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The Effect of Sowing Time and Seed Vernelisation on Nutrient Composition of Wheat Grain and Straw

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ABSTRACT

Wheat, which was domesticated at the beginning of agriculture, continues to be the most important source of energy and macro- and micronutrients in the nutrition of humans and animals. Affordable and easily accessible cereal crops are the primary source of nutrient deficiencies, particularly in underdeveloped countries. Therefore, it is important to determine the varieties with high macro- and micronutrient content of grain and straw in terms of human and animal nutrition. In this study, the effects of winter sowing and spring sowing and vernalization application to seed in spring sowing on the nutrient content of grain and straw were investigated. While thousand-grain weight decreased in spring sowing, macro- and micronutrients gave different responses. In spring sowing, vernalization application caused a decrease in P, Cu, Mn, Fe, and Zn ratios. In terms of macro- and micronutrient contents, Akbaşak, Dumlupınar, and Tosunbey varieties were generally above the average, while Sönmez, Kayra, Basribey, and Ç-1252 varieties were below the average. In terms of straw nutrient contents, K, Ca, and Mg contents were found to be the highest in winter sowings, while N, P, Cu, Mn, Fe, and Zn were found to be the lowest. Straw nutrient contents of the varieties were found to be above average in Akbaşak, Dumlupınar, and Tosunbey varieties and below average in Sönmez, Kayra, Basribey, and Ç-1252 varieties. As a result, the nutrient content of wheat and straw, which are essential for human and animal nutrition, varies as a function of variety, sowing time, and vernalization practices. In late sowing, an aim-based combination of the treatments should be practiced.

Keywords: nutrient content, pre-vernalization, sowing time, wheat cultivars.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important staple food crops globally, contributing significantly to global food security. The annual production of wheat, which is the third most produced food crop in the world, is approximately 798 million tonnes, of which 194 million tonnes are traded (FAO, 2024). It serves as a primary source of calories, proteins, and essential nutrients for a substantial portion (about 20%) of the human population. In some countries, annual per capita wheat consumption is as high as 120 kg (Mickiewicz and Britchenko, 2022). The demand for wheat continues to increase day by day due to its unique climatic adaptability, its ability to be consumed in the form of different products (bread, bakery products, noodles, pasta, etc.), its industrialisation, and the intensive use of wheat flour, including the dietary habits of developed countries (Shewry and Hey, 2015). In addition to its role as a food grain, wheat straw is widely used as livestock feed, a soil amendment, and a raw material for bioenergy production in many agricultural systems. Thus, both the grain and straw of wheat are of considerable agronomic and economic importance. However, despite its global prominence, wheat productivity and nutrient quality are significantly influenced by environmental conditions and agronomic practices, including sowing time and seed pre-treatments such as vernalisation. Understanding how these factors affect the nutritional composition of both grain and straw is crucial for optimizing crop

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management strategies aimed at enhancing yield quality and sustainability.

In recent years, yield is considered the first priority in breeding programs; quality seems to be pushed to the second plan. However, grain nutrient contents directly affect human and animal health (Shewry and Hey, 2015). Wheat varieties have become poor in some nutrients during the modernisation process (Petrović et al., 2024). This situation is especially worrying in terms of nutrient deficiency in developing countries (Cakmak, 2008). In contrast, nutrient-enriched cereals such as those with iron, zinc, etc. are promising and cost-effective approaches to reduce element-based malnutrition (Distelfeld et al., 2007; Ghandilyan et al., 2006).

Sowing time is a critical agronomic practice influencing the growth, development, and eventual yield of wheat. It determines the environmental conditions, particularly temperature, rainfall, and photoperiod, under which the crop completes its phenological stages. Wheat is highly sensitive to both low and high temperature extremes, especially during key developmental stages such as germination, tillering, flowering, and grain filling. With the global climate change, there are significant shifts in temperature and precipitation regimes. As generally practiced, early sowing often enables the crop to establish well before the onset of adverse weather conditions, allowing it to exploit favourable growing conditions (Lee and Shin, 2021). In contrast, delayed sowing may expose the crop to terminal heat stress, shorten the grain-filling period, and adversely affect both yield and grain quality (Farooq et al., 2011). In this context, shifting autumn rainfall towards winter or insufficient rainfall events forces sowing time to shift to spring months. In spring sowing, the need for vernalisation may not be met sufficiently for ensuring high-yielding varieties with high chilling requirements. This problem can be partially solved by pre-vernalisation. Depending on the changing conditions mentioned above, both yield and elemental content of wheat under the same field conditions change as a function of the growing period of the plant. Especially after the spike, the period during which the plant remains green is an important factor in the transfer of plant nutrients accumulated in the vegetative parts to the grain (Farooq et al., 2011). In particular, the extent to which sowing time and seed vernalisation affect macro- and micronutrient accumulation in grain and straw, and whether these effects are additive, synergistic, or antagonistic, is not well defined in the current literature.

Generally, wheat is priced according to its protein ratio and hardness (Peña, 2002). However, in terms of protein, iron, and vitamin B, wheat is the main source of human nutrition not only in undeveloped countries but also in developed countries. The distribution of protein in the grain is 5.10% pericarp, 5.70% testa, 22.8% aleurone, and 34.1% germ (Jensen and Martens, 1983), while nutrients are distributed differently (Pomeranz, 1988). The protein content of white flour was about 2% and less than that of whole wheat flour. Bread made with whole wheat flour and multigrain flour reduces the consumption of simple carbohydrates, fat, and cholesterol, while increasing the consumption of complex carbohydrates, dietary fibre, and vegetable protein (Cauvain, 2015).

Climate change presents new challenges and uncertainties for wheat production. Increasing temperature variability, shifting rainfall patterns, and the growing prevalence of abiotic stresses such as drought and heatwaves are expected to influence both yield and quality. In this context, adaptive agronomic strategies that enhance resilience and maintain the nutritional value of wheat outputs are of paramount importance. Altering sowing time and employing seed treatments like vernalisation represent practical, low-cost approaches that can be tailored to local agroecological conditions. However, their efficacy and underlying physiological mechanisms need to be rigorously tested under contemporary and projected future climate scenarios.

Given the importance of wheat as a dual-purpose crop and the influence of agronomic factors on its nutrient composition, this study aims to investigate the combined and individual effects of sowing time and seed vernalisation on the nutritional quality of wheat grain and straw. This study was carried out to evaluate the impact of different sowing times with and without vernalisation in late sowing on the macro- and micronutrient composition of wheat grain and straw. By addressing the objectives, the study seeks to contribute to a more comprehensive understanding of the agronomic determinants of nutrient composition in wheat, thereby informing best practices for integrated crop management.

MATERIAL AND METHODS

The experiment was conducted under irrigated conditions in Isparta ecological conditions in the 2018-19 growing season. The experiment area has a silty-sandy texture with a pH of 8.2. In the experiment, Akbaşak (*Triticum durum* Desf.), Bolvadin (*Triticum durum* Desf.), Dumlupınar (*Triticum durum* Desf.), Tosunbey (*Triticum aestivum* L.), Emmer [*T. dicoccon* (Shrank)], Sönmez 2001 (*Triticum aestivum* L.), Kayra (*Triticum aestivum* L.), Basribey (*Triticum aestivum* L.), and Ç-1252 (*Triticum durum* Desf.) wheat varieties were used.

Sowings were made in winter (15-20 October) and 2 in late spring (4 April) with and without vernalisation. For vernalisation, the seeds were soaked in pure water at room temperature for 5 hours, then placed in the refrigerator and kept at +4^{o}C for 8 weeks. The experiment was carried out in a randomized complete block design with three replicates. Sowing density was 400 plants m^{-2}. The plots were fertilised with 26 kg ha^{-1} N, 50 kg ha^{-1} P_2O_5, 10 kg ha^{-1} K, 20 kg ha^{-1} SO_3, and 1 kg ha^{-1} Zn. According to the sowing time, 100 kg ha^{-1} N (ammonium nitrate) as top fertiliser was applied at Feekes 3-5. Temperature and rainfall data for the growing period are given in Table 1. In the year the experiment was conducted, a relatively warmer growing period was observed compared to the long-term average. Experimental plots were irrigated regularly by the drip irrigation method, considering the rainfall.

Grains and stems were differently harvested. Possible contaminations were washed with dilute acid, tap water, deionised water and then dried at 65°C to a constant weight. The particle sizes of the samples were reduced below 0.5 mm by grinding. Then they were digested with a concentrated nitric (65%) and perchloric acid (70-72%) mixture (3/1, v/v) by the wet combustion method. Potassium, Ca, Mg, Fe, Cu, Mn, and Zn concentrations of the digests were analysed by ICP-OES (Specro-Arcos), and P content was determined by the vanado-molybdic yellow colour method in a spectrophotometer (T-80 Spectrophotometer). The nitrogen content of the samples was determined by the semi-micro Kjeldahl method. The SPSS 25 statistical package program was used for the variance analysis. Mean separation among the treatments was performed using the Duncan's multiple range test at $p \leq 0.05$ confidence level. Thousand grain weight (TGW) was also measured by taking the averages of 100 grains.

Table 1. Climatic data for wheat growth period and averages

	Year / month	1	2	3	4	5	6	7	8	9	10	11	12
Temperature (°C)	2018									20.5	13.8	9.1	3.5
	2019	2.5	4.5	7.3	9.9	16.8	20.7	23.5	24.4				
	Long term	1.7	2.6	5.9	10.5	15.5	20.1	23.4	22.9	18.3	12.8	6.9	3.0
Precipitation (mm)	2018									1.6	31.8	48.6	107.1
	2019	97.0	55.4	40.3	50.8	34.2	53.3	9.5					
	Long term	81.0	68.2	58.9	51.2	55.9	35.6	15.6	14.2	18.4	37.8	44.3	86.4

RESULTS AND DISCUSSION

Grain and straw nutrient contents

The ANOVA revealed that the main effect of sowing time, variety, and the interaction on nutrient content of the grain were significant (Figures 1, 2). There were no differences between sowing times in terms of N, K, and Mg content; between varieties in terms of Ca content; and between sowing time x variety interactions in terms of Ca and Cu content (Figure 1). The differences between other traits were found to be significant. However, the nutrient content of straw were highly responsive to sowing times, varieties, and interactions (Figure 3).

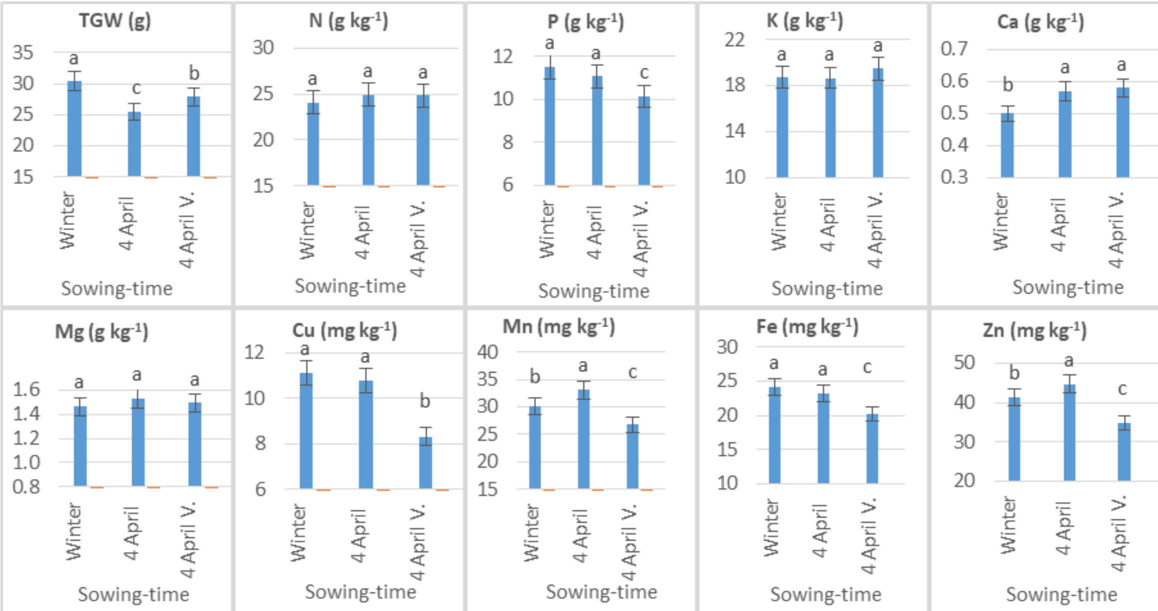

Figure 1. Grain nutrient contents according to sowing time. Different letters indicates statistically significant difference at p≤0.05. TGW, thousand-grain weight. The bars display standard deviations.

Sowing times were an effective agronomic tool on thousand-grain weight. Considering the averages of all varieties, the highest thousand-grain weight (TGW) was found in winter sowing (30.4 g). The lowest TGW was obtained in April sowing without vernalisation (25.5 g). Sowing time did not change grain N, K, and Mg content. There was no difference in grain P, Cu, and Fe content between winter sowing and April sowing; however, lower values were found in April sowing with vernalisation. There was no difference in grain Ca content between April sowings; however, lower values were found in winter sowings. The order of highest concentration for Mn and Zn in grain was obtained in April sowing, winter sowing, and April vernalised sowing, respectively. When April sowings were compared with each other, vernalisation application caused an increase in TGW while causing a decrease in grain P, Cu, Mn, Fe, and Zn contents.

Among the varieties, Dumlupınar, Kayra and Tosunbey had the highest thousand-grain weights, while Sönmez and Kavılca had the lowest. The TGW of other varieties was around the average (27.9 g). The highest grain N content, or in other words the highest protein content, was observed in Akbaşak and Dumlupınar varieties; P, K, Cu, Fe, and Zn content in Akbaşak; Ca content in Basribey and Sönmez; Mg content in Tosunbey; and Mn content in Dumlupınar varieties. The lowest grain N, P, Cu, and Fe contents were determined in Sönmez; Ca content in Bolvadin; Mg content in Basribey; Mn content in Basribey, Kavılca, and Ç-1252 varieties; and Zn content in the Basribey variety. Akbaşak, Dumlupınar, and Tosunbey varieties were generally above the average and stood out as varieties with high nutrient content, whereas Sönmez, Kayra, Basribey, and Ç-1252 were generally below the average in terms of grain nutrient content.

The effect of sowing times on the nutrient contents of straw was significant (Figure 3). Potassium, Ca, and Mg contents were the highest in winter sowings, while N, P, Cu, Mn, Fe, and Zn were the lowest. Compared to winter sowings, N, Ca, Mn, and Fe contents were found to be high in April sowings, while K content was found to be low. In April vernalised sowing, P, Cu, Mn, Fe, and Zn contents were found to be high, while Ca and Mg contents were found to be low. In winter sowings, macronutrients except for N were found to be high, while micronutrients were found to be low. When late sowings were compared among themselves, no significant difference was observed. In other words, the effect of vernalisation was positive on P, Zn, and Cu contents but negative on N and Ca contents.

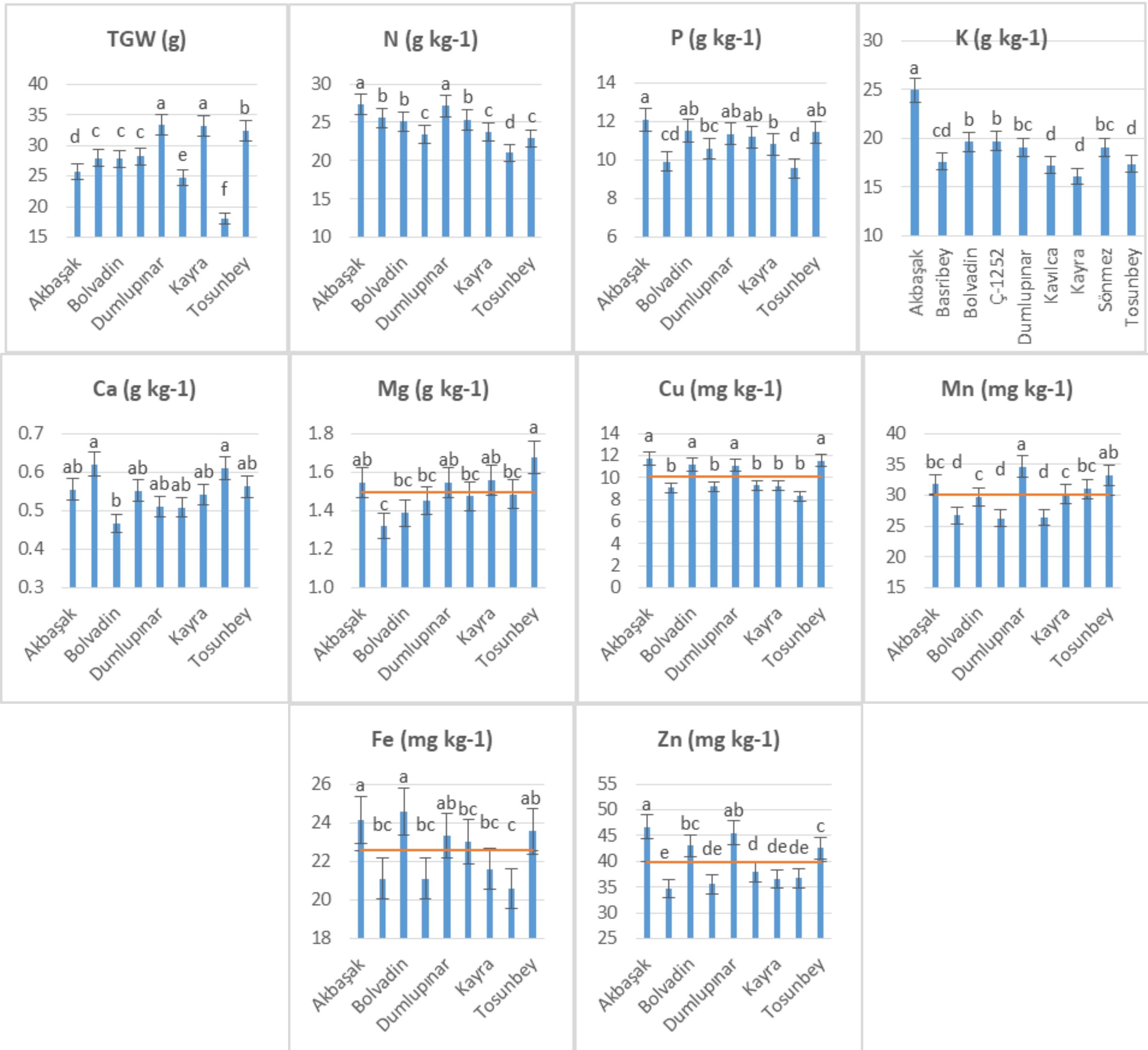

Figure 2. Grain nutrient contents and averages of cultivars. Different letters indicates statistically significant difference at p≤0.05. TGW, thousand-grain weight, the horizontal red lines are the averages. The bars display standard deviations.

Significant reductions in grain yield under conditions where the varieties are not sufficiently vernalised cause the nutrients removed from the soil during the vegetative period to accumulate in the vegetative parts. In this context, in cultivars with low vernalisation requirements or in cultivars whose requirements were met by in vitro cold treatment, grain carryover was high. In this context, N is the element with the highest amount of transport to the grain. Nitrogen can be affected by changes in grain formation and changes in fertilisation timing. The results of the study showed that TGW decreased in late sowing due possibly to limitation of nutrient transport and a shorter green period. Thousand-grain weight in wheat is affected by many factors such as stress conditions (Taghouti et al., 2010), irrigation (Taner et al., 2011), environment and variety (Kahraman et al., 2017), and it is generally known that old wheat varieties have lower TGW than modern wheat varieties (Atar and Kara, 2017). The ideal sowing time of wheat, which is a cool climate grain, is between October and November for mid-latitudes. According to these climatic characteristics, vernalisation is best achieved within the framework of the principle of making the best use of precipitation in dry climatic conditions, and it is an application that increases thousand-grain weight and yield (Başkonuş et al., 2022). As the sowing time is delayed, both yield (Brzozowska and Brzozowski, 2020; Liu et al., 2021) and TGW decrease (Jarecki, 2024; Mohamed et al., 2022; Tekdal and Yıldırım, 2015) due to the decrease in the relative green period of the plant or the nutrient element exploited from the soil under conditions where the need for vernalisation is met.

Under rain-fed farming conditions, vegetative growth with delayed sowing coincides with the hot period with water scarcity, which may lead to a decrease in grain size and an increase in protein ratio as a result of shortening the duration of developmental stages and the grain-filling period (Liu et al., 2021). On the other hand, Dai et al. (2017) found that late sowing results in a decrease in time-dependent nitrogen losses, which leads to an increase in nitrogen use efficiency, especially in basal fertiliser applications. Nitrogen is lost in the form of nitrate, which has very high mobility and is highly susceptible to extreme precipitation in the winter season due to the increased growth period (Kacar, 2015). On the contrary, Chu et al. (2023) reported that a delay in sowing time caused a decrease in grain protein content. However, there are studies showing that the protein ratio increases as the sowing time is delayed (Ferrise et al., 2010). The main reason for these different results is the variability in soil and climatic conditions, especially rainfall and/or irrigation conditions. In light-textured soils, nitrogen in the form of nitrate can be easily transported below the root zone of influence by excessive rainfall or irrigation. According to the results of this experiment, there was an increase in protein ratios in late sowing, but this increase was not found to be statistically significant. It was evaluated that this situation was caused by the fact that the conditions that cause washing did not occur despite the relatively light structure of the experimental soil and the nitrogen given in total remained in a shorter period (April-July) and the effect of the decrease in yield and the partial satisfaction of vernalisation under in vitro conditions. In this context, phosphorus, which has high mobility to the grain and very limited mobility in the soil, also showed significant differences. The high yield in winter sowing resulted in the phosphorus taken up and accumulated during the vegetative growth period to be largely transported to the grain; however, the decrease in grain yield in late sowing and the high usefulness of P given in April as basal fertiliser in the short growth period, because basal P fertilisers have slow solubility in the soil due to their granular structure (Kacar, 2015), are thought to cause P to be in high concentration in the straw in late sowing.

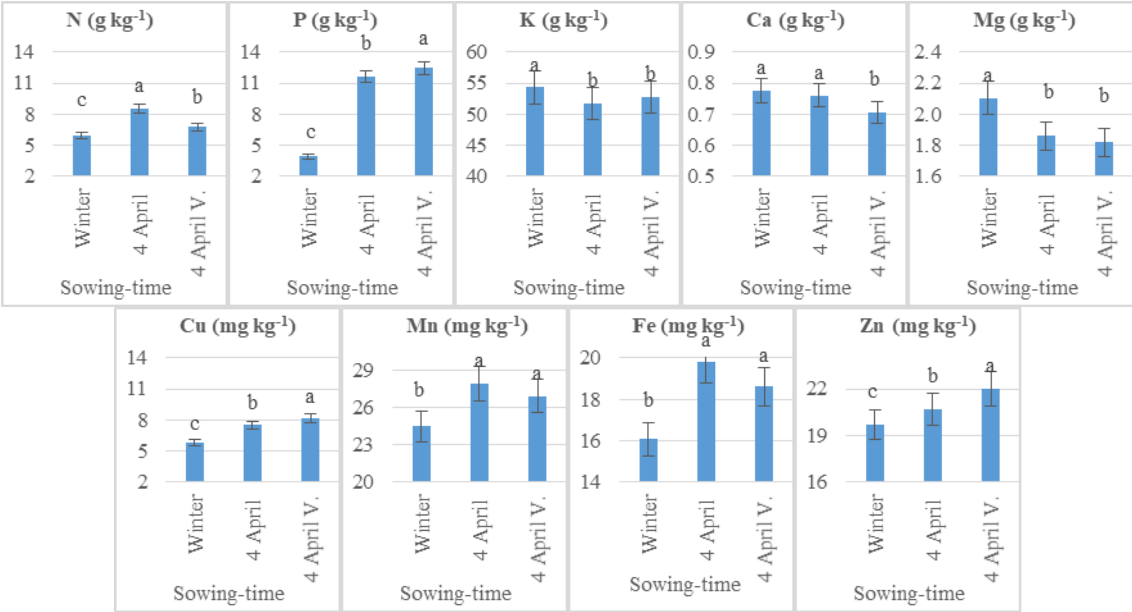

Figure 3. Wheat straw nutrient content according to sowing time. Different letters indicates statistically significant differences at p≤0.05. The bars display standard deviations.

The study indicated that macro- and micronutrients did not exhibit a significant change in response to sowing time. Amarshettiwar and Berad (2018) reported that high temperature stress caused decreases in Zn, Fe, Mn, and Cu concentrations, while Peleg et al. (2008) reported that the contents of micronutrient elements increased, decreased, or remained unchanged under stress conditions. The usefulness of micronutrient elements during the long growing period may have an effect on the element content as it causes the storage of some elements during the early development period (Atar et al., 2020), changes in micro- and macroelement concentrations triggered by the redox potential during periods when the soil is moist (Ören, 2023), and the loss of nutrients with high mobility (Kacar, 2015). Brzozowska and Brzozowski (2020) determined that the effect of sowing dates on macronutrient contents was not significant. Similarly, Singh et al. (2012) stated that there is a wide variation in micronutrient elements, especially Fe, under moist conditions, as in the results of the study. This is because the amount of cationic elements transported to the grain is limited by the effect of phytic acid in the last part of the filling stage (Marschner, 2012).

Since wheat straw is used as a staple food for animal nutrition in many countries, its nutrient content is important. According to the sowing time, late sowing and vernalisation treatments to the seed at late sowing caused an increase in N, P, Cu, Mn, Fe, and Zn among the straw nutrient contents, while it led to a decrease in other nutrient contents. This is thought to be related to the short grain filling period and high temperatures encountered during this period (Liu et al., 2021), the low dry matter accumulation and N accumulation in late sowing (Ehdaie and Waines, 2001), and the mobility of the element in the soil and plant environments.

The effect of varieties on straw nutrient contents (Kacar, 2015) was different (Figure 4). The highest N content was found in Akbaşak; P content in Ç-122; K content in Sönmez and Tosunbey; Ca and Mg content in Bolvadin; Cu content in Bolvadin, Kavılca, and Sönmez; Mn content in Bolvadin; Fe content in Kavılca; and Zn content in Akbaşak and Bolvadin varieties. The lowest nutrient contents were found in N Basribey; P Akbaşak; K Dumlupınar; Ca Akbaşak and Sönmez; Mg Akbaşak; Cu Basribey; Mn Akbaşak, Sönmez, and Tosunbey; and Fe Dumlupınar, Kayra, Sönmez, and Tosunbey; Zn Basribey and Kayra varieties.

In general, Akbaşak, Dumlupınar, and Tosunbey varieties stood out as varieties with high straw nutrient content since they had above-average nutrient content. Sönmez, Kayra, Basribey, and Ç-1252 were below the average in terms of grain nutrient content. The Akbaşak, Dumlupınar, and Tosunbey varieties, which ranked high in terms of grain nutrient content, ranked low in terms of straw nutrient content except for N and Zn. In other words, there was a decrease in the elemental content of straw with the increase of transport to grain.

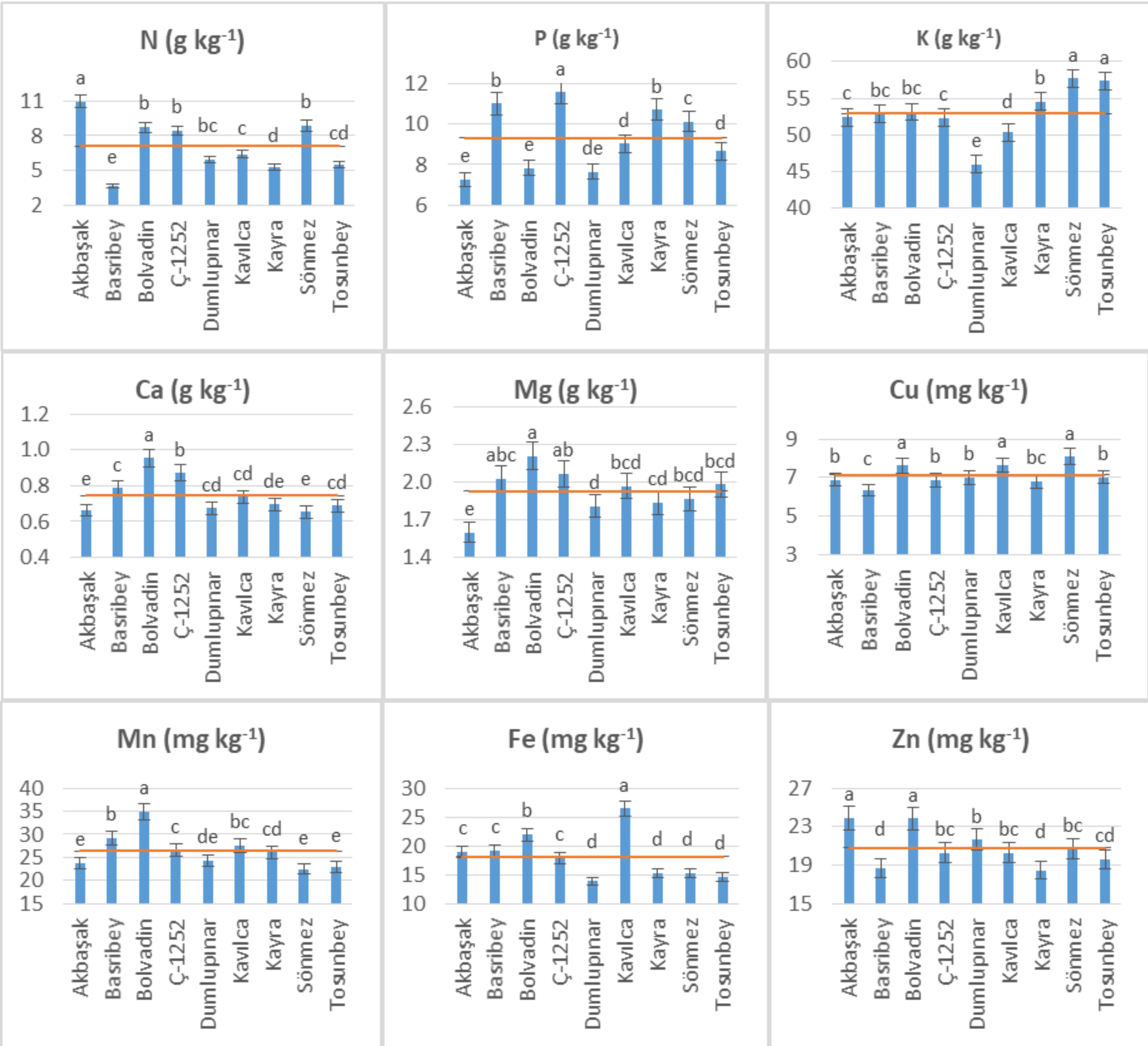

Figure 4. Nutrient contents and averages of wheat straw according to varieties (The horizontal lines are the averages, different letters indicates statistically significant differences at $p \leq 0.05$). The bars display standard deviations

Macro- and micronutrient content of wheat straw, which is largely composed of cellulose, hemicellulose, and lignin, is affected by environmental conditions, agronomic and fertiliser applications (Khan and Mubeen, 2012; Mañas and De Las Heras, 2018; Yasin et al., 2010), and varies from variety to variety (Safdar et al., 2009). In some studies, there was a difference between varieties in terms of P, K, Ca, and Na content (Anjum et al., 2014), but no difference was found in the content of other nutrients. As a result of the study, some varieties were similar, but in general, significant differences were observed.

Relationships between Element Concentrations in Straw and Grain

A negative relationship was found between TGW vs. grain K and Mg; TGW vs. straw N, P, and Cu. Grain and straw nutrient contents were not positively correlated with thousand-grain weight (Table 2). There were positive correlations for N vs. K and Zn; P vs. K, Ca, Cu, Mn, Fe, and Zn; K vs. Cu and Zn; Mg vs. Cu and Zn; Cu vs. P, K, Mg, Mn, Fe, and Zn; Mn vs. P, Mg, Cu, Fe, and Zn; Fe vs. N, P, K, Cu, Mn, and Zn; and Zn vs. N, P, K, Mg, Cu, Mn, and Fe; and negative correlations only between P and Mg. While there was no negative relationship between the nutrient contents of wheat straw, a positive relationship was found for N vs. Zn; P and Cu; K vs. Mg; Ca vs. Mg and Mn; Mn vs. Ca, Mg, Cu, Fe, and Zn; Fe vs. Cu and Mn; and Zn vs. N, Cu, and Fe. The relation in grain is likely to be a response of interaction occurring during the transportation of the elements from the vegetative parts to generative parts, whereas nutrient relation in the straw resulted from both transportation and nutrients chemical reaction in the soil and fertilisation program in short (mainly N, P, and K) or long-term soil fertilisation and pesticide usages (Cu, Zn, Mn, and Fe) and soil genesis (Ca and Mg due to calcareous parent material).

There was a negative correlation between grain N content and straw K only, and no significant correlation was found between other elements. A negative relationship was found between grain P content and straw P and Cu, whereas a positive relationship was found between N, Ca, and Mg. A positive relationship was found between grain K and straw N and Zn. In general, there were positive correlations between straw N and grain macro- and micronutrient contents and negative correlations between grain's Mg, Ca, Cu, Mn, Fe, and Zn and straw nutrient contents, some of which were statistically significant (Table 2). It was evaluated that the mobility of the element in the soil, its uptake and mobility within the plant, and the known synergistic and antagonistic relationships between the elements were effective in the coincidence of this behaviour.

Soil properties, environmental conditions, and agronomic practices (Allaway, 1986; Gondek and Gondek, 2010; Stepien and Wojtkowiak, 2016), irrigation (Bagci et al., 2007; Cakmak, 2002; Peleg et al., 2008), variety tolerance (Rengel, 2001), species or cultivar (Amarshettiwar and Berad, 2018; Gomez-Becerra et al., 2010; Kalayci et al., 1999; Singh et al., 2012), and climatic conditions (Korhova et al., 2023) and yield can affect the nutrient content of grain and/or straw. In suitable growing environments, especially after correcting a nutrient deficiency, a tendency to decrease in the concentrations of some nutrients due to the dilution effect may be observed as yield increased with fertilisation (Jarrell and Beverly, 1981; Smith et al., 2017). It has been observed that during periods when nutrient uptake from the soil slows down or for elements such as phosphorus with low mobility in the soil, the transport from vegetative parts to grain causes more pronounced reductions in straw. For elements with low mobility in the plant, the element concentration of the vegetative parts remains almost constant regardless of yield. There are studies showing that there is a negative correlation between grain nutrient content and yield (Garvin et al., 2006; Ortiz-Monasterio et al., 1997) as well as studies showing no negative or positive correlation between grain nutrient content and yield (Peleg et al., 2008). The nutrient concentration in the grain is kept between certain limits by biochemical processes. In this context, experiment-specific conditions, i.e., nutrient sufficiency conditions during vegetation, may reveal positive or negative relationships.

Crude protein content as a function of N concentration in grain is related to environmental factors, genetic traits, nitrogen availability, and agronomic practices and varies between 7% and 22% of dry matter under field conditions (Shewry and Hey, 2015; Vogel et al., 1976). Since genetic and environmental factors, and their interactions, are influential on grain nutrient content (Jiang et al., 2009; Triboï et al., 2003), it is possible to increase the nutrient content by determining suitable varieties and agronomic practices such as adequate fertilisation and foliar fertilisation at grain filling. In the breeding of varieties with high nutrient contents, the use of old wheat cultivars as genetic resources could also be an alternative tool (Cakmak et al., 2004).

Sattar et al. (2010) and Aydoğan et al. (2014) reported that there was a negative relationship between TGW and grain N content. They found that N content decreased as grain size increased. In the results of the study, although there was no relationship between N and TGW, a similar, i.e. negative, relationship with other nutrients was evident. In other words, as the grain size increases, the nutrient contents are generally diluted. Similarly, Murphy et al. (2008) reported a negative relationship between yield and P, Mg, Mn, Ca, and Cu, and Smith et al. (2017) reported a negative relationship between yield and P, K, Mn, Mg, Ca, and Zn. While there were generally positive relationships between grain nutrient contents, specifically, a negative relationship was determined between P and Mg. Positive relationships between Mn and Fe, Zn, and Mn; K and Cu, Zn, and Fe; and negative relationships between Zn and Ca, Fe, and Ca were also reported in previous studies (Kokten and Akcura, 2018; Morgounov et al., 2007; Peleg et al., 2008).

Table 2. Pearson correlation coefficients between nutrient contents of straw (upper diagonal), grain (lower diagonal), and grain-straw (below) (a), interrelation between grain vs. straw nutrient concentrations (b)

Parameters		STRAW									
		TGW	N	P	K	Ca	Mg	Cu	Mn	Fe	Zn
GRAIN	TGW	1	**-0.565****	**-0.367****	**-0.088**	**-0.065**	**-0.028**	**-.422****	**-0.143**	**-0.139**	**-0.152**
	N	0.044	1	**0.112**	**-0.047**	**0.084**	**-0.083**	**0.220**	**0.147**	**0.122**	**0.358****
	P	0.138	0.226	1	**-0.131**	**-0.133**	**-0.258**	**0.649****	**0.211**	**0.079**	**0.034**
	K	-0.372**	0.372**	0.304*	1	**0.207**	**0.339***	**-0.101**	**-0.069**	**0.002**	**-0.047**
	Ca	-0.023	-0.041	0.389**	0.237	1	**0.543****	**-0.074**	**0.697****	**0.191**	**0.179**
	Mg	-.297*	-0.136	-0.387**	-0.047	0.024	1	**-0.267**	**0.340***	**0.053**	**-0.153**
	Cu	0.136	0.249	0.702**	0.303*	-0.129	0.288*	1	**0.310***	**0.269***	**0.496****
	Mn	-0.159	0.200	0.377**	0.217	0.101	0.290*	0.639**	1	**0.442****	**0.244**
	Fe	0.131	0.248	0.380**	0.086	-0.124	-0.024	0.619**	0.528**	1	**0.385****
	Zn	0.100	0.406**	0.583**	0.394**	-0.124	0.282*	0.821**	0.801**	0.736**	1

		GRAIN								
		N	P	K	Ca	Mg	Cu	Mn	Fe	Zn
STRAW	N	0.037	0.233*	0.584**	0.025	0.083	0.139	0.281**	-0.037	0.215*
	P	0.098	-0.518**	-0.018	0.531**	-0.007	-0.484**	-0.069	-0.395**	-0.258**
	K	-0.370**	-0.088	-0.012	-0.034	-0.008	-0.017	-0.136	-0.038	-0.058
	Ca	-0.022	0.241*	0.027	-0.355**	-0.193*	0.211*	-0.195*	0.008	-0.016
	Mg	-0.029	0.180*	0.005	-0.287**	-0.285**	0.165	-0.045	0.166	0.003
	Cu	-0.030	-0.343**	0.130	0.223*	0.159	-0.380**	-0.132	-0.426**	-0.201*
	Mn	0.101	0.045	-0.012	-0.131	-0.296**	-0.011	-0.183*	-0.140	-0.137
	Fe	-0.073	-0.035	0.001	-0.025	-0.101	-0.162	-0.282**	-0.030	-0.075
	Zn	0.179	0.124	0.503**	-0.164	0.180	0.030	-0.075	-0.045	0.171

*, ** significant at 5% and 1% level respectively, TGW - thousand grain weight.

CONCLUSIONS

Climatic abnormalities may cause a considerable delay in sowing or replanting. In such cases, it is important to test possible results in order to make more accurate predictions. Thousand-grain weight decreased significantly in late sowing resulting in a decrease in yield. In late sowings, seed vernalisation applications caused an increase of approximately 10% in thousand-grain weight. This increase in yield is a significant amount. However, in vitro vernalisation caused a general decrease in the nutrient contents of grain in late sowing. In winter sowing, straw K, Ca, and Mg contents were high, and N, P, Cu, Mn, Fe, and Zn contents were low.

In terms of grain nutrient content, Akbaşak, Dumlupınar, and Tosunbey were above the average macro- and micronutrients, while Sönmez, Kayra, Basribey, and Ç-1252 were below the average. Straw nutrient contents of the varieties were above average in Akbaşak, Dumlupınar, and Tosunbey, and below average in Sönmez, Kayra, Basribey, and Ç-1252. Since the nutrient content of wheat grain and straw varies as a function of agronomic practices, variety, sowing time, and vernalisation practices, particularly in late sowing, it is necessary to select practices according to the target. As can be seen in the previous studies, it is necessary to continue the research to determine the effective factors in increasing the nutrient content. The in vitro vernalisation could be an alternative agronomic tool, especially after a dry winter season, to ensure food/fodder security to some extent.

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