Effect of phosphorous and iron fertilization on wheat grains surface color characteristics

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Abstract: The objectives of this study were to investigate the effects of phosphorous and iron fertilizer rates on the surface color characteristics of wheat grains. The treatments were a combination of four rates of phosphorus (0, 75, 150 and 225 kg ha^{-1}) and three rates of foliar iron (0, 1.2 and 2 L ha^{-1}) based on the factorial experiment as randomized design with three replications. The results of the study showed that some of the surface color values of wheat grains were depended on the phosphorous and foliar iron application rates; resulting color shift toward the lighter regions. Phosphorus rates created higher variations than iron rates. With increasing the iron rate from 0 to 2 L ha^{-1}, the average value of L* and ΔE color units increased significantly from 40.01 to 41.16, and from 1.56 to 3.33 respectively. No effect of foliar iron on the b* value was observed. As the phosphorus rate changed from 0 to 75 kg ha^{-1}, the mean values of L*, b* and ΔE of grains increased significantly from 38.98 to 42.02, from 27.89 to 29.78 and from 1.34 to 3.67, respectively, although, additional increase in the rate of phosphorus, caused a decreasing trend in the values of the above scales. No effect of phosphorus rate on a* value was observed.

Keywords: wheat, surface color, phosphorus, foliar iron, fertilization

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1 Introduction

Wheat has been cultivated for more than 10000 years as primary human foods and has a significant impact on the social, population and cultural development of humankind (Popovic, 2015). In addition to rice, bread made from wheat grains forms the leading human food. Like other cereal grains, wheat grains are the primary source of energy supply, carbohydrates (such as starch), protein, minerals, all kinds of vitamins and fiber. The protein content of wheat grains varies from 8% to 20% depending on their type and classes (Popovic, 2015).

The quality parameters of wheat grains heavily depend on growth conditions, soil fertility, fertilizer application, water ability, genotype, grain transport and storage situations (Uhlen et al., 1998; Carson and Edwards, 2009; Popovic, 2015). Some of these essential quality factors of grains, such as wheat, include grain structure, grain cover and grain composition (Shahbazi et al., 2012; Shahbazi et al., 2015b), in which these parameters are affected by the rates of inorganic fertilizers. Also, the yield and quality parameters of grains are affected by agronomic practices such as the tillage system (Ruiz et al., 2019; Le Campion et al., 2020; Garakishi, 2020; Yousefian et al., 2021).

Cereal crops such as wheat nowadays include the high application of chemical fertilizers to increase nutrients in agricultural lands and ensure more significant crop production potential. Therefore, determining and understanding the changes in grain quality properties is in response to the application of the rates of fertilizers such

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as phosphorus and iron (Shahbazi et al., 2015 a).

Wheat crop cultivation requires the 17 balanced fertility elements including macro-nutrients elements (such as phosphorus) and micro-elements (such as iron) (Halvin et al., 2005). Phosphorus is required for photosynthesis in plants and is also crucial for the transfer and storage of energy in the plant's cells (Taiz et al., 2015). Besides, phosphorus causes root growth and helps plant growth be earlier in the season (Popovich, 2015). Fertilization of iron is commonly used to improve the density and ability of Fe in cereal products, similar to wheat, to increase the quality of the foods for humans (Shahbazi et al., 2015b).

Achieving the purpose of increasing the generation of products made from cereal seeds, such as wheat, with optimum quality parameters, requires improvement of the research and knowledge development. This is a big competition for every corporation of the food production link from farmers to consumers, who subjected to variability in the modality of wheat grains. Modifying science of the quality properties in crop product programs and managing the application of fertilizer technique practices reduce the change in the higher quality parameters of the wheat grains and ensure that they attend qualitative properties of wheat grains (Popovic, 2015).

Color is an important quality parameter in food engineering. Wheat grain surface color is an essential feature in grain sorting and fabrication (Wu et al., 1999; Jiang et al., 2011).

The surface color of wheat grains is a significant factor affecting the color of the final product made from grains. In the literature, several research results on the color measurement of wheat grains are available. Many researchers reported that the color of wheat grains affects the color and taste of the finished product made from grains, such as bread and tortilla (Li and Posner, 1989; Seib et al., 2000; Hatcher et al., 2006; Jayas et al., 2008; Jiang et al., 2011).

Researchers also reported the association of wheat grain color with other factors such as environment and cultivation. Groos et al. (2002) examined the communication among pre-harvest exercises with the color of wheat grains. Matus-Cádiz et al. (2003) investigated the interaction between cultivar and environment on hard white spring wheat grain color and they reported that the color of whole grains varied among genotypes, but genotype × location interaction was not significant. Humphries et al. (2004) showed a positive communication amongst b^* content in wheat and triticale with lutein concentration. McCaig et al. (2006) studied the color change of wheat grains about field weathering, and they reported that weather increased the color of the grain L^* values, decreased in a^* values and a slight increase in b^* values in the nuclei. Lukow et al. (2013) investigated the effect of environs on the wheat grain color and they reported that wheat grain color change was ascribed to the annual variation in climatic (73% － 79%) and agro-climatic conditions (13%－18%). Horváth and Véha (2015) investigated the dependence of wheat grain color characteristics on the grain size and they found that as the grain size raised, the L^* scale decreased and a^* and b^* co-ordinates increased in all cases of studied wheat grains. Tanska et al. (2018) investigated wheat grain color concerning crop diet and reported that cultivar had a significant effect on grain surface color.

Yousefian et al. (2021) reported that the tillage system had significant effects on the surface color of wheat grain. As the level of tillage increased from no tillage to conventional tillage system, the mean values of the L^* (whiteness) from wheat grains color parameter, increased significantly from 59.33 to 60.15, and as the level of tillage decreased from conventional tillage to no tillage system, the redness color parameter of wheat grains surface increased. The result of the study showed that as the level of soil tillage decreased from conventional tillage to no tillage system, the yellowness color parameter of the wheat grains decreased.

Little published work on the effect of P and Fe fertilizer rates on the surface color attributes of wheat grains has been found. Hence, this research aimed to appreciate the impact of Fe (0, 1.2 and 2 L ha^{-1}) and P (0, 75, 150 and 225 kg ha^{-1}) on the surface color properties of wheat grains at CIE $L^*a^*b^*$ color scale and total color change (ΔE) of grains.

2 Material and methods

Wheat seeds (*Triticum aestivum* L.) of the Chamran cultivar were chosen to be used in this research. An experiment was conducted during 2019 – 2020 growing seasons, at the experimental research station of Lorestan University, Iran. The cropping system used in the experiment was irrigated by continuous cereal cultivation under conventional tillage. The wheat plots were planted in a randomized complete block design with three replications in the fall 2019. Wheat cultivar and planting dates were chosen based on the best recommendation for farmer's practices in the area of the study. Crop management practices (except iron fertilization) varied among locations depending on the requirements based on soil test results. Row spacing (six rows in each plot) was 0.2 m and plots size was 4 m in length and 1.5 m in width.

After complete maturity, samples of wheat grains were harvested by hand. Grain samples were stored for six months to standardize their moisture (Shahbazi, 2012). The mean value of the moisture content (water content) of wheat grain samples after storage and test start was about 7.5% (wet basis) measured by using near infrared reflectance (NIR) analyzer instruments (Perten-Instruments, Ab, Huddinge, Sweden) (Shahbazi and Nematollahi, 2019).

For surface color parameter measurements, glass dishes containing wheat grains samples were placed under the light source of four LED lamps (12 W, 230 V, AC, and 50 Hz). The images of the whole grains surface were captured using a 24.5 megapixels digital color camera (Nikon digital SLR camera D53000). The camera was positioned 20 cm vertically above the grain sample surface and has been mentioned before picture captured with no flash or zoom (Yousefian et al., 2021).

The color properties of the recorded images were determined using the Image J software version 1.32g. Finally, for quantization of grains surface color L^*, a^*, b^* coordinates of CIELAB color scale were calculated from red, green and blue (RGB) values from grains digital image using a color converter of the ColorMine (http://colormine.org). In the CIE $L^*a^*b^*$ color scale space, the L^* amount represents a light score of 100 in white and 0 in black. The values a^* denote red to green, which mean positive amounts of a^* red and negative values of green. The b^* values indicate yellow-blue, with positive amounts indicating yellow and minus amounts indicating bruising (Peterson et al., 2001; Horrobin et al., 2003; Leon et al., 2006; Tanska et al., 2005; Afshari-Jouybari and Farahnaky, 2011; Komyshev et al., 2020; Yousefian et al., 2021). The total color change of the grains (ΔE) was calculated using Equation 1:

$$\Delta E = \left[(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^3\right]^{1/2} \quad (1)$$

Where: L_0^*, a_0^* and b_0^* are color values of control samples (0 doses of fertilizers) and L^*, a^*, and b^* are color scales of fertilized samples.

In this study, the effects of foliar iron (0, 1.2 and 2 L ha^{-1}, fusion) and phosphorus (0, 75, 150 and 225 kg ha^{-1}, P_2O_2) fertilizers on the surface color factors of wheat grain were investigated based on the factorial experiment as randomized design with three replications. For the color measurement test, the required grains were selected from samples and their surface color parameters were measured. For determining the main treatment effects and the effects of their interactions on the surface color parameters of wheat grain, variance analysis (ANOVA) was performed. Mean values were compared using Duncan's multiple range tests.

3 Results and discussion

The results of data analysis (ANOVA) indicated that phosphorus fertilization at 1% portability significantly affected the L^* and b^* color parameters of wheat grains. The effect of phosphorus on a^* surface color scale of grains was not significant (Table 1). Foliar iron fertilization rate significantly affected L^* and a^* color values at 5% and 1% portability levels, respectively. The effect of iron fertilization on b^* was not significant. The interaction effects of the iron and phosphorus on the L^* scale at 5% ($p < 0.05$) and on a^* and b^* scales at 1% ($p < 0.01$) were significant (Table 1).

The rate of application of these two fertilizers had a significant effect on the total surface color change (ΔE) of the tested grains at 1% probability levels (Table 1). Still, the impact of iron on total color change was more (F = 10.67) than phosphorus (F = 9.66) within the range of variables studied (Table 1). The interaction of two fertilizers on the total color change was not significant ($p > 0.05$).

Table 1 Results of analyses of variance (Mean Square Error) for the color parameters of wheat grains as affected by phosphorus and iron fertilization rate

Source of variation	Dependent variable	df	Mean square error	F value
Iron rate (IR)	L^*	2	4.419	4.23 *
	a^*	2	1.681	7.43*
	b^*	2	0.270	0.650 ^{ns}
	ΔE	2	9.375	10.67**
Phosphorus rate (PR)	L^*	3	13.973	13.38**
	a^*	3	0.100	0.44 ^{ns}
	b^*	3	5.437	12.06**
	ΔE	3	8.486	9.66**
IR ×PR	L^*	6	4.620	4.43*
	a^*	6	1.387	6.13*
	b^*	6	2.762	6.13*
	ΔE	6	1.954	2.22^{ns}
Error	L^*	24	1.044	
	a^*	24	.226	
	b^*	24	.450	
	ΔE	24	.879	

* - Significant at 0.05 level, ** - Significant at 0.01 level, ^{ns} - Not Significant

3.1 Effect of phosphorus on wheat grains surface color

The mean comparison results for surface color parameters of wheat grains at different phosphorus and iron fertilizer speeds are presented in Table 2. It is evident that the lightness (L^*) of the grains increased with increasing the application of phosphorus fertilizer, thus changing the surface color of the grains toward a lighter and whiter area. These results show that the uses of fertilizers such as phosphorus have considerable effects on the physicochemical properties of grains, and also have significant effects on other grains quality properties such as surface color. As the rate of the application of phosphorus increased from 0 to 75 kg ha^{-1}, the mean values of the L^* wheat grains color parameter increased significantly from 38.98 to 42.02, however, there was a further addition of the rate of phosphorus from 75 to 150 kg ha^{-1}, causing the decrease of the mean values of the L^* from 42.02 to 40.33. On the other hand, a significant increment in the rate of phosphorus from 150 to 225 kg ha^{-1}, terminated in a slight increase in L^* mean values from 40.33 to 40.54. From the data in Table 2, it can be seen that the mean values of L^* at 75 kg ha^{-1} rate of phosphorus are significantly different and higher than the mean values at 0, 150 and 225 kg ha^{-1} rates. According to the results of previous studies, for each crop such as wheat, there is a desirable individual level in each fertilizer, where maximum qualitative factors such as surface color lightness occur. Therefore, in this study, for the wheat crop, at the optimum rate of phosphorus fertilization, the higher surface lightness was obtained at about 75 kg ha^{-1}.

No research report was found to compare the effect of phosphorus fertilization on color parameters of wheat grains for comparison with the results obtained in this study. Shahbazi and Nematollahi (2019) reported that an increase in phosphorus fertility caused a change in the quality of wheat grains increasing in the content of protein but decreasing in the contents of water and fiber.

For a^* (redness/greenness) mean values of the wheat grains surface color scale, the influence of phosphorus application rate on this scale was not significant. From data in Table 2, it is evident that mean values a^* surface color scale of tested grains ranged from 10.28 (in 75 kg ha^{-1} application of phosphorus) to 10.51 (in 0 kg ha^{-1} rate of phosphorus). The mean values of a^* surface color scale of the tested grains for phosphorus rates of 0, 75, 150 and 225 kg ha^{-1}, were 10.51, 10.28, 10.49 and 10.39, respectively. Besides, there was no considerable difference among the mean values of a^* (redness) of wheat grain at different rates of phosphorus.

The effect of phosphorus application at different rates on the variation of b^* (yellowness) values was significant at the 1% possibility level. The results of the comparison of the mean of Table 2 show that the mean b^* level of wheat grain color increased with increasing phosphorus fertilization rate and, as a consequence of phosphorus application, increased the yellowness of grains.

As the amount of phosphorus increased from 0 to 75 kg ha^{-1}, the average values of b^* significantly increased from 27.89 to 29.78. However, with a further addition to the rate of phosphorus from 75 to 150 kg ha^{-1} the mean values of b^* reduced from 29.78 to 29.03. Then, as the amount of phosphorus increased from 150 to 225 kg ha^{-1}, the mean values of b^* reduced from 29.03 to 28.83. The mean values of b^* color scale of wheat grains with different amounts of phosphorus, 0, 75, 150 and 225 kg ha^{-1}, were found to be 27.89, 29.78, 29.03 and 28.83, respectively. By stating that it is the same amount of lightness (L^*), higher b^* mean values (yellowing) for wheat grains were obtained at about 75 kg ha^{-1} phosphorus fertilization rate. Also, the mean values of b^* of grain at 75 kg ha^1 rate of phosphorus were statistically different from that at other phosphorus (Table 2).

For the ΔE (the total color change) values of grains, the phosphorus rate created a significant effect at the 1% portability level (p < 0.01). From the results the comparison of means in Table 2, it is evident that the total color change of grains increased by increasing the amount of the phosphorus fertilization application. The mean values of the total color change for wheat grain at different phosphorus fertilization applications of 0, 75, 150 and 225 kg ha^{-1}, were found to be 1.34, 3.67, 2.22 and 2.65, respectively. Also, this result shows that similar to other color parameters (L^* and b^*), the 75 kg ha^{-1} rate of phosphorus caused the higher total surface color change in wheat grains.

The results are exciting. However, regarding stability, no results were found regarding the effect of phosphorus fertilization on the surface color characteristics of wheat grain compared by the consequences obtained in this research.

Techniques of regression used to find and fit suitable models for the relationship between the surface color properties of wheat grains and the amounts of fertilization by phosphorus. The results indicated that the color parameters of studied wheat grains including L^* (lightness), b^* (yellowness) and ΔE (total color change) were quadratic equations (cubic) of phosphorus fertilization rate. Also, there were positive communications among phosphorus fertilization rate and all the above grains surface color parameters. These communications patronize the supposition of the considerable effect of phosphorus on the quality properties of wheat grains, such as surface color. Therefore, the dependence of L^* (lightness), b^* (yellowness), and ΔE (total color change) of the tested wheat seeds on the P fertilization rate (P, kg ha^{-1}) is expressed via the following best fit models:

$$L^* = 2.55\times10^{-6}P^3 - 0.001P^2 + 0.102P + 38.981$$
$$R^2=0.999 \tag{2}$$

$$b^* = 1.25\times10^{-7}P^3 - 0.001P^2 + 0.057P + 27.90$$
$$R^2=0.999 \tag{3}$$

$$\Delta E = 2.23\times10^{-6}P^3 - 0.001P^2 + 0.81P + 1.34$$
$$R^2=0.999 \tag{4}$$

3.2 Effect of foliar iron on wheat grains surface color

The results of the comparison of mean values in Table 2, indicated that with increasing the use of foliar iron fertility, the lightness scale (L^*) of wheat grain increased compared to control (untreated samples 0 L ha^{-1}). The result is exciting. However, unfortunately, no result on the effect of iron fertilization on the wheat grains surface color has been presented in the literature to contrast with the obtained results in this research. Shahbazi and Nematollahi (2019) reported that the quality parameters of wheat grain, such as the content of protein, increased by increasing the amounts of iron fertilization.

As the rate of foliar iron increased from 0 to 2 L ha^{-1}, the mean values of grains lightness (L^*) increased significantly about 1.03 times (from 40.01 to 41.16) (Table 2). The mean values of lightness of wheat grains (L^*) for foliar iron applications of 0, 1.2 and 2 L ha^{-1}, were found to be 40.01, 40.25 and 41.16, respectively (Table 2). Also, the mean values of L^* at the iron rate of 2 L ha^{-1} (41.16) were statistically different (p < 0.05), which were higher than those at the other rates, based on the mean comparison results (Table 2). These results show the significant influence of foliar iron fertilization rate on the chemical composition and color of the surface of wheat grains. These may be due to the effect of Fe on the respiration and the establishment of the enzymes, chlorophyll and photosynthetic orders of plants (Halvin et al., 2005; Ali, 2012).

The application of the different amounts of foliar iron significantly ($p < 0.05$) influenced the surface redness (a^*) color scale of wheat grains. It is evident from the data in Table 2, that the mean values of a^* range from 10.02 (in 1.2 L ha^{-1}of iron) to 10.76 (in 2 L ha^{-1} of iron) and the mean values of a^* at the rate of 1.2 L ha^{-1} of iron fertilization are statically different, which are lower than those at the rates of 0 and 2 L ha^{-1} (Table 2).

In terms of b^* (yellowing) of wheat, grains surface color, the effect of iron fertilization on this color scale was not significant ($p > 0.05$) (Table 1), also the difference between the mean values of b^* in the different rates of iron was not significant (Table 2). The mean values of b^* for wheat grains surface color were found to be 28.98, 28.96 and 28.71 for 0, 1.2 and 2 L ha^{-1} rates of foliar iron, respectively.

The effect of foliar iron on the total color change (ΔE) of wheat grains was significant at the level of 1% probability. From the mean values in Table 2, it is evident that as the iron fertilizer rate increased, the total color change of wheat grains increased. The mean values of the total color change for wheat grains at iron rates of 0, 1.2 and 2 L ha^{-1} were 1.56, 2.51 and 3.33, respectively. Also, the differences between mean values of ΔE wheat grains at different foliar iron rates were statistically significant ($p < 0.05$).

Regression techniques used to find the relationship between surface color characteristics and the amount of foliar iron fertilizer application. The results showed that the surface color characteristics of wheat grain surface including lightness (L^*), redness (a^*) and ΔE (total color change) were polynomial functions (quadratic) of the foliar iron fertilization rates. These relationships support the supposition of the significant effect of foliar iron fertilizers on the quality parameters of what grains such as surface color. Therefore, the best fit models derived for the relationship between CIE L^*, a^*, and ΔE wheat grains surface color parameters and foliar iron content (Fe, L ha^{-1}) as following:

$$L^* = 0.467Fe^2 - 0.359Fe + 40.01 \quad R^2=0.999 \quad (5)$$

$$a^* = 0.656Fe^2 - 1.173Fe + 10.48 \quad R^2=0.999 \quad (6)$$

$$\Delta E = 0.1148Fe^2 + 0.653Fe + 1.656 \quad R^2=0.999 \quad (7)$$

Table 2 The results of mean comparison for wheat grains surface color parameters based on Duncan's multiple tests ranges at different levels of phosphorus and iron fertilization

Independent variable	Dependent variable (wheat grain surface color parameters)			
	L^*	a^*	b^*	ΔE
phosphorus rate (kg ha^{-1})				
0	38.98 b*	10.51 a	27.89 c	1.34 c
75	42.02 a	10.28 a	29.78 a	3.67 a
150	40.33 b	10.49 a	29.03 b	2.22 bc
225	40.54 b	10.39 a	28.83 b	2.65 b
Foliar iron rate (L ha^{-1})				
0	40.01 b	10.48 a	28.98 a	1.56 c
1.2	40.25 b	10.02 b	28.96 a	2.51 b
2	41.16 a	10.76 a	28.71 a	3.33 a

* Different letters in the column section imply statistically significant differences at the 0.05 level.

3.3 Phosphorus and iron interaction effects

The results of the statistic resolution of the measured data showed that the interplay of the iron and phosphorus fertilization rates on the surface color lightness (L^*) of wheat grains at the 5% probability level was significant. The average values of the L^* color scale for wheat grains in the interplay of the iron and phosphorus fertilization rates are shown in Figure 1. As shown from the data in Figure 1 the lightness of wheat grains varies with the amount of phosphorus at all levels of iron. However, the variations in the grain lightness with the amount of phosphorus are not the same at different rates of iron fertilizer.

The effect of phosphorus rates on change in the lightness of grain is more robust in higher amounts of iron (2 L ha^{-1}) than in lower ones (0 L ha^{-1}). As can be seen from the data in Figure 1, at all levels of iron, the lightness (L*) of the seeds increased by increasing phosphorus rate from 0 to 75 kg ha^{-1} and then decreased by further increase in the phosphorus rates from 75 to 225 kg ha^{-1}.

In the rate of 0 L ha^{-1} of foliar iron, the lightness of the grains was changed from 38.78 to 40.46 by increasing the rate of phosphorus from 0 to 75 kg ha^{-1} and then decreased with further increase in the phosphorus rate from 75 to 225 kg ha^{-1}. For the other 1.2 and 2 L ha^{-1} iron rates, the corresponding changes in the lightness of wheat grains were from 39.54 to 42.10 and from 38.63 to 43.52, respectively, with an increase in the phosphorus rates from 0 to 75 kg ha^{-1} and then decreased to 40.58 and 42.47, respectively with increasing in phosphorus from 75 to 225 kg ha^{-1}.

As can be seen from the data in Figure 1, the lightness of the surface of the grains changed as the rate of the foliar iron changed at all rates of phosphorus, but the changes in the lightness with the iron rate in the different phosphorus rates were not the same.

At phosphorus rates of 0 and 150 kg ha^{-1}, the lightness of the seeds changed from 38.78 to 39.54 and from 40.40 to 40.58, respectively, with a change in foliar iron content from 0 to 1.2 L ha^{-1} and then decreased to 38.63 and 40.02 respectively, with further increasing of the iron to 2 L ha^{-1}.

At 75 kg ha^{-1} rate of the phosphorus, the lightness of the seeds increased from 40.46 to 42.10 with increasing iron rate from 0 to 1.2 L ha^{-1} and then further increasing iron rate to 2 L ha^{-1} rose to 43.52. At the phosphorus content of 225 kg ha^{-1}, increasing the iron rate from 0 to 1.2 L ha^{-1} caused a decreased trend in the lightness of wheat grains from 40.39 to 38.77 and then increased to 42.47 by increasing the iron rate to 2 L ha^{-1}.

As can be seen from the results of the above data, the effect of foliar iron rate on change in wheat grain lightness with a 75 kg ha^{-1} rate of phosphorus is more durable than other ones. The grains surface lightness (L*) data of wheat grains in Figure 1 vary from 38.63 to 43.52. The maximum value (43.53) was obtained for interaction of 75 kg ha^{-1} phosphorus with 2 L ha^{-1} irons content and the lowest amount (38.63) was collected for 0 kg ha^{-1} phosphorus and 2 L ha^{-1} iron fertilization rate showed that the effect of 75 kg ha^{-1} phosphorus fertilization was higher than other rates.

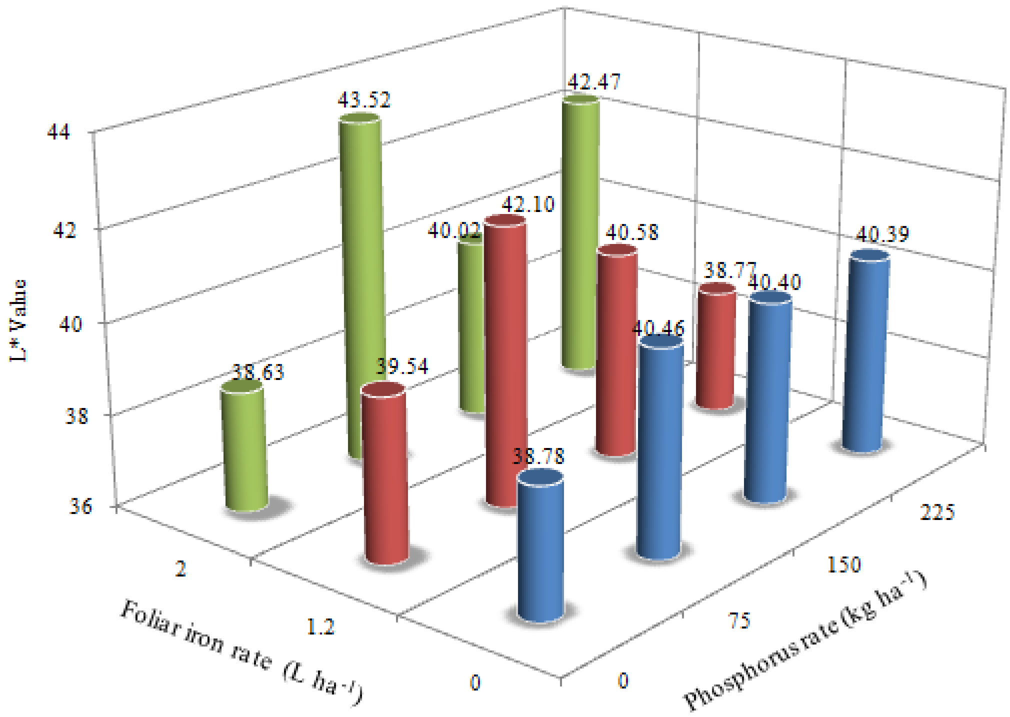

Figure 1 The mean values of Lightness (L*) surface color parameter of the wheat grains surface in the interaction between the fertilization of phosphorus and foliar iron

The interaction of phosphorus and iron fertilizer on *a** (redness) color scale of grains was significant ($p < 0.01$) at 1% probability level (Table 1). Mean values of *a** color scale were positive for all interactions between phosphorus and iron fertilizer (Figure 2), indicating the presence of red surface color. As shown in Figure 2, at various rates of foliar iron, the redness of wheat grain samples changed with increasing the rate of phosphorus. However, the change in the redness values of grains was not the same by changes in phosphorus levels at different levels of iron fertilizer. At the iron rate of 0 L ha^{-1}, *a** (redness) of the grains decreased from 10.83 to 9.91, with increasing the rate of phosphorus from 0 to 150 kg ha^{-1} and then increased to 11.25 with further increase in the rate of phosphorus to 225 kg ha^{-1}. At 1.2 L ha^{-1} rate of iron, with increasing the rate of phosphorus from 0 to 150 kg ha^{-1}, the redness of the seeds increased from 9.62 to 10.84 and decreased to 9.93 with a further increase of phosphorus level to 225 kg ha^{-1}. At 2 L ha^{-1} rate of iron, the redness of the seeds decreased from 11.09 to 10.60, with increasing phosphorus from 0 to 225 kg ha^{-1}.

As can be seen in Figure 2, in almost all of the phosphorus rates studied, the redness values of wheat grains were changed by varying the amount of iron fertilization. However, the rate of change in grains redness was not the same for all levels of phosphorus fertilization. At 0 and 225 kg ha^{-1} rates of phosphorus, surface redness of grains decreased from 10.63 to 9.62 and from 11.25 to 10.63, respectively, by increasing the rate of iron from 0 to 1.2 L ha^{-1} and then it increased to 11.09 and 10.63 respectively, with an increase in the iron rate to 2 L ha^{-1}. At 75 and 155 kg ha^{-1} levels of P fertilization, the redness of grains increased from 9.93 to 10.63 and from 9.91 to 10.71, respectively, by an increase in the iron rate from 0 to 2 L ha^{-1}. The data for *a** (redness) of wheat grains in Figure 2 vary from 9.93 to 11.25. The minimum value (9.93) was obtained for 75 kg ha^{-1} rate of phosphorus with the iron rate of 0 L ha^{-1}. The maximum amount (11.25) was hatched in the interactions of the rates 225 kg ha^{-1} of phosphorus and 0 L ha^{-1} of foliar iron fertilization.

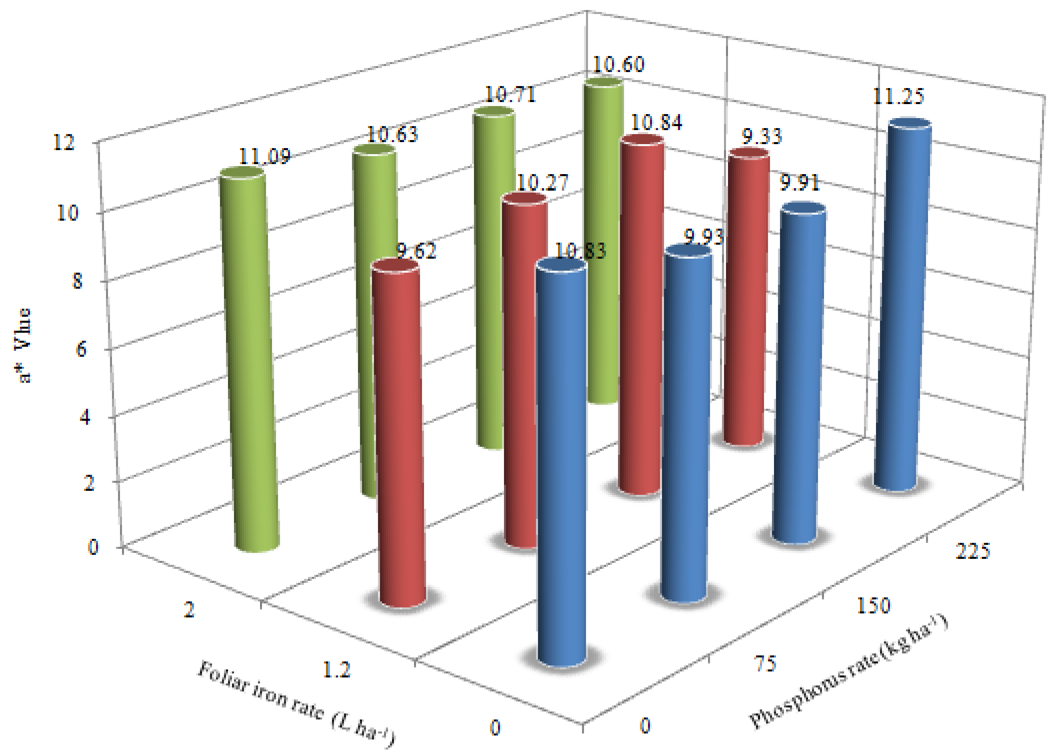

Figure 2 The mean values of *a** (redness) surface color parameter of wheat grains surface in the interaction between the fertilization of phosphorus and foliar iron

The yellowness (*b**) color parameter of wheat grains was significantly influenced by the interaction effects of phosphorus and iron fertilizers at the 1% probability level (Table 1). Figure 3 shows the mean values of the *b** color parameter of grains in the interplay among fertilization by phosphorus and foliar iron. The *b** color scale showed positive values in all cases of interaction between phosphorus and iron, indicating a yellow surface color of tested grains (Figure 3).

According to the data in Figure 3, at 0 L ha^{-1} rate of iron, the yellowness of grains increased from 27.41 to 30.08 by an increase in the rate of phosphorus from 0 to 150 kg ha^{-1} and then decreased with a further increase in the rate of phosphorus from 150 to 225 kg ha^{-1}. At another rate of 1.2 and 2 L ha^{-1} of iron, the yellowness (*b**) increased from 27.66 to 30.29 and from 28.62 to 30.02 respectively, by increasing the rate of phosphorus from 0 to 75 kg ha^{-1}, but by a major increase in the rate of phosphorus from 75 to 150 and from 150 to 225 kg ha^{-1}, caused decreasing trends in the surface yellowness of grains.

Also from the data in Figure 3 it can be seen that the surface yellowing of grains changed by variation of the application rate of foliar iron at all the rates of phosphorus, but these changes are not the same at different levels of phosphorus. At 0 and 75 kg ha^{-1} rates of phosphorus, the *b** scale of grains increased from 27.41 to 28.62 and from 29.05 to 30.02, respectively, by increasing the iron rate from 0 to 2 L ha^{-1}. At concentrations of 150 and 225 kg ha^{-1} of phosphorus, the yellowness of tested grains decreased from 30.08 to 27.54 and from 29.39 to 28.67, respectively, by increasing the iron rate from 0 to 2 L ha^{-1}. The *b** amounts in Figure 3 ranged from 27.41 to 30.29. The highest yellow saturation (30.29) was for the interaction of 75 kg ha^{-1} of phosphorus and 1.2 L ha^{-1} of iron and the lowest *b** was obtained in the 0 kg ha^{-1} of phosphorus and 0 L ha^{-1} of iron rates interactions.

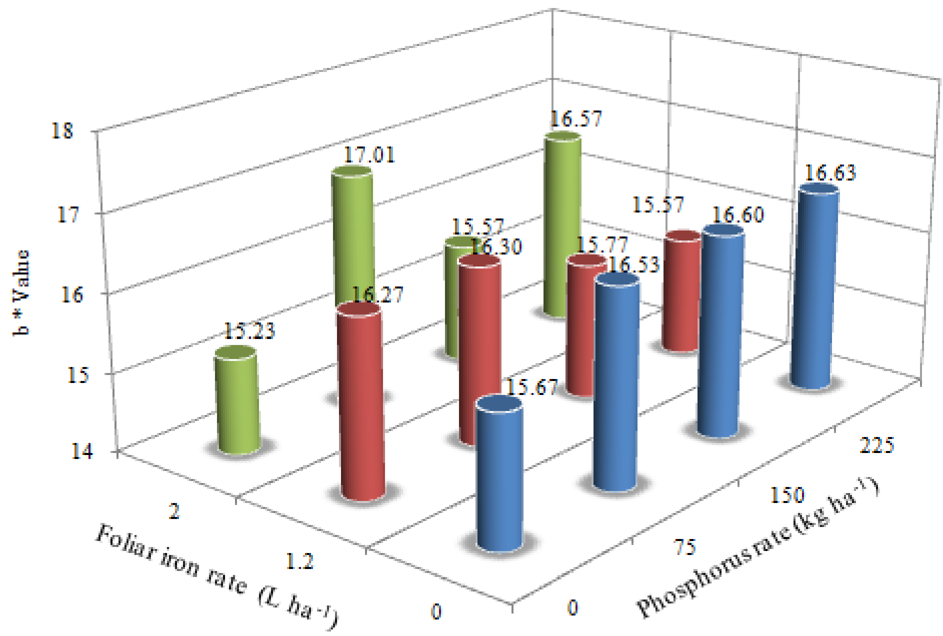

Figure 3 The mean values of *b** (yellowness) surface color parameter of the wheat grains surface in the interaction between the fertilization of phosphorus and foliar iron

3.4 Relationship between measurements

The Pearson correlation coefficients between the color parameters of the wheat grains at different rates of foliar iron and phosphorus are shown in Table 3. From the data in Table 3, it is immediately clear that the red parameter of the wheat grain level (*a**) had no significant relationship with other parameters ($p < 0.05$). The wheat grains surface lightness (*L**) and yellowness (*b**) were observed significantly ($p < 0.01$) and positive correlation ($R = 0.484$). The change in total color (ΔE) was high ($R = 0.85$) significantly ($p < 0.01$) and had a positive correlation with lightness (*L**). However, a positive and significant ($p < 0.05$) low correlation ($R = 0.0354$) was observed between total color change (ΔE) and yellowness (*b**).

Table 3 Pearson correlation coefficients between measured surface color parameters of wheat grains

	Correlation coefficients		
	*L**	*a**	*b**
*L**	-		
*a**	0.104	-	
*b**	0.484**	0.031	-
ΔE	0.850**	-0.103	0.354*

*-Correlation is significant at the 0.05 level, **-Correlation is significant at the 0.01 level.

4 Conclusions

The results of this study indicated that the fertilization of wheat crops by phosphorus and iron at different rates has a considerable effect on the surface color parameters of grains. The effect of phosphorus on changing the surface color parameters of grains was higher than that of iron fertilizer. The key results are noticeable: the use of phosphorus fertilizer increases the level of the lightness, yellowness, and the total grain color change comparing to control samples. The mean values of lightness, yellowness, and total grain color change increased from 38.98 to 42.02, from 27.89 to 29.78, and from 1.34 to 3.67, respectively, as phosphorus rate changed from 0 to 75 kg ha^{-1}. However, with the increase in the phosphorus rate to 150 and 225 kg ha^{-1}, no further increase was observed in the above scales. So, the best dose of phosphorus was about 75 kg ha^{-1}. Phosphorus fertilization did not cause significant changes in wheat grains' redness. The use of iron fertilizers significantly increased the amounts of lightness and total grain color change but did not cause significant changes in the amount of yellowing. Average surface lightness values and total color change as quadratic relationships increased from 40.01 to 41.16 and from 1.56 to 3.33, respectively, with changes in iron levels from 0 to 2 L ha^{-1}. It seems that the change in the surface color parameters of wheat grain, along with the content of chemical compounds in the grain, notwithstanding this battle, studies on the relationship among chemical communed and wheat grain surface color should be consecutive.

References

Afshari-Jouybari, H., and A. Farahnaky. 2011. Evaluation of Photoshop software potential for food colorimetry. *Journal of Food Engineering*, 106(2): 170-175.

Ali, E. A. 2012. Effect of iron nutrient care sprayed on foliage at different physiological growth stages on yield and quality of some durum wheat (Triticum durum L.) varieties in sandy soil. *Asian Journal of Crop Science*, 4(4): 139-149.

Carson, G. R., and N. M. Edwards. 2009. Criteria of wheat and flour quality. *Wheat: Chemistry and Technology*, 4: 97-118.

Garakishi, H. K. 2020. Evaluation of wheat varieties in response to low and moderate input farming systems. *Research on Crops*, 21(1): 26-30.

Groos, C., G. Gay, M. R. Perretant, L. Gervais, M. Bernard, F. Dedryver, and G. Charmet. 2002. Study of the relationship between pre-harvest sprouting and grain color by quantitative trait loci analysis in a white× red grain bread-wheat cross. *Theoretical and Applied Genetics*, 104(1): 39-47.

Halvin, J. L., J. D. Beaton, S. L. Tisdale, and W. L. Nelson. 2005. *Soil Fertility and Fertilizers: an Introduction to Nutrient Management*. New Jersey: Pretice Hall.

Hatcher, D. W., O. M. Lukow, and J. E. Dexter. 2006. Influence of environment on Canadian hard white spring wheat noodle quality. *Cereal Foods World*, 51(4): 184-190.

Horrobin, D. J., K. A. Landman, and L. Ryder. 2003. Interior and surface colour development during wheat grain steaming. *Journal of Food Engineering*, 57(1): 33-43.

Horváth, Z. H., and A. Véha. 2015. Colour characteristics of winter wheat grits of different grain size. *Acta Universitatis Sapientiae, Alimentaria*, 8(1): 70-77.

Humphries, J. M., R. D. Graham, and D. J. Mares. 2004. Application of reflectance colour measurement to the estimation of carotene and lutein content in wheat and triticale. *Journal of Cereal Science*, 40(2): 151-159.

Jayas, D. S., P. K. Ghosh, J. Paliwal, and C. Karunakarna. 2008. Quality evaluation of wheat. *Computer Vision Technology for Food Quality Evaluation*, 351–376.

Jiang, H., J. Martin, M. OkotKotber, and P. A. Seib. 2011. Color of whole wheat foods prepared from a bright white hard winter wheat and the phenolic acids in its coarse bran. *Journal of Food Science*, 76(6): C846-C852.

Komyshev, E. G., M. A. Genaev, and D. A. Afonnikov. 2020. Analysis of color and texture characteristics of cereals on digital images. *Vavilov Journal of Genetics and Breeding*, 24(4): 340.

Le Campion, A., F. X. Oury, E. Heumez, and B. Rolland. 2020. Conventional versus organic farming systems: dissecting comparisons to improve cereal organic breeding strategies. *Organic Agriculture*, 10(1): 63-74.

Leon, K., D. Mery, F. Pedreschi, and J. Leon. 2006. Color measurement in *L* a* b** units from RGB digital images. *Food Research International*, 39(10): 1084-1091.

Li, Y. Z., and E. S. Posner. 1989. Determination of wheat milling potential and its influence on flour quality deterioration rate. *Cereal Chem*, 66(5): 365-368.

Lukow, O. M., K. Adams, J. Suchy, R. M. DePauw, and G. Humphreys. 2013. The effect of the environment on the grain colour and quality of commercially grown Canada hard white spring wheat, Triticum aestivum L.'Snowbird'. *Canadian Journal of Plant Science*, 93(1): 1-11.

Matus-Cádiz, M. A., P. Hucl, C. E. Perron, and R. T. Tyler. 2003. Genotype × environment interaction for grain color in hard white spring wheat. *Crop Science*, 43(1): 219-226.

McCaig, T. N., Y. T. Gan, P. Clarke, J. M. Clarke, and R. M. DePauw. 2006. Kernel colour changes associated with field weathering of spring wheat. *Canadian Journal of Plant Science*, 86(2): 371-377.

Peterson, C. J., D. R. Shelton, T. J. Martin, R. G. Sears, E. Williams, and R. A. Graybosch. 2001. Grain color stability and classification of hard white wheat in the US. *Euphytica*, 119(1-2): 101-107.

Popovic, O. 2015. Protein content and gluten quality of Norwegian grown wheat influenced by fertilization. M.S. thesis, Norwegian University of Life Sciences, Ås.

Ruiz, M., E. Zambrana, R. Fite, A. Sole, J. L. Tenorio, and E. Benavente. 2019. Yield and quality performance of traditional and improved bread and durum wheat varieties under two conservation tillage systems. *Sustainability*,11(17): 1-22.

Seib, P. A., X. Liang, F. Guan, Y. T. Liang, and H. C. Yang. 2000. Comparison of Asian noodles from some hard white and hard red wheat flours. *Cereal Chemistry*, 77(6): 816-822.

Shahbazi, F. 2012. A study on the seed susceptibility of wheat (triticum aestivum L.) cultivars to impact damage**.** *Journal of Agricultural Science and Technology*, 14(3): 505-512.

Shahbazi, F., and A. Nematollahi. 2019. Influences of phosphorus and foliar iron fertilization rate on the quality parameters of whole wheat grain. *Food Science & Nutrition*, 7(2): 442-448.

Shahbazi, F., R. Sharafi, F. Biranvand, and N. Z. Tolabi. 2012. Influence of different fertilization level of zinc sulphate and plant density on the breakage susceptibility of triticale seeds. *Cercetari Agronomice in Moldova*, 45(1): .5-13.

Shahbazi, F., R. Sharafi, S. J. Moomevandi, and M. Daneshvar. 2015a. Mechanical damage to wheat seeds as affected by phosphorus and iron fertilization rate. *Quality Assurance and Safety of Crops & Foods*, 7(3): 385-391.

Shahbazi, F., R. Sharafi, S. J. Moomevandi, and M. Daneshvar. 2015b. Influence of foliar iron fertilization rate on the breakage susceptibility of wheat seeds. *Journal of Plant Nutrition*, 38(14): 2204-2216.

Taiz, L., Zeiger, E., Møller, I.M. and Murphy, A., 2015. *Plant physiology and development* 6th ed. MA, USA: Sinauer Associates, Inc.

Tanska, M., D. Rotkiewicz, W. Kozirok, and I. Konopka. 2005. Measurement of the geometrical features and surface color of rapeseeds using digital image analysis. *Food Research International*, 38(7): 741-750.

Tanska, M., J. Buczek, W. Jarecki, A. Wasilewska, and I. Konopka. 2018. Grain morphology, texture and colour-related compounds of bread wheat cultivars in relation to cultivation regimes and growing location. *Zemdirbyste-Agriculture*, 105(2): 105-112.

Uhlen, A. K., R. Hafskjold, A. H. Kalhovd, S. Sahlström, Å. Longva, and E. M. Magnus. 1998. Effects of cultivar and temperature during grain filling on wheat protein content, composition, and dough mixing properties. *Cereal Chemistry*, 75(4): 460-465.

Wu, J., B. F. Carver, and C. Goad. 1999. Kernel color variability of hard white and hard red winter wheat. *Crop science*, 39(3): 634-638.

Yousefian, M., F. Shahbazi, and K. Hamidian. 2021. Crop yield and physicochemical properties of wheat grains as affected by tillage systems. *Sustainability*, 13(9): 4781.