Effects of light stress on wheat and rye varieties grain composition

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Abstract Integrating woody perennials and agricultural crops combined is a centuries-old practice, nowadays called agroforestry. Because agroforestry is being promoted by public administrations, it is essential to obtain scientific knowledge about the effect of different factors (e.g. tree shade) on crop characteristics. In this study, the effects of light intensity variation on the nutrient composition of wheat (*Triticum aestivum* L,) and rye (*Secale cereale* (L.) M. Bieb.) grain were analyzed, focusing on the concentration of macronutrients such as N, P and Mg and micronutrients such as Zn, Mn and Fe. To evaluate nutritional quality, 17 wheat and 11 rye varieties, grouped by t their flowering time (precocity), were studied. A randomized complete block design with four replications per variety and light intensity was used to carry out this study. These varieties were grown, in pots, under greenhouse conditions, during 2016-2017. To simulate different intermediate (IS) and high shade (HS) conditions, polyurethane meshes of different hole diameter sizes 0.0075 cm^2 and 0.0026 cm^2, respectively; applied in April, were used. In both species, an increase in nutrient concentration was observed under HS conditions. Micronutrients showed the greatest sensitivity to the variation in light intensity, especially Zn and Fe in wheat and Zn and Mn in rye.

Keywords: Food safety, climate change, shade, nutrients, winter cereals, greenhouse

1. Introduction

Humans obtain nutrients from their diet, being staple grains a keystone in it. In a world with a growing human population expected in the coming decades (UN 2019), it is essential to assess and remedy factors that may lead to a reduction in agricultural yields (e.g. climate change, pests, superweeds) and truncate the necessary increase in production. In view of this prospect, agroforestry approaches are being evaluated and implemented as a climate change mitigation tool due to carbon sequestration. Furthermore, agroforestry can increase soil and crops resilience due to wind erosion reduction, soil fertility preservation and increased moisture retention. Nevertheless, since a nutritional standpoint, both nutrients (e.g. proteins) and micronutrients (e.g. Fe, Mn and Zn).

Cereals constitute one of the most important bases of human and animal food on a global scale (Koehler and Wieser, 2013). Wheat (*Triticum aestivum* L.) is the third cereal with the highest production worldwide after rice and maize. Rye (*Secale cereale* (L.) M. Bieb.) is one of the most widely produced cereals in Europe. Wheat produces flour as the main product and husk and germ as by-products (Dexter and Sarkar, 2004), as well as rye. Many authors have studied grain composition in wheat (Brewer et al., 2014; Onipe et al., 2015; Kawaguchi et al., 2017) and to a lesser extent in rye (Kowieska et al. 2011), in which they document the series of beneficial properties they have for human and animal health, as well as the main role they play in degenerative diseases. Billions of people are deficient in some micronutrients such as Zinc and Fe (Bailey et al., 2015), with well nutritional-quality cereals being one of the key factors in lessening this problem.

This experiment belongs to the set of studies that analyze the role of agroforestry as a tool for mitigation and adaptation to climate change in the framework of the National Project AFCLIMA (Agroforestry Systems for Cereal Production as a Strategy for Adaptation and Mitigation of Climate Change in the Iberian Peninsula). The objective of this study is to analyze the variation of grain nutrient concentration (N, P, Fe, Mg, Mn, P and Zn) in wheat and rye varieties grouped by precocity (early, medium, late flowering time); subjected to different light levels in a greenhouse, to select the most suitable for field application.

2. Material and Methods

The present study was carried out in the area that the Department of Plant Production and Project Management of the University of Santiago de Compostela (Campus Lugo), has designated inside the greenhouse (29T 42- 59.607'N, 7-32.799'W), in the winter cycle-spring 2016-2017. There were 17 wheat and 11 rye varieties sowed in pots (15x15x30 cm), to analyze the effect of light intensity variation on the concentration of N, Mn, Fe, Mg, Zn in wheat grain and on the N, P, Fe, Mn and Zn, in rye grain. The different varieties of each species were selected for their characteristics such as recommended sowing time, resistance to diseases, yield and plant size, seed quality, but above all considering the type of cycle of the different varieties of the species used, since their precocity (flowering time) was the main factor to consider when comparing the results between the different varieties of each species. To carry out this study, a complete block design with four replications per variety and light variation (no shade, NS; shade (S): intermediate shade, IS; high shade, HS) was used. Thereafter, in March 2017, mulch fertilization was performed on all wheat and rye pots, using 10 cm^3 of NPK 10-5-5 in each. Once both rye and wheat were properly developed reaching the spiking stage, around May 2017, each block of pots was subjected to the corresponding treatment. To simulate light variation, two different hole diameter screens were applied in April, which simulated intermediate shade intensity (IS) and high shade intensity (HS) conditions. The crop was monitored until harvest in July. Once the crop reached the phenological maturity stage and the grain was mature and dry, the crop was harvested by weighing all replicates of each variant and treatment green and weighing them again after drying in an oven at 40°C for 15 days. Nutrient concentration was measured in the laboratory. N and P were measured by Microkjeldahl digestion using the AA3 AUTOANALYZER or method G-189-97 (multitest) from Seal Analytical (2011). Measurement of the remaining macro- and micronutrients was performed by Microkjeldahl digestion using SPECTRAA-220FS.

An ANOVA was carried out for statistical analysis using IMB SPSS version 23 (2014) for Windows. Duncan's significant difference ($p<0.05$) was calculated if the ANOVA was significant.

3. Results

Variation in light intensity was one of the factors affecting nutrient concentration in both species, as shown in Table 1. Variety cycle was another factor influencing grain N concentration ($p<0.001$). No significant effects were observed for the interaction precocity* of light intensity in both species ($p>0.05$). In wheat, micronutrients such as Fe and Zn showed the greatest variation in grain concentration in all varieties. A greater increase in the concentration of these trace elements was observed under HS conditions, as showed Figure 1.

Early rye varieties were the only varieties that showed significant variation in macronutrient (N and P) concentration under HS conditions. However, the variation in micronutrients under different light intensity conditions was different depending on the variety and type of nutrient evaluated. An increase in Fe was observed in intermediate varieties under shade (IS and HS) conditions. Zn concentration was higher under HS conditions in late varieties and under shade conditions in early varieties, with no differences observed between light intensities ($p<0.05$) in medium varieties. Unlike what was observed for Mn. Magnesium concentration was observed to vary significantly (Figure 1) under shade conditions in varieties with shorter-medium cycles.

Table 1. Effect of precocity and light intensity on the concentration of nutrients

	Wheat		**Rye**	
Factors	Nutrients	Sig.	Nutrients	Sig.
Precocity	%N	**	%N	ns
	%Mg	ns	%P	ns
	%Fe	ns	%Fe	ns
	mg kg^{-1}Mn	ns	mg kg^{-1}Mn	ns
	mg kg^{-1}Zn	ns	mg kg^{-1}Zn	ns
Light intensity	%N	*	%N	*
	%Mg	*	%P	**
	%Fe	***	%Fe	*
	mg kg^{-1}Mn	***	mg kg^{-1}Mn	**
	mg kg^{-1}Zn	***	mg kg^{-1}Zn	**
Precocity * Light intensity	%N	ns	%N	ns
	%Mg	ns	%P	ns
	%Fe	ns	%Fe	ns
	mg kg^{-1}Mn	ns	mg kg^{-1}Mn	ns
	mg kg^{-1}Zn	ns	mg kg^{-1}Zn	ns

*Ns= not significant, * ($p<0.05$), ** ($p<0.01$), ***($p<0.001$)*

4. Discussion

Cereals are part of the set of staple foods in the food chain on a global scale. They are a rich source of carbohydrates, fibber, protein, B vitamins and other nutrients such as Fe, Ca, P, Zn, K and Mg (Shewry, 2009). Its production and quality are being threatened by the effects of climate change (Stocker et al., 2014) and by extensive agriculture whose ecological footprint is greater than the carrying capacity of the area in which it is developed, with the strong impact on the decrease and difficult availability of mineral resources for the correct use and development of the plant, posing a great threat to food security worldwide (Vermeulen et al., 2012). The present study is included within the framework of increasing resilience and adaptation to climate change and food security, through the study of the variation of wheat and rye quality under shade conditions, simulating the shade cast under the tree canopy by agroforestry systems.

In both species, the choice of varieties related to precocity would have reduced influence in nutritional composition. Nevertheless, light intensity has influenced on variation of concentration in N, Mg, Fe, Mn and Zn in wheat grain as the same as concentration in N, P, Mn, Zn. This result is similar to those found in the study conducted by Iwane and Bessho (2006), who investigated the variation in light intensity on the mineral content of apples. They observed a higher concentration in varieties grown under shade than those grown under full radiation conditions.

The increase in nutrient concentration in grain under shade conditions can be justified on the basis that these two crops are two monocarpic species, in which senescent resources are mobilized to the grain. Distelfeld et al. (2014), showed that the success of nutrient remobilization is related to senescence time. Some studies indicate that early nutrient remobilization is associated with higher grain protein concentration, but also with higher micronutrients such as Zn and Fe (Heidlebaugh et al., 2008; Waters et al., 2009).

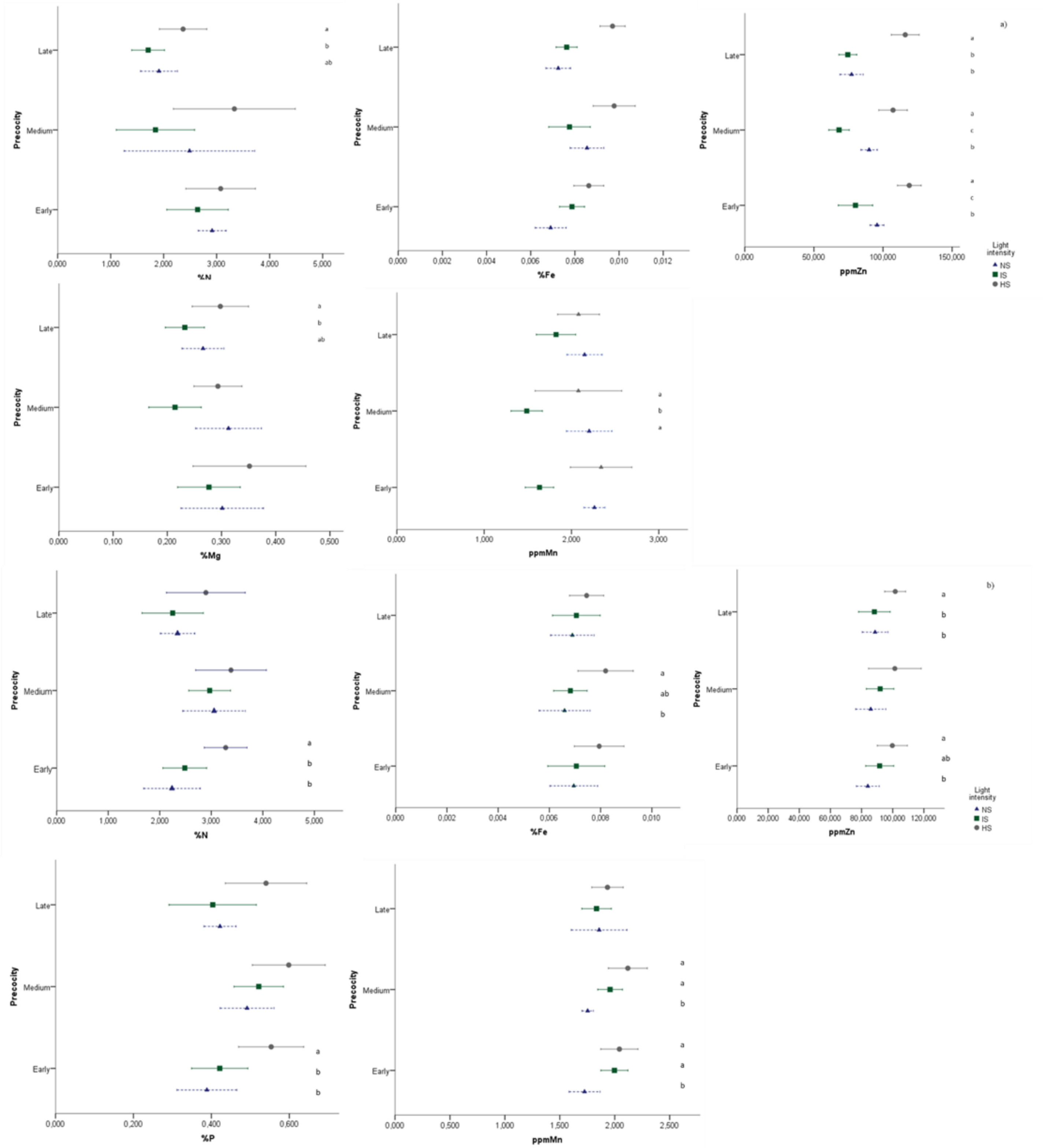

Figure 1 Variation on concentration nutrients of wheat and rye varieties, sown in December, under different degrees of light intensity (NS= no shade; IS= intermediate shade; HS= high shade), applied in April. Significant differences were found between varieties under HS conditions in all nutrient concentration. Different letters indicate differences between in the same varieties under different light condition, with the letter a assigned to high values (p<0.05). The lack of letters indicates that no significant differences were found between treatments for the same variety.

5. Conclusion

Environmental factors, such as temperature, soil nutrient concentration, crop management practices, light intensity and other factors, such as precocity, will determine grain quality. In the present study, only two factors were studied, light and precocity, to consider the influence that light can have on the development of the most critical ontogenetic stages of the crop, and thus analyze what type of varieties are and which, according to yield and quality, are the most suitable to recommend for field cultivation.

Zn and Fe were more sensitive to light variations was observed in all wheat varieties, with an increase in concentration under HS conditions. On the other hand, early and late varieties showed a higher concentration of Zn under HS conditions, as well as of Mn in the earliest varieties of rye, among these nutrients were Zn and Fe, whose deficiency in food is associated with serious health problems in both animals and humans. However, it would be interesting to establish this study under controlled field conditions, and to analyze the concentration as a function of the interaction with other biotic and abiotic factors, and management practices throughout crop development. Conduct a study of nutrient compartmentalization between the different structures of the grain (husk, endosperm and germ) as well as the percentage of assimilation by animals and humans.

6. Acknowledgments

This experiment was partly funded by the European Union (Agforward, FP7-KBBE-2013-7-single-stage; No. 613520) and the Spanish Ministry of Science and Innovation (CTM2016-80176-C2-2-R).

Vanessa Álvarez-López is grateful for the postdoctoral "Juan de la Cierva-formación" fellowship (FJCI-2017-32852) financed by the Spanish Ministry of Science and Innovation.

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