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Participation of urea application stages on flour quality in bread wheat

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Abstract

Laboratory studies, which field trial was conducted in the 2020-2021 growing season at the Eastern Mediterranean Agricultural Research Institute, were conducted at Gümüşhane University. In this study, the findings showed that urea was used as the top fertilizer in different growth stages of the 'Yakamoz' bread wheat cultivar used as material, and the effects of urea application periods and flour type, on the quality traits, such as dry matter, ash, protein, acidity, fresh and dry gluten, gluten index, sedimentation, and falling number were investigated. For this purpose, in addition to the control application, tillering, stem elongation, milky and dough stages were chosen as urea application periods. Laboratory studies were carried out in randomized plots using the split-plot design with three replications. In the present study, all quality traits showed statistically significant differences for urea application periods; these values were ranged as follows: Dry matter: 90.20-90.77%, ash: 1.037-1.213%, protein: 14.01-15.15%, acidity: 0.037-0.056%, wet gluten: 41.49-43.67%, dry gluten: 14.75%-15.46, gluten index: 69.28-80.38%, sedimentation: 20.0-21.0 mL, late sedimentation: 23.5-29.8 mL and falling number: 753.8-881.7 s. In addition, other quality parameters except dry matter, protein and sedimentation changed statistically for flour type. Accordingly, whole wheat flour for ash (1.443%), acidity (0.051%) and gluten index (82.53%); white flour showed high values for wet (44.90%) and dry (15.96%) gluten, late sedimentation (35.60 mL) and falling number (836.4 s). As a result, while applying urea as a top fertilizer, it is recommended to choose the stem elongation stage for high gluten index, delayed sedimentation and protein, and the dough maturity stage for high dry matter. It would be appropriate to represent more genotypes and different nitrogen sources in further studies to be more inclusive.

Keywords: Bread wheat, Nitrogen, Flour, Quality traits

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INTRODUCTION

Since the early ages of human history, cereals have been used as one of the basic nutritional sources of societies. Cereals commonly grown in countries around the world include wheat, paddy, corn, barley and oats. According to data from FAO, the Food and Agriculture Organization, in 2021, the most produced grains worldwide were corn, wheat and paddy rice, respectively (FAOSTAT, 2022). Wheat covers approximately 17% of the cultivated areas in the world and constitutes a large portion of the protein and carbohydrate source in nutrition. Wheat constitutes 35% of the world's food resources thanks to its ability to meet food needs, climatic adaptation, ease and efficiency in production, ease of transportation, and ease of storage and processing. It is a nutritional source of great importance in human nutrition, thanks to the rich carbohydrates, proteins, vitamins and minerals it contains (Tosun, 1980). In addition, wheat is the type of grain with the highest protein value among the grain types used for nutrition. People meet more than 20% of their daily calorie needs from wheat and products made from wheat

(Peng et al., 2011; Anonymous, 2017). Wheat grain contains approximately 65-75% starch, 8-15% protein, 1-5% fat, 1.5-3% sugar, 1-2% ash and 11-13% water (Kün, 1996; McKevith, 2004).

The lands on which crops are cultivated during crop production, including wheat, become poorer over time. Thus, essential nutritional elements, such as C, O, H, N, P, K, Ca, Mg, S, Fe, Mn, Mo, Cu, B, and Zn, which are extremely important in plant growth and significantly affect the quantity and quality of the product, must be returned to the soil for the sustainability of crop production (Kacar and Katkat, 2009). To obtain 5.5 t ha^{-1} biomass (grain + straw) from wheat, 78 kg N, 37 kg P_2O_5 and 57 kg K_2O are removed from the soil per hectare (Cooke, 1982). It can be understood that wheat removes mostly nitrogen (N) elements from the soil. According to IFA (1992), 13% of the total nitrogen required for the wheat crop is taken between germination and tillering. Nitrogen uptake increases rapidly from the beginning of tillering to the heading stage, and 55% of the total nitrogen is taken in this period. From heading to maturity, 32% of the total nitrogen is taken.

The first known synthetic nitrogenous fertilizer was calcium nitrate (Collings, 1949). Another known nitrogenous fertilizer is urea, first synthesized from ammonium carbamate in Germany in 1920. By 1970, urea had become the most used nitrogen fertilizer (Kacar and Katkat, 2009). Obtaining urea (CO(NH)2) is primarily based on the synthesis of ammonia and carbon dioxide (Kacar, 1997), and it is an odorless, white, easily soluble fertilizer containing 46% N (TSE, 1986).

Among the quality criteria in wheat, grain moisture content is a criterion that affects storage; if the amount of water in wheat is high, it will cause the dry matter to decrease. Thus, storage problems will arise due to bacterial and fungal growth (Elgün et al., 1998). The falling number is an important criterion in terms of the amount of gas to be released during the making of bread, the bread's volume and the bread's color. It is also a criterion used to determine diastatic activity in terms of flour (Ünal, 2002). The ash ratio gives information about the yield of flour. Ash content varies depending on the type of wheat and the climatic conditions during the growing process (Elgün et al., 1998). Wet gluten ratio is an important factor indicating the quality of bread wheat, and it is an elastic protein that helps to determine whether the dough is suitable for bread making (Tayyar, 2008).

In this study, urea fertilizer was applied at different development stages of bread wheat to examine the effect of grain on quality criteria, such as moisture, dry matter, falling number, ash content, acidity, wet and dry gluten, gluten index, sedimentation and late sedimentation value.

MATERIALS AND METHODS

Identification of plant material and trial site

In the trial, the 'Yakamoz' cultivar, registered by the Eastern Mediterranean Agricultural Research Institute in 2014, was used as plant material. Yakamoz *cv* has the following features: early in heading, plant height around 119 cm, resistant to lodging, grain yield of 6.5-9.7 t ha^{-1}, moderately resistant to drought and cold, moderately resistant to yellow and brown rust, resistant to septoria disease, protein content between 12.1-13.5%, 36.0-41.0 g thousand grain weight, white and awny ears, white grain, use for bread purposes and base areas, with spring nature, 75.8-81.0 kg hL^{-1} hectoliter weight, and 29-65 mL sedimentation value (Anonymous, 2024).

The experiment was established on the lands of the Eastern Mediterranean Agricultural Research Institute in Doğankent location. 'Yakamoz' bread wheat cultivar, widely planted in Çukurova Region, was used as seed material. Soil samples were taken from the trial area before planting and fertility status and micro-element contents were determined. Soil analysis results for the trial site are shown in Table 1. Thus, trial land has a slightly alkaline-saline and loamy structure, high iron and potassium, moderate copper and lime and low content of organic matter, phosphorus, manganese, and zinc content.

Table 1. Soil Analysis Results for The Trial Site.

Saturation		pH	Salt	Lime	Organic matter	P_2O_5	K_2O	Zn	Fe	Cu	Mn
%	Class		%	%	%	kg ha^{-1}		mg kg^{-1}			
53	loamy	8.05	0.02	11.46	1.64	44.3	1095.0	0.41	4.99	10.8	26.0

Climatic data

The climate characteristics of the trial area, located in the Eastern Mediterranean Region, including the wheat season, are given in Table 2. During the 2020-2021 wheat growing season, the average temperature values on a monthly basis were higher in the first four months and the last two months compared to many years; the highest temperature (26.00ºC) was in June. Since the amount of precipitation during the wheat growing season in the Mediterranean climate is more than the water consumption of wheat, wheat can generally be grown without irrigation in Cukurova. However, rainfall must be sufficient and in the appropriate regime for optimum efficiency. In the 2020-2021 season, the amount of precipitation in other months except November and May was higher than in many years. When we look at the amount of precipitation in the trial location during the wheat growing season, it is seen that it is 58.79% more than the long-term average (Table 2). Approximately 34.62% of the seasonal precipitation fell in January alone. This situation has negatively affected tillering in places where water accumulates. When we look at the relative humidity values, higher values were detected in all months except May compared to many years. Regarding the highest relative humidity (81.10%) value, it was observed that the rainfall was 83.12 mm more in December than in many years. The lowest relative humidity values were 69.90% and 62.94% in November and May.

Table 2. Climatic Data Which belong to The Trail Area.

Months	Mean temperatures (ºC)		Total precipitation (mm)		Relative humidity (%)	
	Long years	2020-2021	Long years	2020-2021	Long years	2020-2021
November	14.82	15.82	75.360	45.80	65.17	69.90
December	10.43	11.50	121.48	204.6	68.67	81.10
January	9.05	9.86	109.01	306.0	67.69	78.50
February	10.15	10.78	81.860	96.60	65.68	79.70
March	13.14	13.00	63.080	104.2	66.74	76.30
April	17.27	16.00	49.670	102.2	68.02	75.54
May	21.40	22.77	42.150	6.900	68.03	62.94
June	25.17	26.00	13.970	17.50	69.01	76.96
Total			556.58	883.80		

Crop management

The experiment was carried out with four replications according to the split-plot trial design in completely randomized plots at a planting norm of 450 pieces m^{-2}. The size of the test plots was adjusted to be 1.4 m wide and 5 m long. With the planting, base fertilization was applied at the rate of 15 kg DAP da^{-1} per unit area. In top fertilization, it was applied at 30 kg UREA per dam per unit area in four different periods: tillering, stalking, milk formation and yellow maturity periods. This study, in which five subjects were examined, including negative control, was carried out under normal rainfall and no external irrigation was applied.

All necessary maintenance procedures were carried out to ensure the healthy running of the trials and wheat cultivation. As herbicide in weed control, 20 mL da^{-1} 'Terdok 240 EC' was used against narrow-leaved weeds during the tillering period. At the end of the tillering period, herbicide applications were made against broad-leaved weeds with '2-4 D Amine'. As a precaution against fungal diseases (yellow rust-brown rust-black rust-septoria) that may be seen in April and May, 'Opera-max' fungicide at a dose of 200 mL da^{-1} was applied twice with an interval of 25 days.

Evaluated quality traits and experiments

Dry matter, which expresses the remaining mass of a substance without considering the amount of water it contains, was defined by Wulyapash et al.'s (2021) method. After the wheat samples were weighed as 2.5 g, they were burned in a muffle furnace at 900°C for an hour and at 550°C for four hours. The amount of ash was determined by burning it until it reached a constant weight (Anonymous, 2007). Protein amount determination of wheat samples was made using the Kjeldahl Method according to TS 2282. Total protein was calculated by multiplying the amount of nitrogen obtained by a factor of 6.25 (Anonymous, 2014). After weighing 5 g of wheat samples into centrifuge tubes, 30 mL of ethanol was added. The prepared tubes were mixed in the mixer at 20°C for an hour and then centrifuged in the centrifuge at 2000 rpm for five minutes. After centrifugation, 20 mL of the upper liquid was taken and placed in the conical flask. The titration process was carried out after dropping phenolphthalein solution onto it (Anonymous, 2019). After weighing 10 g of wheat samples, 5.5 mL of buffer solution was added. Then, the mixture was mixed and kneaded with a spatula. The kneaded mixture was washed with a buffer solution. The wet gluten obtained was weighed, and the wet gluten was found by proportioning it to the sample amount (Anonymous, 2008a). 10 g of wheat samples were weighed and placed in the prepared wet gluten drying device, dried for four minutes and weighed (Anonymous, 2008b). The wet gluten obtained by washing was centrifuged for 60 seconds, and the gluten index was calculated by proportioning the remaining part on the cassette sieve to gluten and finding its percentage. After weighing the wheat samples into a graduated cylinder, 50 mL of bromophenol solution was added. After the resulting mixture was shaken by hand in a horizontal position 12 times, it was placed in the shaking device, and the device was turned on for five minutes. After the time was up, 25 mL of the sedimentation test reagent was added and placed back into the device. After another five minutes of shaking, the cylinder was removed from the device and kept upright for five minutes. The volume of the resulting sediment was read and recorded as Zeleny sedimentation (Anonymous, 2013a). After adding 50 mL of bromophenol solution to the weighed wheat samples, the cylinders were placed in the shaking device set for five minutes. After the time was up, the cylinders were taken from the device and kept for two hours. At the end of two hours, 25 mL of test reagent was added and placed in the shaking device set for five minutes. After the time expired, the cylinder was removed from the device, and after waiting for five minutes, the volume of the sediment obtained was read and recorded as late sedimentation (Anonymous, 2013a). The weighed 7 g flour sample was placed in a viscometer tube, and 25 mL of pure water was added. Then, it was shaken with a mixer and placed in a water bath. The experiment was completed when the viscometer stirrer reached the bottom of the gelatin suspension. The number that appeared determined the number of falls (Anonymous, 2013b).

Statistical analysis

Laboratory studies were conducted in three replications using a split-plot trial design in completely randomized plots. Urea application periods were the main-pilot factors and flour types were the sub-pilot factors. Variance analysis (effect tests), the compares of treatment means (by LSD test), and correlation coefficients were made by the JMP (2007) packet programme.

RESULTS AND DISCUSSION

Dry matter

Urea application stages (AS) and application stages×flour type (AS×FT) interaction had statistically significant effects on the dry matter (DM) of flour; however, there was a non-significant difference between whole grain flour (WGF) and White flour (WF) for DM (Table 3). While the maximum DM mean (90.76%) was obtained from the urea applied during the dough ripeness stage of bread wheat, the lowest DM (90.20%) was obtained from the control in which urea was not applied. In bread wheat, the interaction observed between the different growth stages at which urea is applied and the flour type is due to the reactions of the fertilizer applied during the stem elongation stage to the flour type. Shahzad et al. (2019) examined the effect of different nitrogen levels on the dry matter content and other quality characteristics of wheat grains. They observed that nitrogen fertilizer application significantly affected the dry matter content of wheat grains, and that the highest dry matter content was observed in wheat plants fertilized with the highest nitrogen level. Researchers also found that improved dry matter content positively affected other quality parameters of the flour, such as protein content and baking properties.

Ash content

All variation sources, such as AS, FT and AS×FT, showed statistically significant differences at $p < 0.01$ (Table 3). When an evaluation is made according to the urea AS, while the highest ash content was obtained from the control application (no-urea) with 1.21%, the lowest ash content was from the urea application of the milky stage with 1.04%. According to FT, the highest ash content was not surprisingly obtained from WGF (1.44%), while the lowest ash content was obtained from WF (0.78%). AS×FT interaction arises from the fact that flour type showed different ash content values with urea applied at different growth stages of bread wheat (Table 3). Turan et al. (2017) evaluated the effect of nitrogen fertilization on the ash content of wheat grains and flour. Although the ash content of wheat grains and flour increases linearly with increasing nitrogen levels, it was determined in our study that the control application gave higher ash values than the others. Elgün et al. (1998) also emphasized that the ash rate can vary depending on the wheat variety, climate and soil conditions, and the ash rate decreases on dry days. It has been observed that the ash ratio decreases as the whiteness degree of the bread increases and increases as the whiteness degree of the bread decreases (Anonymous, 2012).

Table 3. Mean values for dry matter and ash content of whole grain flour (WGF) and white flour (WF) from the urea application to bread wheat at different growth stages

Application stage (AS)	Dry matter (%)			Ash content (%)		
	WGF	WF	Mean	WGF	WF	Mean
Control (no urea)	90.27^{ef*}	90.14^{f}	90.20^{c}	1.62^{a}	0.80^{d}	1.21^{a}
Tilling	90.46^{cd}	90.59^{bc}	90.52^{b}	1.45^{b}	0.80^{d}	1.12^{b}
Stem elongation	90.73^{ab}	90.37^{de}	90.55^{b}	1.35^{c}	0.79^{de}	1.07^{c}
Milky	90.52^{cd}	90.58^{bc}	90.55^{b}	1.32^{c}	0.75^{e}	1.04^{d}
Dough	90.76^{a}	90.77^{a}	90.76^{a}	1.47^{b}	0.75^{e}	1.11^{b}
Mean	90.55	90.49	90.52	1.44^{a}	0.78^{b}	1.11
Brief view from the analysis of variance (p values)						
AS	$p < 0.01$			$p < 0.01$		
Flour type (FT)	ns			$p < 0.01$		
AS×FT	$p < 0.01$			$p < 0.01$		

*There was no statistical difference between the same letter groups at the 0.05 significance level by LSD test. ns: non-significant.

Protein content

While protein content showed statistically significant differences in terms of AS at the $p<0.05$ probability level, FT had no significant effects on protein content. On the other hand, AS×FT affected protein content at a probability level of $p<0.01$ (Table 4). In this concern, the highest protein content (15.15%) was from the stem elongation stage while the lowest protein content (14.00%) was from the tilling stage for AS. Also, AS×FT interaction originated from the fact that FTs statistically differed in terms of protein content at the tillering stage (Table 4). The protein ratio of wheat flour is an important quality parameter that affects the nutritional value and processing properties of the flour; Xu et al. (2017) evaluated the effect of nitrogen on the protein content and baking properties of wheat flour. As a result, they stated that increasing nitrogen levels significantly increased the protein content of wheat grains and flour. Abedi et al. (2011) reported that nitrogen applied in the vegetative period increased the yield, and nitrogen applied in grain filling increased the protein ratio.

Acidity

The effects of urea applied in different growth stages of bread wheat on the acidity value of flour were significant at the $p<0.01$ probability level according to AS and FT (Table 4). Thus, the highest acidity value was from the control application (0.06%), but the lowest values were from stem elongation, milky and dough stages with the value of 0.04%. Also, acidity was higher in WGF (0.05%) compared to WF (0.04%) (Table 4). The acidity content of wheat flour is an important quality parameter that affects the taste, texture and processing properties of the flour; the acidity value is higher in whole wheat flour than in white flour.

Table 4. Mean values for protein content and acidity of whole grain flour (WGF) and white flour (WF) from the urea application to bread wheat at different growth stages

Application stage (AS)	Protein (%)			Acidity (%)		
	WGF	WF	Mean	WGF	WF	Mean
Control (no urea)	14.57^{bcd*}	14.97^{ab}	14.77^{ab}	0.06	0.05	0.06^{a}
Tilling	14.53^{bcd}	13.48^{e}	14.00^{c}	0.06	0.04	0.05^{b}
Stem elongation	14.98^{ab}	15.31^{a}	15.15^{a}	0.05	0.03	0.04^{c}
Milky	14.45^{cd}	14.33^{d}	14.39^{bc}	0.05	0.03	0.04^{c}
Dough	14.43^{cd}	14.84^{abc}	14.63^{ab}	0.04	0.04	0.04^{c}
Mean	14.59	14.58	14.59	0.05^{a}	0.04^{b}	0.04
Brief view from the analysis of variance (*p* values)						
AS	$p < 0.05$			$p < 0.01$		
Flour type (FT)	ns			$p < 0.01$		
AS×FT	$p < 0.01$			ns		

*There was no statistical difference between the same letter groups at the 0.05 significance level by LSD test. ns: non-significant.

Wet and dry gluten

Wet and dry gluten contents were affected at the $p<0.01$ significance level in terms of all variation sources (AS, FT and AS×FT) (Table 5). In this context, mean wet gluten content varied from 41.49% (Tilling) to 43.66% (control, no urea) for AS. Also, the wet gluten content of WF (44.90%) was higher than WGF (40.27%). AS×FT interaction varied from 39.36% to 45.91%; the interaction is because the WF values were in the higher group than the WGF values in each AS. Dry gluten content changed between 14.75% and 15.46% for AS. Thus, the application stages with the lowest dry gluten values were the tillering (14.75%) and stem elongation (14.87%), while the highest dry gluten value was from the milky stage (15.46%). Additionally, the dry gluten value of WF (15.96%) was higher than WGF (14.25%). AS×FT values varied from 13.83% to 16.57%. It is thought that the interaction is because dry gluten is in a higher group in WF than in WGF for each application stage. Abedi et al. (2011) found that when nitrogen was not applied during the grain filling period, the gluten content of the grain decreased significantly; nitrogenous fertilizer given during the vegetative period (such as tillering) results in productivity; however, they reported that nitrogen given during late development periods would result in improved gluten quality. Because gluten parts, "gliadin and glutenin," are known as proteins that build up in the grain during the grain-filling period (Shewry and Halford, 2002). In addition, Marconi et al. (1999) found dry gluten values in the range of 11.2-14.7%; these values are consistent with the findings obtained in this study.

Table 5. Mean values for wet and dry gluten content of whole grain flour (WGF) and white flour (WF) from the urea application to bread wheat at different growth stages

Application stage (AS)	Wet gluten (%)			Dry gluten (%)		
	WGF	WF	Mean	WGF	WF	Mean
Control (no urea)	41.50^{e*}	45.83^{a}	43.66^{a}	14.63^{d}	15.89^{b}	15.26^{ab}
Tilling	39.59^{g}	43.40^{d}	41.49^{d}	13.83^{f}	15.67^{bc}	14.75^{c}
Stem elongation	40.53^{f}	43.79^{c}	42.16^{cd}	14.37^{de}	15.38^{c}	14.87^{c}
Milky	40.38^{f}	45.91^{a}	43.14^{ab}	14.34^{de}	16.57^{a}	15.46^{a}
Dough	39.36^{g}	45.56^{b}	42.46^{bc}	14.07^{ef}	16.30^{a}	15.18^{b}
Mean	40.27^{b}	44.90^{a}	42.58	14.25^{b}	15.96^{a}	15.10
Brief view from the analysis of variance (*p*-value)						
AS	$p < 0.01$			$p < 0.01$		
Flour type (FT)	$p < 0.01$			$p < 0.01$		
AS×FT	$p < 0.01$			$p < 0.01$		

*There was no statistical difference between the same letter groups at the 0.05 significance level by LSD test.

Gluten index

Gluten index values were affected at the $p<0.01$ significance level in terms of all variation sources (AS, FT and AS×FT) (Table 6). The highest gluten index value (80.38%) was from the stem elongation stage, while the lowest value (69.28%) was from the control. In addition, the gluten index of WGF (82.53%) was higher than the value of WF (66.07%). AS×FT interaction differed between 55.86% and 80.38%; the reason for interaction is attributed to the fact that WGF values being in the higher group than WF values in each application stage (Table 6). Hao et al. (2023) stated that nitrogen applied during the flowering and grain-filling periods increased the gluten index (80.5-86.2%) and brought it almost to 100%.

Falling number

Falling number values showed statistical differences at the $p<0.05$ significance level for urea application stages, and they also differed according to flour type at the $p<0.01$ significance level. AS×FT interaction was not statistically significant (Table 6). Thus, the highest value (881.67 s) was observed from the control application, while the lowest value (753.83 s) was from the dough stage. Also, falling numbers of WF (836.40 s) were higher than the value of WGF (741.87 s) (Table 6). Al-Saadi et al. (2021) investigated the effects of nitrogen management on the falling number value of wheat flour. It has been reported that the falling number value of wheat flour decreases with increasing nitrogen application doses, indicating an increase in amylase activity and starch damage.

Table 6. Mean values for gluten index and falling number of whole grain flour (WGF) and white flour (WF) from the urea application to bread wheat at different growth stages

Application stage (AS)	Gluten index (%)			Falling number (s)		
	WGF	WF	Mean	WGF	WF	Mean
Control (no urea)	82.69^{ab*}	55.86^{h}	69.28^{c}	803.00	960.33	881.67^{a}
Tilling	83.64^{ab}	60.71^{g}	72.18^{bc}	698.33	835.00	766.67^{b}
Stem elongation	81.86^{bc}	78.90^{d}	80.38^{a}	758.33	751.67	755.00^{b}
Milky	79.90^{cd}	64.95^{f}	72.42^{bc}	763.00	814.00	788.50^{b}
Dough	84.56^{a}	69.94^{e}	77.25^{ab}	686.67	821.00	753.83^{b}
Mean	82.53^{a}	66.07^{b}	74.30	741.87^{b}	836.40^{a}	789.13
Brief view from the analysis of variance (*p* values)						
AS	$p < 0.01$			$p < 0.05$		
Flour type (FT)	$p < 0.01$			$p < 0.01$		
AS×FT	$p < 0.01$			ns		

*There was no statistical difference between the same letter groups at the 0.05 significance level by LSD test. ns: non-significant.

Zeleny and late sedimentation

Zeleny and late sedimentation values were affected at the $p<0.01$ significance level in terms of all variation sources (AS, FT and AS×FT) (Table 7). Thus, the highest Zeleny sedimentation values (21.0 mL) were observed from the control and dough stages while the lowest values were determined from the stem elongation stage. Also, the Zeleny sedimentation value of WF (30.53 mL) was higher than that of WGF (10.60 mL). AS×FT interaction values of Zeleny sedimentation changed between 10.00 mL and 30.67 mL. The difference in interaction values has been explained by the fact that the WF Zeleny sedimentation value was higher than the WGF value at each urea application stage (Table 7). For late sedimentation value, the highest values were from stem elongation (29.83 mL) and milky stages (29.50 mL), while the lowest value was from the control application (23.50 mL). As with the Zeleny sediment, the late sedimentation value of WF (35.60 mL) was higher than that of WGF (19.20 mL).

AS×FT interaction values of late sedimentation differed between 17.00 mL and 39.00 mL. The impact of interaction (AS×FT) originated from the late sedimentation value of WF, which was higher than the WGF value at each urea application stage (Table 7). Hao et al. (2023) reported that nitrogen given by dividing into two during the flowering and grain-filling periods increased sedimentation values both years and in two of three varieties.

Table 7. Mean values for Zeleny sedimentation and late sedimentation of whole grain flour (WGF) and white flour (WF) from the urea application to bread wheat at different growth stages

Application stage (AS)	Zeleny sedimentation (mL)			Late sedimentation (mL)		
	WGF	WF	Mean	WGF	WF	Mean
Control (no urea)	12.00[d*]	30.00[c]	21.00[a]	17.00[h]	30.00[d]	23.50[d]
Tilling	11.00[e]	30.00[c]	20.50[b]	18.67[g]	35.00[c]	26.83[c]
Stem elongation	10.00[f]	30.00[c]	20.00[c]	20.67[f]	39.00[a]	29.83[a]
Milky	10.00[f]	30.67[b]	20.33[b]	22.00[e]	37.00[b]	29.50[a]
Dough	10.00[f]	32.00[a]	21.00[a]	17.67[h]	37.00[b]	27.33[b]
Mean	10.60[b]	30.53[a]	20.57	19.20[b]	35.60[a]	27.40
Brief view from the analysis of variance (p values)						
AS	$p < 0.01$			$p < 0.01$		
Flour type (FT)	$p < 0.01$			$p < 0.01$		
AS×FT	$p < 0.01$			$p < 0.01$		

*There was no statistical difference between the same letter groups at the 0.05 significance level by LSD test.

Correlations between quality traits

Acidity showed a significant negative correlation (r=-0.38*) with dry matter and a significant positive correlation (r=0.68**) with ash content. Wet gluten content was significantly negative correlated with ash content (r=-0.88**) and acidity (r=-0.47**). Dry gluten content showed significant negative relationships with ash content (r=-0.0.88**) and acidity (r=-0.55**), whereas it showed significant positive correlation with wet gluten content (r=0.96**). Gluten index was significantly positively correlated with ash content (r=0.78**) and significantly negatively correlated with wet (r=-0.81**) and dry gluten (r=-0.81**) content. Zeleny sedimentation showed significant negative relationships with ash content (r=-0.96**), acidity (r=-0.60**) and gluten index (r=-0.78**), and significant positive relationships with wet (r=0.93**) and dry (r=0.92**) gluten content. Late sedimentation showed significant negative correlations with ash content (r=-0.97**), acidity (r=-0.73**) and gluten index (r=-0.65**), and significant positive correlations with wet gluten (r=0.85**), dry gluten (r=0.87**) and Zeleny sedimentation (r=0.95**). Falling number was significantly negative correlated with dry matter (r=-0.41*), ash content (r=-0.46**), and gluten index (r=-0.61**), although it was significant positive correlated with wet gluten (r=0.62**), dry gluten (r=0.59**), and Zeleny sedimentation (r=0.52**) (Table 8).

Table 8. Correlation coefficients (r) between investigated quality traits (n=30)

Traits	Dry matter	Ash	Protein	Acidity	Wet gluten	Dry gluten	Gluten index	Sedim	Late sedim
Ash	0.03								
Protein	-0.08	0.00							
Acidity	-0.38*	0.68**	0.04						
Wet gluten	-0.21	-0.88**	0.13	-0.47**					
Dry gluten	-0.07	-0.88**	-0.05	-0.55**	0.96**				
Gluten index	0.22	0.78**	0.18	0.33	-0.81**	-0.77**			
Zeleny sedim	-0.14	-0.96**	-0.01	-0.60**	0.93**	0.92**	-0.78**		
Late sedim	0.00	-0.97**	0.03	-0.73**	0.85**	0.87**	-0.65**	0.95**	
Falling	-0.41*	-0.46**	-0.05	-0.05	0.62**	0.59**	-0.61**	0.52**	0.37*

* and ** indicate probability levels of $p < 0.05$ and $p < 0.01$, respectively.

CONCLUSION

Wheat is a strategic product that is crucial to human nutrition. Both breeding research and agronomy research are continuing worldwide to produce more efficient and high quality wheat in agricultural production. Wheat quality can mean different things to the farmer who grows the wheat, the miller who mills it and the industrialist who processes it into the final product. Wheat quality may vary according to the species and variety, ecological regions and cultivation techniques applied. One of the most critical factors in yield and quality in agricultural production is balanced fertilization. The most important nutrient element affecting yield and quality in wheat is nitrogen. Generally, nitrogen applied in the top fertilization of wheat in the Çukurova region is applied during the tillering period. However, the nutrient requirements of wheat at different developmental stages may have different effects on its quality. In this study, nitrogen applications were made at tillering, stalk emergence, milk maturity and yellow maturity stages of wheat. It was determined that nitrogen applications were more important for high gluten index, delayed sedimentation and protein at emergence and for high dry matter at yellow maturity. For high yield and quality in wheat, it will be significant to conduct research with more genotypes with different yield potentials in different regions according to climatic conditions and soil characteristics and with new-generation fertilizer sources in further studies.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of interests

The authors declare that they have no competing, actual, potential or perceived conflict of interest.

Author contribution

BBK: MSc thesis and experiments; BB: Thesis supervisor and paper writing; CB: Arrangement of laboratorial experiments; SA and HB: Seed providing (field experiments).

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