EFFECT OF FOLIAR ZINC APPLICATION ON SPRING WHEAT GRAIN YIELD AND QUALITY

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ABSTRACT

Zinc (Zn) deficiency represents a common micronutrient deficiency in human populations, especially in regions of the world where staple food crops are the main source of daily calorie intake. Micronutrients like Zn also plays an important role in growth and development of plant thereby affecting crop yield and quality. A two-year field trial was conducted at Sidney, Montana, to investigate the effect of foliar application of Zn on yield and grain quality of spring wheat. Zinc treatment included foliar application of Zinc Sulfate at a rate of 1.12 kg ha^{-1} 1) at heading (Feekes 10.1) and 2) at both heading and flowering (Feekes 10.5) stages compared to control (nill Zn application). Cultivars responded differently to Zn fertilization but grain Zn concentration as well as grain yield increased in overall with Zn treatments. First application of Zn only increased grain Zn concentration marginally and, for most of the tested cultivars, the second application at flowering was required to bring grain Zn concentration above the health limit. Zinc fertilization also increased chlorophyll and carotenoid contents in wheat crops. Our results showed that Zn foliar application can be used as an efficient biofortification tool to increase nutritional quality of Montana wheat.

INTRODUCTION

Considering the area cultivated (232 million ha) and amount of grain produced (595 million t) (Sultana, et. al., 2016), wheat (*Triticum spp*.) is the third most-produced cereal after corn and rice (Kandoliya, et. al., 2018). The amount of Zn in wheat grain must meet a standard for human health in many countries, and nutritionists suggested that 40 mg Zn kg^{-1} is required in grain wheat (Ram, et. al., 2016). Management strategies targeting grain Zn densities are urgently needed to fight Zn deficiency in human populations. Approximately two billion of world population is affected by Zn deficiency (Zn D) due to low dietary intake of Zn (Chen, et. al., 2017). Zinc is a crucial element in regard to plant growth, as a functional, structural, or regulatory cofactor of many enzymes (Ma, et. al., 2017). However, information is lacking if there is Zn D in Montana produced wheat and if late-season foliar application of Zn will improve spring wheat yield and Zn concentration. It is, however, important to notice that genotypes may respond differently to foliar Zn application in terms of absorption and translocation at the reproductive stage (Mabesa, et. al., 2013). The timing of Zn fertilization is also critical when looking to improve Zn concentration in wheat grains (Zou, et. al., 2012). More information is needed on behavior of wheat genotypes in respect to Zn absorption and distribution in plants, which will contribute to improvement of the agronomic and genetic biofortification strategies.

The objective of this study was to assess the effects of foliar Zn application on the uptake, translocation and accumulation of Zn in five cultivars of spring wheat with different timing and rates of foliar application of Zn.

MATERIALS AND METHODS

A 2-yr field trial (2017 and 2018) was carried out at the Eastern Agricultural Research Center at Sidney, MT. Five cultivars of spring wheat (Velva, Faller, Prosper, Glenn, Eagan) were used in this study. Zinc treatment included 1) foliar application of Zn sulfate ($ZnSO4$ containing 35.5% Zn), at a rate of 1.12 kg ha^{-1} at heading stage (Feekes 10.1), 2) foliar application of 1.12 kg ha^{-1} at both heading and flowering stages (Feekes 10.5), and 3) control (nill Zn application).

The experiment was set up in a factorial arrangement within randomized complete block design with four replications. Wheat was planted on April 21st. The measurements in season included: photosynthesis pigments (chlorophyll and carotene) at four times (June 23, July 03, July 11, and July 14). After harvesting plants on August 15th, plant parts were separated into straw and grain. The measurements included total biomass, grain yield, grain protein, grain and straw Zn concentration.

Zinc use efficiency (ZUE) (Fageria and Baligar, 2001) and Zn translocate ratio (ZTR) (Impa et. al., 2013) was calculated to reflect varietal difference among tested cultivars in term of efficient use of applied Zn as follows:

$$ZUE = \frac{\text{Zn concentration in grain}}{\text{Total Zn applied}}$$

$$ZTR = \frac{\text{Zn content in grain}}{\text{Zn content in whole plant}}$$

Data Analysis:

Data were analyzed using analysis of variance (ANOVA) in SAS. Mean were separated using the Tukey test at 95% confidence level ($P < 0.05$).

RESULTS AND DISCUSSION

Grain yield and protein

Zinc foliar application affected wheat grain yield significantly (Table 1). Zinc application at heading stage (Zn1) increased grain yield by 10.7 % and the second application at flowering stage (Zn2) further increased yield by 19.7 % compared to untreated control (average over all cultivars). Similar results have been reported by others indicating that foliar application Zn can improve cereal yield (Cakmak and Kutman, 2018). Foliar application Zn also enhanced grain protein concentration from 156 g kg^{-1} (in control) to 158 and 161 g kg^{-1} in Zn1 and Zn2 treatments, respectively (Table 1). This enhancement in grain protein can be attributed to the role of microelements in maintaining balanced plant physiological growth and activation of plant enzymes. In fact, micronutrients have been reported to affect the physiological processes of plants, which has a significant impact on grain yield and quality (Niyigaba, et. al., 2019).

Table 1. Effect of Zn foliar application on grain yield, protein content, grain and straw Zn concentration of five spring wheat varieties in field trial.

Spring wheat	**Grain yield (kg ha^{-1})**	**Protein (g kg^{-1})**	**Grain Zn (mg kg^{-1})**	**Straw Zn (mg kg^{-1})**
Ctrl	2057c	156b	29.9c	5.0c
Zn1	2277b	158ab	37.6b	13.9b
Zn2	2462a	161a	48.3a	38.2a
Level of significance	**	*	**	**
Velva	2687a	155c	35.4c	19.4b
Faller	2353b	153c	39.6ab	21.0ab
Prosper	2295c	153c	38.1b	19.3b
Glenn	2203c	159b	40.3a	13.9c
Egan	1928d	172a	41.6a	23.9a
Level of significance	**	**	**	*
Zn*V	ns	ns	*	*

*Significant at $P \leq 0.05$; **Significant at $P \leq 0.01$; ns: non-significant

Zn concentration in grain and straw

Grain and straw Zn concentrations were influenced by foliar Zn application (Fig. 1 a, b). Cultivars, however, responded differently to Zn application in terms of grain Zn concentration. Velva was the least responsive cultivar to Zn application at heading. The second application of Zn significantly boosted grain Zn concentration in all cultivars. Average over all cultivars, grain Zn concentration raised from 29.9 mg kg^{-1} (in control) to 37.6 mg kg^{-1} in response to one time foliar application at heading, and to 48.3 mg kg^{-1} in response to the second application of Zn at flowering (Fig. 1 a, b). A successful biofortification treatment should bring up grain Zn concentration to about 40–45 mg kg^{-1} (Cakmak, 2008). In our study, this level was achieved by the second application of Zn at flowering stage. While enhancement of grain Zn concentration was slight in response to the foliar application of N, a notable increase in straw Zn concentration was observed in response to Zn application specifically in Zn2 treatment. As shown in Fig. 2, some cultivars have a greater capacity to translocate absorbed Zn into the grain (with greater ZTR values) so have greater potential for biofortification of Zn.

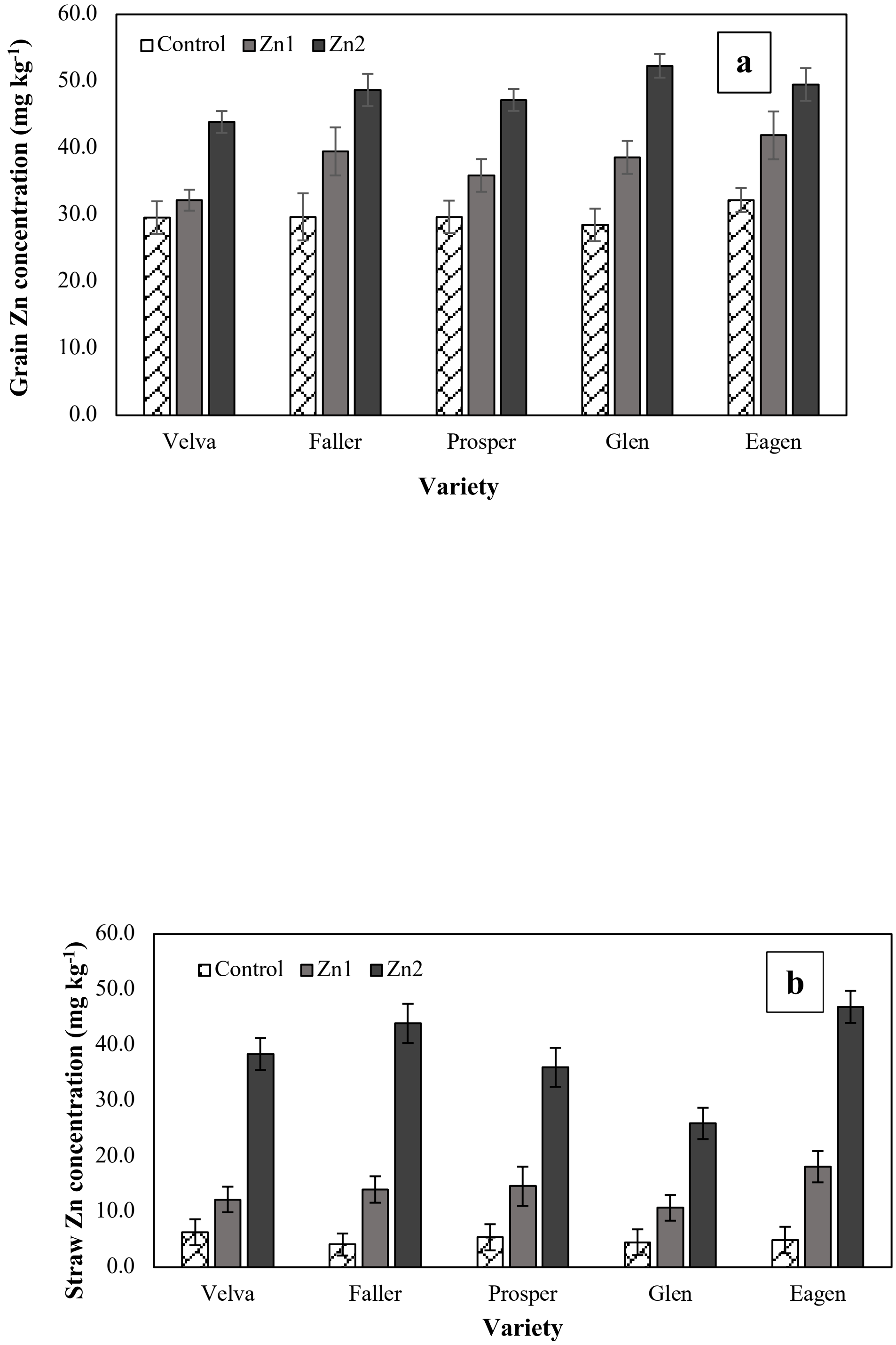

Figure 1. Effect of Zn application on spring wheat grain (a) and straw (b) in field trial

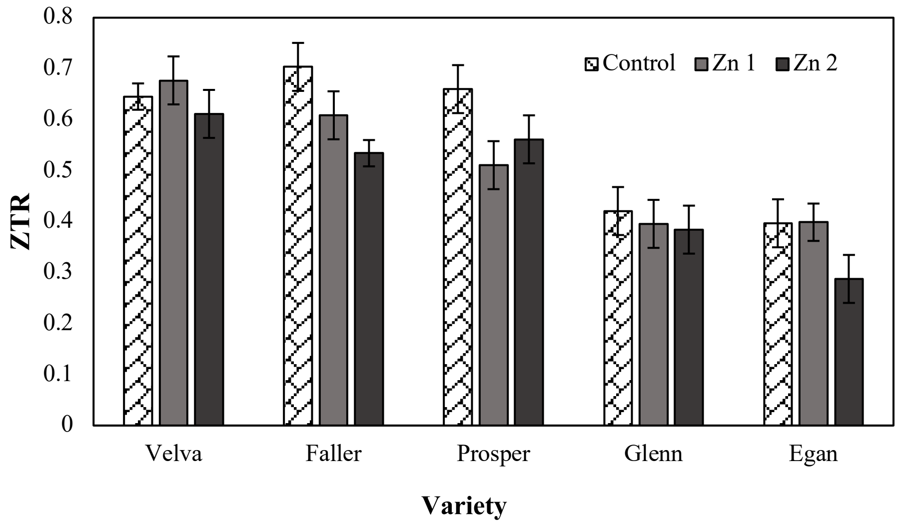

Figure 2. Zinc translocation ratio on spring wheat grain in field trial

Leaf pigments

In this experiment, Zn foliar application affected the chlorophyll content in wheat leaves (Table 2). At all growth stages, leaves of plant treated with Zn showed greater concentrations of total chlorophyll content compared to untreated control. Carotenoid content also showed a similar response to Zn application (Table 3). It has been hypothesized that chlorophyll synthesis is improved by Zn application, because Zn acts as a structural and catalytic component of proteins, enzymes, and as co-factor for normal development of pigment biosynthesis (Ma, et. al., 2017). This indicates that sufficient Zn can prolong the period of flag leaf active photosynthesis, which is the most important for grain filling. This could explain, in part, the grain yield increased in response to Zn application.

Table 2. Effect of Zn foliar application on chlorophyll content (mg/g) on June 23, July 03, 11, and 14 in two spring wheat varieties (Velva, Glenn).

	June 23		**July 03**		**July 11**		**July 14**
	Flag	**Second**	**Flag**	**Second**	**Flag**	**Second**	**Flag**
Ctrl	11.8b	7.0a	3.9b	1.6a	2.6a	0.7a	0.5b
Zn1	14.9a	7.6a	4.5b	1.8a	3.0a	1.2a	1.2a
Zn2	-	-	5.6a	2.1a	3.1a	1.3a	1.3a
Level of significance	**	ns	*	ns	ns	ns	*
Velva	13.7ab	5.8b	4.9a	1.8a	2.6ab	1.5a	1.1a
Glenn	11.6c	6.4b	4.4a	1.9a	2.0b	0.6b	1.2a
Level of significance	*	ns	ns	ns	*	*	ns
Zn*Variety	*	ns	ns	ns	ns	ns	*

*Significant at $P \leq 0.05$; **Significant at $P \leq 0.01$; ns: non-significant

Table 3. Effect of Zn foliar application on Carotene (µg/g) on June 23, July 03, 11, and 14, in two spring wheat varieties (Velva, Glenn).

	June 23		July 03		July 11		July 14
	Flag	**Second**	**Flag**	**Second**	**Flag**	**Second**	**Flag**
Ctrl	2.1b	1.3b	0.8a	0.2a	0.5b	0.2a	0.2a
Zn1	2.8a	1.4a	0.8a	0.3a	0.5b	0.2a	0.3a
Zn2			0.9a	0.3a	0.7a	0.3a	0.4a
Level of significance	**	*	ns	ns	*	ns	*
Velva	2.3ab	1.0b	1.0a	0.4a	0.5a	0.2a	0.2ab
Glenn	2.1b	1.2b	0.7a	0.2a	0.6a	0.2a	0.1b
Level of significance	*	ns	ns	ns	ns	ns	*
Zn*Variety	*	ns	ns	ns	ns	ns	*

*Significant at $P \leq 0.05$; **Significant at $P \leq 0.01$; ns: non-significant

CONCLUSION

Foliar application of Zn increased grain yield, grain protein, and grain Zn concentration. In four out of five tested cultivars, one single application of Zn at heading was not sufficient to boost grain Zn concentration and a second application at flowering stage was required to significantly enhance grain Zn concentration. Majority of Zn applied remained in wheat leaves and stems, and was not translocated to the grain at grain filling stage. Cultivars represented various abilities and efficiencies for Zn translocation. Our results showed that ZTR could be used as an effective measure to select those with greater potential for biofortification Zn. Therefore, this index can be integrated into a breeding program for improving cultivars more suitable for biofortification and production healthier grain with a higher Zn concentration.

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