development before the stress period intensifies [25]. This trait further enables the varieties to generate sufficient biomass before flowing and minimize losses in floral fertility caused by heat, frost, water stress, while also ensuring enough water is available for grain filling [28].

4.2. Enhance productivity: G × E × M for improved grain and biomass yields

When analyzing the relationship between durum wheat yield and agronomic traits, a linear increase of grain yield was observed. Increases the seeding rate resulted in a linear increase in grain yield, with a significant rise of 23.5% (Table 4). This increase in grain yield was attributed to a higher number of productive tillers per meter square [29]. These findings suggest that adjusting the seeding rate based on the specific cultivation conditions could play a crucial role in addressing food insecurity, particularly in developing nations. Studies have estimated that a mere 1% improvement in agricultural yield could lead to a reduction of 0.6–1.2% in the number of low-income households [30]. While adjusting the seeding rate can be available strategy it should be considered other agronomic based practices such as soil management, irrigation, and nutrients as well. Hence, agronomic based research areas should be linked to a wide range of interdisciplinary and food industry sectors to reduce any adverse reaction. This interdisciplinary approach ensures that agronomic research aligns with broader industry goals and promotes positive outcomes across the entire durum wheat supply chain. Another notable observation regarding seeding rate is its impact on biomass yield, with higher seeding rates resulting in maximum biomass production. The other effect of seeding rate has been observed for biomass yield, where maximum biomass was attained under higher seeding rate. Higher biomass production under such scenarios could be influenced by different factors and an increase in plant height is one of them [23]. This indicated that the grain and biomass yields could be improved in a seeding rate dependent manner, to the extent that even the smallest changes in the number of seeds sown per unit area can lead to notable variation in both grain and biomass yields.

The combination of higher biomass and grain yields at higher seeding rates can greatly benefit smallholder farmers, particularly in dryland areas. This trait allows the farmers to overcome the challenges posed by fodder shortages, enhance food security, and potentially improve their income. Incorporating these traits into agronomic packages and varietal selection processes can help optimize crop production and contribute to the overall sustainability and resilience of smallholder farming systems. In the farming community wheat straw has been traditionally utilized both as animal fodder and roof thatching material [14]. Adjustment in a seeding rate for a particular cultivation environment can possibly attain the highest possible grain and biomass yield, despite the disparity between the optimum seeding rate discovered in the current experiment and the nationally recommended seeding rate. Similarly, the interaction effect of the treatments being tested also has a significant effect on grain yield, particularly in the case of the density-tolerant variety. These findings indicate that cultivating density-tolerant cultivars at a moderate planting density holds promise as an effective strategy for stabilizing grain yield and promoting sustainable agricultural development [31]. The highest grain yield was obtained when using the higher seeding rate, whereas a decrease of 12% in grain yield was observed when employing a lower seeding rate for the same variety. Therefore, increasing the seeding rate could serve as a strategy for improving yield for resource limited areas by compensating for seed germination failures, especially in varieties with limited tillering potential [3]. Increasing seeding rate in dryland conditions offers the advantage of establishing a denser plant population early in the season, which results in enhanced ground cover. This, in turn, leads to a reduction in water loss through evaporation and promotes a greater allocation of evapotranspiration to transpiration during the pre-anthesis stage [32]. In a wet growing environment, the response of grain yield exhibited a quadratic pattern across the tested varieties. This explicitly indicated that higher seeding rate do not always result in improved grain yield, as higher seeding rate can intensify inter-plant competition for growth resources. In such cases, the benefits of increased seeding rate may be outweighed by the negative effects of inter-plant competition. When considering multiple locations, it was evident that durum wheat varieties displayed significantly variation in both yield and tillering potential (Table 4, Table 5). This highlights the importance of maintaining varietal-specific seeding rate to optimize the performance of each variety. One possible explanation for the observed phenomenon is that low populated conditions where a seeding rate of 100 kg ha^{-1} was used each main plant has more resource available and less competition from neighbor plants. This favorable environment could allow each main plant to allocate more resource towards the production of secondary tillers, which are additional shoots that emerge from the base of the main stem (Table 4). However, it is important to note that the optimum seeding rate Geleta et al. [6] have been noted that optimization of seeding rate shows variation across different location, primarily influenced by factors such as soil fertility status, fluctuation in moisture content, and varietal difference. In other perspectives, it has been reported that a higher seeding rate can contribute to maintaining crop uniformity [26]. This uniformity provides a dual advantage by protecting crops against pests such as weeds and enhance fungicide efficiency [26].

Another significant interaction effect was observed between seeding rate and zinc foliar application. In the absence of zinc application, the grain yield was decreased by about 13.64%, even under a higher seeding rate (Table 6). The fact that even higher seeding rate did not compensate for the lack of zinc implies that the primarily factor contributing to the grain yield reduction was the deficiency of this specific nutrient rather than the seeding rate itself. Hence, ensuring the plants have adequate zinc can mitigate the negative consequences of zinc deficiency and potentially improved grain yield. Studies has demonstrated that the utilization of biofortified seeds leads to a significant enhancement in grain yield, exhibiting an increasing of 5.35%, and positively impact plant population with a notable rise of 26.8% [33].

4.3. Evaluated combinations of management practices and impact indicator on yield attributed traits

When exploring the relationship between management practices and yield attributed traits, it is important to evaluate various combinations and their impact indicators. This comprehensive analysis allows for understanding of how different management strategies influence specific traits associated with crop yield. One notable observation in the study was the effect of higher seeding rate on plant height, being likely the most plausible explanation for the observed increase in aboveground biomass yield. Tallest plant height has been reported when using higher seeding rate. This information supports our findings, suggesting that the increase in plant height can be attributed to the higher seeding rate which promotes greater biomass yield [23,34,35].

The observed phenomenon can be attributed to the fact that higher seeding rates can lead to increased competition among plants, resulting in several effects. Firstly, the higher seeding rate contributes to more vertical growth as plants compete for sunlight. This leads to increased plant stature, as the plants strive to reach for available light. Additionally, the denser plant population created by the higher seeding rate can cause shading of ambient light. This shading effect prompts the plants to develop longer internodes, which subsequently impacts their overall stature during the later stages of growth [36]. Furthermore, the increase in plant height and the presence of more leaves also give rise to competition for carbohydrates between the developing spikes and the elongating stem [37]. As resources become limited due to the intensified competition, the developing spikes and the elongating stem may not receive sufficient carbohydrates, affecting their growth and development. These interactions among increased seeding rate, plant competition, shading, and resource allocation contribute to the complex dynamics observed in grain yield in the wet growing environment.

The association between seed rate and varieties exhibited an inverse correlation with respect to 1000-grain weight. As the seed rate increased, the weight of individual grains decreased, and this decrease varied in response across different varieties. Employing lower seeding rate could potentially offer benefits in terms of generating heavier grain weight [23]. This advantage is likely attributed to the reduction of interplant competition for limited resource, thereby optimizing resource allocation with each plants. Furthermore, lower the seeding rate could enable the durum wheat to accumulate a greater amount of biomass, characterized by a heightened capacity to efficiently convert assimilates into the sink. This enhanced assimilate allocation towards grain development during the later stages results in increase grain size and weight. This has been verified that increased seeding rate leads to greater sink size, primarily attributed to a higher number of plants produced per unit area, and as a consequence the availability of resources becomes a limiting factor Julio et al. [38]. This variability in grain weight could play a great role in determining the optimal seeding rate for specific durum wheat variety, specific growing location. As the heavier, the grain weight is the lesser the number of grains per kilogram prior to sowing, thus, ultimately this will determine the number of plants per a given area of land. Hence, agronomist take into account factors such as grain weight, specific crop varieties and pedoclimatic conditions of the growing location to calculate the ideal number of seeds to be sown per unit area. Similarly, a decrement in the number of grains spike^{-1} caused by a higher seeding rate was observed, mainly due to shorter spike length as a result of strong inter-plant competition (Table 4), which is corroborated with Hiromi and Taiichiro [35].

4.4. G × E × M dynamics and grain quality

As the seeding rate increased there was a noticeable decline in grain quality traits such as protein content, gluten content, and zeleyn index, especially under higher seeding rate (Table 4). This means that as the seeding rate increases, the grain quality traits tend to decrease while grain yield increase. This finding further highlights that the optimal seeding rate sought to obtain acceptable grain protein content may be significantly lower than that has been required simply to improve grain yield and associated traits in durum wheat. However, the extent to which grain qualitative traits influenced by the seeding rate has been varied according to a given set of environmental conditions. This means that the grain characteristics such as grain protein, gluten, and zeleyn index can be affected differently depending on the specific environmental factors at play. The differences in soil nutrient levels and rainfall between the two growing locations are the probable reasons for this variation. It is commonly observed that grain protein content increases in areas experiencing moisture stress [6,39]. This can be attributed to higher accumulation of nitrogen in the grains and a lower concentration of carbohydrates. As carbohydrate content and protein content are inversely related, a decrease in carbohydrate content caused by drought conditions may result in an increase in grain protein content [39].

The application of $FeSO_4$ and $ZnSO_4$ in the form of fertilizers, in combination with a rate of 100 kg ha^{-1}, resulted in a significant increase in grain protein content. However, the extent of this increase varied depending on the specific varieties and locations. Previous studies have consistently reported a strong association between high grain protein content and micronutrients [12]. This suggests that fertilizers containing iron and zinc play a crucial role in enhancing the quality of durum wheat grain. The improvement in grain quality can be attributed to several factors. Firstly, iron plays a critical role in activating enzymes and participating in the biological redox system. These processes are essential for various biochemical reactions in the plant, including the accumulation of assimilates in the grain. The presence of iron in the form of fertilizers aids in facilitating these processes, ultimately leading to an increase in grain protein content [40,41]. Similarly, zinc, as a micronutrient, contributes to various physiological functions in the plant, including protein synthesis and grain development. Therefore, the application of iron and zinc-containing fertilizers can significantly enhance the grain quality of durum wheat by promoting enzyme activation, facilitating assimilate accumulation, and supporting protein synthesis.

The results of the study showed a significant difference in how management practices interacted with the environment. This difference was mainly due to the higher concentration of grain protein, gluten, and zeleyn found in a low-yielding variety compared to high-yield varieties. Similar findings were reported for other grain quality traits in a previous study [42]. The present study confirmed that there is an inverse relationship between the potential yield of durum wheat varieties and the concentration of grain protein. This means that as yields increase, the concentration of grain protein tends to decrease. This inverse relationship could be explained by the possibility that genes responsible for increasing grain protein content are closely linked to genes that have a negative effect on other desirable traits [3]. It has been observed that high-yielding durum wheat varieties have lower storage grain protein content, while low-yielding varieties have higher storage grain protein [43,44]. This could be due to the ability of low-yielding varieties to convert soil nitrogen into grain protein [43,44]. Therefore, when selecting durum wheat varieties, both grain protein content and yield should be taken into consideration.

4.5. Agronomic biofortification and its implication to reduce the hidden hunger

The analysis of micronutrient concentrations in the imposed factors, such as seeding rate and varieties, reveals distinct differences. These differences suggest that the mineral content in the grains is influenced by the genetic makeup of the specific durum wheat varieties employed [18]. However, this assumption was found inconsistent due to variability in varietal response to the applied agronomic packages. It has been observed that the combined implementation of nutrient-efficient varieties (such as acc.208,304), foliar-based zinc fertilization, and a higher seeding rate of 175 kg ha^{-1} has resulted in a substantial improvement in grain zinc concentration from 35.72 to 59.27 mg kg^{-1}. Agronomic biofortification with micronutrients can be an effective approach to address micronutrient deficiency-related health issues. To combat zinc and iron deficiencies in humans, a target level of 45 mg kg^{-1} of zinc and iron in the harvested grain has been suggested [45,46] (Liu, Liu, Zhang, Chen, Zou, 2017; Ortiz-Monasterio et al., 2007). The average daily intake of zinc varied across different age groups ranged from 4.6 to 6.2 mg/day in children aged one to less than three years, from 5.5 to 9.3 mg/day in children aged 3 to under 10 years, from 6.8 to 14.5 mg/day in adolescents (10 to under 18 years), and from 8.0 to 14.0 mg/day in adults [47]. Hence, the study confirms that the target concentrations of zinc required for human nutrition can be satisfactorily achieved by applying 25 kg ha^{-1} of zinc-containing fertilizer, such as zinc sulfate.

The study further suggests that a suboptimal establishment of the plant stand can have a detrimental impact on the agronomic biofortification of durum wheat. The most likely explanation is that when the durum wheat is sown at a higher seeding rate, it can efficiently utilize the applied nutrients due to competition for limited resources. This efficient resource utilization can subsequently impact the development of grain nutrition. Previous research has shown that increasing the planting density can effectively enhance nutrient accumulation and redistribution in maize crops [48]. This finding suggests that studying the relationship between seeding rate dynamics and micronutrient concentration in grains could provide valuable insights for simultaneously improving nutritional compounds and grain yield. By understanding these allometric relationships, it may be possible to develop strategies that enhance both grain yield and nutritional quality, thereby meeting the future food and nutritional demands of a growing global population. In other studies, the foliar application of zinc sulfate has been widely acknowledged as an effective method for enhancing the mineral content of grains [12,13]. This implies that applying zinc sulfate to the leaves of durum wheat plants can be a beneficial approach to improve the mineral composition of the grains.

4.6. Relationships between grain yield, yield components and phenological traits

Except for certain yield component parameters, most of the parameters displayed a statistically significant positive relationship with phenological traits. Additionally, there was a positive correlation observed among the phenological traits themselves. For instance, the number of days to maturity exhibited a positive and significant correlation with the number of days to booting and flowering ($r = 0.46$, 0.89, for days to booting and flowering, respectively). This suggests that the length of the maturity period is influenced by both the booting and flowering phases. Any delay in these stages can consequently impact the number of days required for maturity. However, when examining the relationship between phenological traits and aboveground biomass, a positive correlation was observed but it did not reach statistical significance ($r = 0.06^{ns}$, 0.22^{ns}, for days to booting and flowering, respectively). This indicates that the length of the flowering period and days to booting may not significantly affect aboveground biomass yield. Furthermore, it was found that phenological traits did not have any significant impact on the number of tillers per plant. While most parameters showed a positive relationship with phenological traits, only certain factors had a notable influence on yield components such as aboveground biomass, while tiller numbers per plant remained unaffected by the phenological traits.

A statistically significant relationship has been observed between plant height and aboveground biomass, indicating that an increase in plant height corresponds to an increased potential for aboveground biomass production. Similarly, a relationship has been identified between plant height and effective tiller number. This association suggests that as the number of tillers increases, the overall plant stature also increases, likely due to inter-plant competition for light. The correlation results align with a previous study conducted by Bhutto et al. [49], where they also reported a positive and highly significant correlation between plant height and tiller number. This supports the consistency of our findings with their research, further reinforcing the relationship between these two variables. However, the number of effective tillers was showed positive, but not statistically significant with aboveground biomass. This association could be result from a higher seeding rate, which reduces the number of effective tillers $plant^{-1}$ due to inter-plant competition for the shared resources.

A positive and significant correlation was observed between spike length and the number of grains per spike. The correlation between spike length and the number of grains per spike is of particular importance in crop productivity. A longer spike provides more space for grain development and can accommodate a greater number of grains. This relationship has been supported by the findings of Muhammad et al. [50], who reported a positive and significant association between spike length and the number of grains per spike. In the same way, spike length also correlated with grain yield. This association clearly implies that the longer the spike length is, the more would be the grains $spike^{-1}$, which may reflect again on the grain yield. This result is consistent with Bhutto et al. [44,49]. This association was also found true for plant height ($r = 0.57, p < 0.01$). It means that any increment of the spike length could have a great contribution to plant height. Important correlation was also observed between Grain yield and effective tiller number and grain yield with above ground biomass yield. This correlation emphasized that any increment in the number of tillers $plant^{-1}$ increases the grain yield. This could be explained by the fact that the more the secondary tillers are formed, the more would be the number of spikes per unit area, resulting in higher grain yield which indicating any increases of single grain weight will increase the grain yield. In a related study, Jinwook et al. [51] reported similar findings regarding the impact of integrated agronomic management practices on grain yield. Increase in biomass production during the growth stages of crops can enhance the photosynthesis rate, ultimately leading to improved grain yield [52].

5. Conclusion

In conclusion, this study reveals that while there has been a consistent increase in grain yield with a high seeding rate, the response of grain protein content and other agronomic traits to higher seeding rates demonstrates diminishing returns. This implies that the seeding rate required to attain acceptable grain protein content and quality traits is lower than what is needed solely for improving grain yield in durum wheat. Therefore, determining an optimal seeding rate for a specific location necessitates considering both yield achievement and the quality of the final products. Furthermore, there exists divergent behavior among durum wheat varieties in terms of growth patterns, yield, grain protein, and mineral concentration. By utilizing density-tolerant varieties, implementing a high seeding rate, and applying foliar-based iron, it is possible to enhance grain yield from 2.01 to 3.20 t ha^{-1} under favorable environmental conditions. Consequently, it is crucial for agronomists and durum wheat breeders to consider the combined effects of genotype, environment, and management practices, along with their interactions, when aiming to optimize both grain yield and quality simultaneously. Understanding and optimizing these factors and their synergistic relationships are paramount to achieving desired outcomes in terms of both quantity and quality of the durum wheat crop. By considering the interplay of these elements, responsible bodies can make well-informed decisions that benefit farmers and consumers alike. Through considering the interplay of these elements, the stakeholders can make informed decisions to enhance both grain yield and quality, ultimately benefiting farmers and consumers alike.

Author contribution statement

Melash A.A. and Dejene K. M.: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Alemtsehay T.: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Dereje A.A.: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Amare A.B.: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Shegaw G.M.: Analyzed and interpreted the data; Wrote the paper.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors greatly acknowledge the financial support provided by Regional Universities Forum for Capacity Building in Agriculture (RUFORUM – WVC), and the DUREP project for providing the two durum wheat varieties.

Appendix A. Supplementary data

Supplementary data to this article can be found online at .https://doi.org/10.1016/j.heliyon.2023.e18733

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