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Biofortification via foliar application of zinc in oat grains and the effects on nutritional quality and productivity indicators

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Abstract

Foods enriched with zinc can reduce the rates of many diseases and health expenses. Oat, as a nutraceutical food, represents a potential nutritional source by increasing the levels of zinc in the grains by biofortification. The objective of the study is zinc enrichment in oat grains and caryopses, with analysis of productivity indicators, industrial and chemical quality of the grains for technology validation. The experiment was carried out in 2017, 2018 and 2019, in Augusto Pestana, RS, Brazil. The experimental design was randomized blocks with eight replications and five levels of zinc doses (0, 500, 1000, 2000 and 4000 g ha^{-1}) applied via foliar in the grain filling phase. There are almost no changes in oat panicle components due to the effect of biofortification doses by the compound with zinc, and no change in grain yield regardless of agricultural year. Indicators of industrial quality and organic composition of oat grains are not effectively affected by biofortification, ensuring the use of technology without compromising these variables. Considering caryopsis the edible product of oats, from 2000 g ha^{-1} of zinc sulfate, biofortification of the product is guarantee. Biofortification via foliar by the compound with zinc promotes a significant increase of zinc in oat grains and caryopsis, however, reducing the iron content in these structures.

Keywords: *Avena sativa* L., leaf biofortification, biometric models, regression.
Abbreviations: GY_grain yield; PL_panicle length; NSP_number of spikelets per panicle; NGP_ number of grains per panicle; PM_panicle mass; PGM_panicle grain mass; PHI_panicle harvest index; MTG_mass of a thousand grains; MH_mass of hectoliter; NG>2mm_number of grains larger than two millimeters; MG_mass of grains; CM_caryopsis mass; HI_husking index; IP_industrial productivity; CP_crude protein; CF_crude fiber; ST_starch; FND_fiber in neutral detergent; AS_ash; EN_energy; NIRS_Near Infrared Reflectance Spectrometer; UY_unfavorable year; IY_intermediate year.

Introduction

The lack of zinc and iron is a deficiency that severely affects a third of the world's population (Okwuonu et al., 2021; Sharma et al., 2020). Zinc deficiency can cause the onset of numerous diseases such as growth retardation, delay in healing, immune dysfunctions, skin, hair and nail problems (Pal et al., 2019; Melash and Mengistu, 2020). The lack of iron reduces the body's defenses and can cause fatigue, lack of attention, malnutrition and anemia (Connorton and Balk 2019; Majumder et al., 2019). Measures capable of increasing the content of this element in agricultural products are necessary to reduce the lack of zinc and iron. Among these measures is the use of agronomic biofortification, a management technique, with relatively affordable cost, which aims to increase minerals and vitamins in food, a sustainable way to provide the population with access to more nutritious and healthy foods (Prasad and Shivay, 2020; Grujcic et al., 2021).

The recovery of zinc extracted from the soil by the vast majority of plants is generally very low, which creates the need to enrich these elements in agricultural species that are more easily available to the population. In this scenario, agronomic biofortification is a method that helps to promote the accumulation of nutrients and important compounds in plants, based on agronomic practices, thinking about the enrichment of edible structures (Ramzan et al., 2020; Zhang et al., 2022). Although genetic biofortification is also possible, the increase in nutrients by crossing and selection poses difficulties with the possible inverse relationship between productivity and mineral concentration, apart from the time to reach this concentration in the cultivars to be made available for cultivation and its interaction with the availability of these nutrients in the soil (Kumar et al., 2019; Krishna, Maharajan & Ceasar, 2023).

Oats have received great attention from doctors, nutritionists and consumers due to their nutritional characteristics. It is noteworthy the ability to reduce LDL cholesterol by soluble fiber and good intestinal functioning by insoluble fiber (Soycan et al., 2019; Scremin et al., 2017). The technology of biofortification by zinc in a food of high biological value such as oats can leverage nutritional quality bringing great benefits to human health. Understanding the dynamics of action of biofortification via foliar zinc by oats and the reflexes on indicators of productivity and chemical quality of the grains is decisive for the validation and use of the technology in the production field. Thus, the objective of the study is zinc enrichment in oat grains and caryopses, with analysis of productivity indicators, industrial and chemical quality of the grains for technology validation.

Results and Discussion

Classification of agricultural year

The year 2017 was marked by the combination of high temperatures and reduced precipitation, with low soil moisture content throughout the crop development cycle. This condition makes it difficult for the plant to absorb nitrogen, with reduced vegetative growth and low tiller production. The total rainfall recorded in the period was lower than the historical average obtained in the last 25 years (Table 1) and its distribution was irregular throughout the cycle (Figure 1-A), with emphasis on the occurrence of volume greater than 80 mm at the end of the cultivation cycle. This condition was decisive in reducing productivity, with values below 1500 kg ha^{-1} of grains (Table 1), characterizing the year 2017 as unfavorable for cultivation (UY). In 2018, during nitrogen application, the average air temperature was around 10 °C and the soil had favorable conditions of humidity, due to the accumulation of rainfall from previous days (Figure 1-B). The total rainfall recorded was lower than the historical average of the last 25 years (Table 1), with adequate distribution throughout the cycle (Figure 1-B), a decisive condition to characterize the year 2018 as intermediate to cultivation (IY), with values close to 2500 kg ha^{-1} of grains (Table 1). In 2019 (Table 1), the first days of the cycle were marked by high maximum temperatures and low rainfall throughout the crop cycle. The time of nitrogen application was marked by reduced rainfall and with an average temperature close to 15°C. Total precipitation in this period was lower than the historical average of the last 25 years (Table 1). At the end of the cycle, the rains were well distributed, at which point the grain yield was already defined, however, with the grain quality still being influenced (Figure 1-C). The grain yield recorded this year was approximately 2000 kg ha^{-1} of grains (Table 1) characterizing the year 2019 as the intermediate to cultivation (IY).

Of the meteorological factors, rainfall, radiation and air temperature act directly on grain yield and quality (Coelho et al., 2018; Kraisig et al., 2020). Knowledge of meteorological trends can indicate ways of management that ensure the success of the activity (Scremin et al., 2017; Reginatto et al., 2021). Temperature acts as a catalyst for biological processes, which is why plants require a minimum and maximum temperature for normal physiological activities (Tonin et al., 2014; Marolli et al., 2017). In cereals such as oats and wheat, the milder temperatures and quality of radiation favor tillering and grain filling, with direct effects on productivity (Djanaguiraman et al., 2018; Trautmann et al., 2020). In nitrogen management, the occurrence of high volume and/or intensity of rainfall, soon after fertilization, reduces plant efficiency due to lack of oxygen and generates nutrient loss by leaching (Scremin et al., 2017; Kaur et al., 2019). The same authors also report that high temperatures reduce fertilization efficiency due to volatilization losses. It is noteworthy that rainfall volumes on the mature crop reduce the hectoliter mass and, consequently, affect the quality of grains, giving it a dark color, an undesirable condition for the manufacture of flakes or flour (Mantai et al., 2021). Thus, in oat, rainfall without large volumes, however, which favors adequate soil moisture and well distributed throughout the crop cycle with low temperatures from germination to the grain filling phase and high daytime temperatures during the maturation period, characterize a favorable environment for greater expression of grain yield and quality (Marolli et al., 2018; Silva et al., 2020).

Analysis of productivity averages, industrial and chemical quality of grains

In Table 2, from the analysis of averages in the years 2017 and 2019, the doses of biofortification by the compound with zinc showed no differences in productivity indicators. Although the relative contribution analysis in 2017 shows a trend of change on the panicle grain mass and panicle harvest index, no linear relationship of the compound dose on the expression of these characters was detected. This same behavior was also observed in 2019, with the panicle length, number of grains and panicle mass and panicle grain mass, with more expressive values of alteration by the doses of the compound with zinc, however, without effectiveness of differentiation of the means and of linear relation.

In 2018, differences were obtained by the doses of the compound with zinc on the number of grains and panicle mass and panicle grain mass, with the analysis of means differentiating the standard dose with that of 4000 g ha^{-1}, showing an increase in the higher dose. The variables with the greatest contribution of change by the effect of biofortification doses were the number of panicle grains, panicle mass and panicle grain mass. Even the doses of the compound with zinc showed a significant positive correlation with panicle mass and panicle grain mass, however, these differences were not enough to change the final grain yield, confirming the low effectiveness of these changes.

In Table 3, of the industrial quality indicators, there is a trend of contribution of the dose of the compound on the mass of one thousand grains, number of grains larger than two millimeters and mass of caryopsis in 2017, mass of one thousand grains, mass of caryopsis and industrial productivity in 2018, and grain mass and caryopsis mass in 2019. However, the average test showed no change, confirming the absence of a relationship between the dose of the compound and these variables, regardless of the conditions of the agricultural year.

In Table 4, on the organic compounds content in oat grains, differences in the doses of zinc biofortification did not change in 2017, however, with a significant and positive linear relationship with total fiber and neutral detergent fiber and negative with the starch content. By the analysis of relative contribution, more effective results of alteration of the doses of biofortification on starch and neutral detergent fiber are verified. In 2018, neutral detergent fiber was also changed by the compound with zinc, a trend of increasing expression with increasing doses. There was also a significant positive correlation of the doses of the compound with total fiber and neutral detergent fiber and a negative correlation with grain starch, similar to that found in 2017. The greatest relative contribution is observed in the variables total fiber and neutral detergent fiber. In 2019, no differences were detected between the biofortification doses in all variables of the organic composition, however, an inverse relationship was detected between the dose of the compound with starch and a positive relationship with neutral detergent fiber.

Table 1. Average values of temperature and precipitation in the months of cultivation and average productivity of oat grains in the soybean/oat succession system.

Month	Temperature (°C)			Precipitation (mm)		GY_{XS}	Class
	Minimum	Maximum	Average	25 years*	Occurred	(kg ha^{-1})	
2017							
June	6.90	27.85	17.38	134.80	1.75	1338 c	UY
July	-4.20	30.14	12.97	128.10	10.75		
August	0.26	31.56	15.91	111.80	117.75		
September	12.58	33.78	23.18	155.80	161.50		
October	6.17	34.32	20.24	241.50	214.00		
Total	-	-	-	772.00	506.00		
2018							
June	-1.60	28.71	13.56	133.80	90.25	2462 a	IY
July	2.40	28.97	15.68	123.50	79.50		
August	-1.59	33.40	15.92	115.60	99.75		
September	5.36	32.12	18.74	160.30	183.75		
October	9.25	32.22	20.73	240.70	0.00		
Total	-	-	-	773.90	453.00		
2019							
June	0.80	29.30	15.05	130.70	53.40	2020 b	IY
July	-4.20	26.80	11.30	120.10	90.00		
August	-1.30	32.70	15.70	114.90	68.75		
September	1.70	33.50	17.60	157.50	99.40		
October	12.10	36.10	24.10	240.60	67.00		
Total	-	-	-	763.80	379.00		

GY_{XS} - Average grain yield of the soybean/oat system; *- Average rainfall obtained from May to October from 1989 to 2019; Averages followed by the same letter in the column do not differ at 0.05 probability of error by Scott & Knott test; IY - Intermediate year; UY - Unfavorable year.

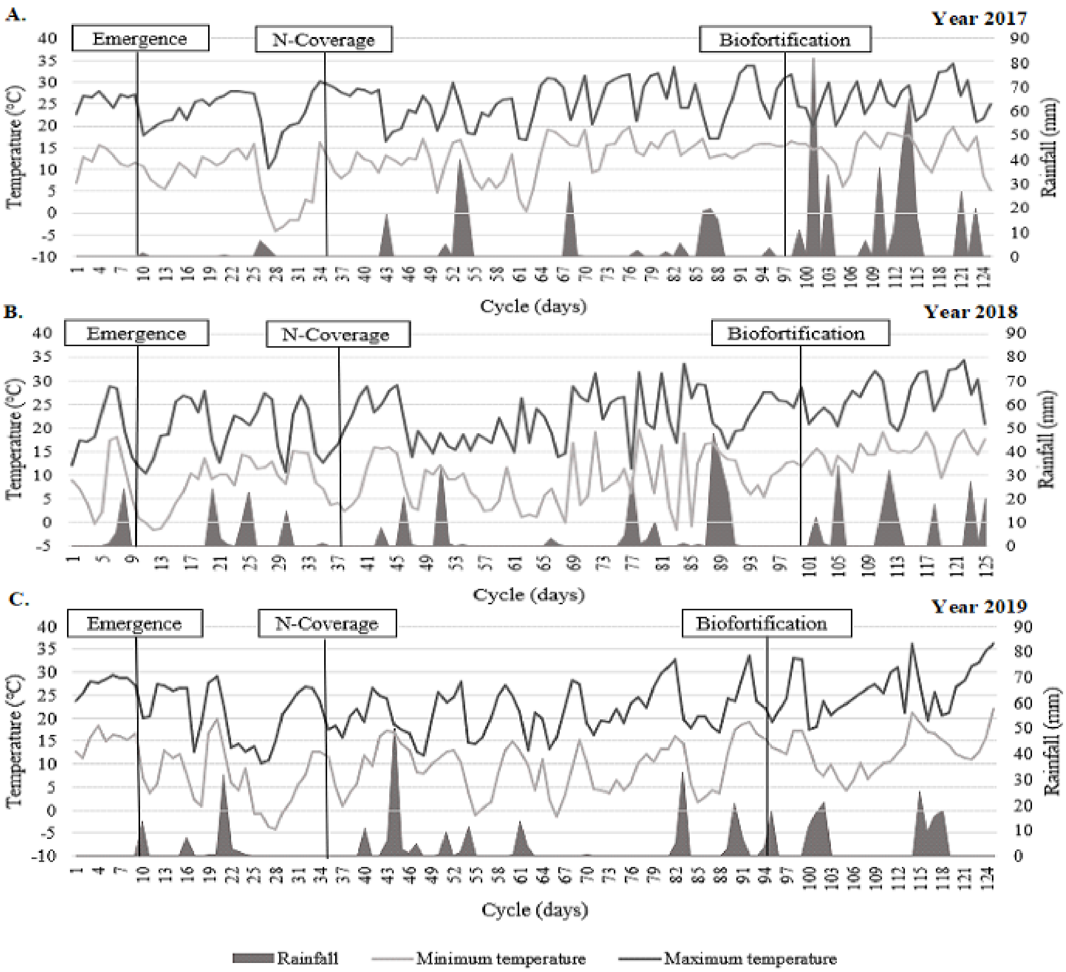

Fig 1. Rainfall and air temperature in the oat crop cycle. Data obtained from the meteorological station located at the the Regional Institute for Rural Development IRDeR/UNIJUÍ.

Table 2. Average values, relative contribution and correlation of doses of the compound with zinc on grain yield indicators.

Zn Dose	Productivity Indicators (y)						
	PL	NGP	NGP	PM	PGM	PHI	GY
(g ha^{-1})	(cm)	(n)	(n)	(g)	(g)	(g g^{-1})	(kg ha^{-1})
2017 (UY)							
0	19.57 a	31.07 a	59.80 a	1.84 a	1.60 a	0.87 a	1460 a
500	19.57 a	32.47 a	62.53 a	1.95 a	1.69 a	0.87 a	1353 a
1000	21.10 a	34.67 a	65.47 a	1.89 a	1.55 a	0.82 a	1408 a
2000	20.83 a	32.67 a	63.40 a	1.92 a	1.63 a	0.85 a	1268 a
4000	20.43 a	32.40 a	62.47 a	1.85 a	1.55 a	0.84 a	1203 a
$r_{(dose\ x\ y)}$	0.41	0.06	0.10	-0.07	0.14	-0.23	-0.36
CR (%)	9.30	6.08	0.18	13.14	37.57	33.70	0.03
2018 (IY)							
0	19.80 a	26.93 a	53.93 b	1.98 b	1.70 b	0.85 a	2440 a
500	20.36 a	29.20 a	59.93 ab	2.13 ab	1.83 ab	0.85 a	2329 a
1000	20.36 a	32.53 a	68.06 ab	2.48 ab	2.20 ab	0.88 a	2670 a
2000	19.76 a	32.20 a	64.80 ab	2.31 ab	2.01 ab	0.87 a	2384 a
4000	20.66 a	33.66 a	70.93 a	2.65 a	2.31 a	0.87 a	2488 a
$r_{(dose\ x\ y)}$	0.22	0.40	0.43	0.49*	0.49*	0.29	0.05
CR (%)	0.71	8.95	27.52	41.03	11.42	8.79	1.58
2019 (IY)							
0	20.20 a	30.73 a	60.00 a	1.86 a	1.68 a	0.92 a	1898 a
500	19.33 a	29.00 a	60.53 a	2.06 a	1.78 a	0.87 a	2304 a
1000	21.13 a	35.20 a	69.87 a	2.18 a	1.90 a	0.87 a	2126 a
2000	19.47 a	32.93 a	66.40 a	2.14 a	1.90 a	0.87 a	1994 a
4000	20.32 a	35.87 a	73.89 a	2.29 a	2.02 a	0.88 a	1778 a
$r_{(dose\ x\ y)}$	0.03	0.36	0.40	0.29	0.30	0.07	-0.28
CR (%)	37.06	3.32	13.40	17.02	29.12	0.07	0.01

r – Pearson's correlation; CR_Relative contribution (Mahalanobis); Grouping - Grouping by Tocher; Zn Dose_Biofortification dose by zinc sulfate (g ha^{-1}); PL_Panicle length; NSP_Number of spikelets in the panicle; NGP_Number of grains per panicle; PM_Panicle Mass; PGM_Panicle Grain Mass; PHI_Panicle Harvest Index; GY_Grain yield; IY_Intermediate year to cultivation; UY_Unfavorable year for cultivation; * – Significant at p ≤ 0.05 by the F test; In each dose, averages followed by the same letter do not differ from each other by Fischer's test at a level of 0.05 error probability.

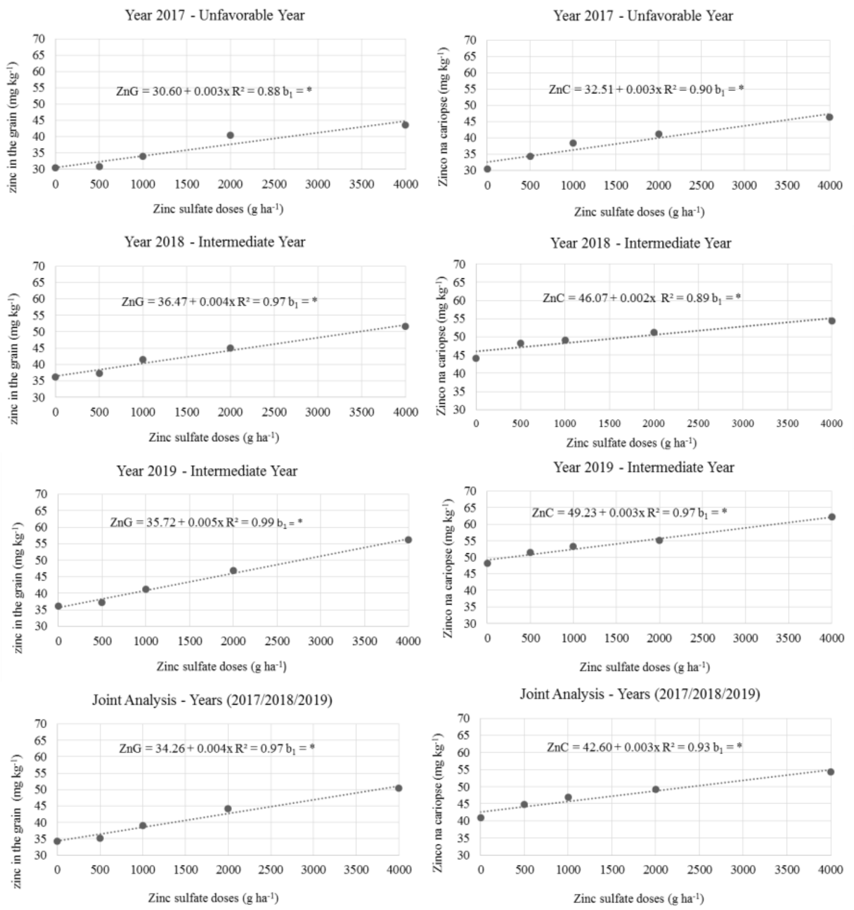

Fig 2. Regression models for the average values of zinc in grain and oat caryopsis as a function of zinc sulfate doses. ZnG_Zinc in the grain; ZnC_Zinc in caryopsis; R^2_Coefficient of determination; b_n_Significance of the angular parameter of the regression equation at 0.05 error probability

Table 3. Average values, relative contribution and correlation of doses of the compound with zinc on indicators of industrial grain quality.

Zn Dose	Industrial Quality Indicators (y)						
	MTG	MH	NG > 2mm	MG	CM	HI	IP
(g ha-1)	(g)	(kg hl-1)	(n)	(g)	(g)	(g g-1)	(kg ha-1)
2017 (UY)							
0	24.49 a	40.14 a	58.75 a	1.25 a	0.77 a	0.61 a	512 a
500	22.89 a	40.00 a	55.75 a	1.25 a	0.80 a	0.64 a	480 a
1000	22.13 a	40.01 a	54.75 a	1.21 a	0.72 a	0.65 a	503 a
2000	21.79 a	39.90 a	51.75 a	1.17 a	0.79 a	0.67 a	447 a
4000	22.96 a	40.01 a	59.25 a	1.15 a	0.81 a	0.70 a	498 a
$r_{(dose\ x\ y)}$	-0.25	-0.03	0.08	-0.28	0.11	0.39	-0.04
CR (%)	33.26	0.76	25.64	1.43	24.82	10.89	3.20
2018 (IY)							
0	32.45 a	47.92 a	61.75 a	1.92 a	1.36 a	0.71 a	1061 a
500	33.17 a	46.77 a	62.00 a	1.99 a	1.59 a	0.80 a	1167 a
1000	32.00 a	48.48 a	65.75 a	1.90 a	1.46 a	0.76 a	1323 a
2000	32.31 a	47.63 a	68.75 a	1.89 a	1.40 a	0.74 a	1219 a
4000	31.55 a	47.05 a	63.25 a	1.92 a	1.42 a	0.72 a	1134 a
$r_{(dose\ x\ y)}$	-0.37	-0.12	0.10	-0.08	-0.10	-0.15	0.02
CR (%)	22.33	0.14	3.57	8.93	20.23	9.39	35.41
2019 (IY)							
0	24.19 a	42.38 a	52.25 a	1.37 a	1.02 a	0.74 a	742 a
500	26.84 a	41.95 a	58.25 a	1.53 a	1.08 a	0.70 a	935 a
1000	22.20 a	39.80 a	56.25 a	1.40 a	0.99 a	0.70 a	846 a
2000	22.36 a	40.32 a	56.00 a	1.41 a	1.05 a	0.75 a	854 a
4000	23.57 a	41.75 a	59.75 a	1.37 a	0.99 a	0.72 a	767 a
$r_{(dose\ x\ y)}$	-0.25	-0.04	0.31	-0.13	-0.10	0.01	-0.08
CR (%)	0.46	0.47	0.55	49.69	37.70	7.80	3.33

r – Pearson's correlation; CR_Relative contribution (Mahalanobis); Grouping - Grouping by Tocher; Zn Dose_Biofortification dose by zinc sulfate (g ha^{-1}); MTG_Mass of a thousand grains; MH_Mass of hectoliter; NG > 2 mm_Number of grains greater than 2 mm; MG_Grain mass; CM_Caryopsis mass; HI_Husking index; IP_Industrial Productivity; IY_Intermediate year to cultivation; UY_Unfavorable year for cultivation; * – Significant at p ≤ 0.05 by the F test; In each dose, averages followed by the same letter do not differ from each other by Fischer's test at a level of 0.05 error probability

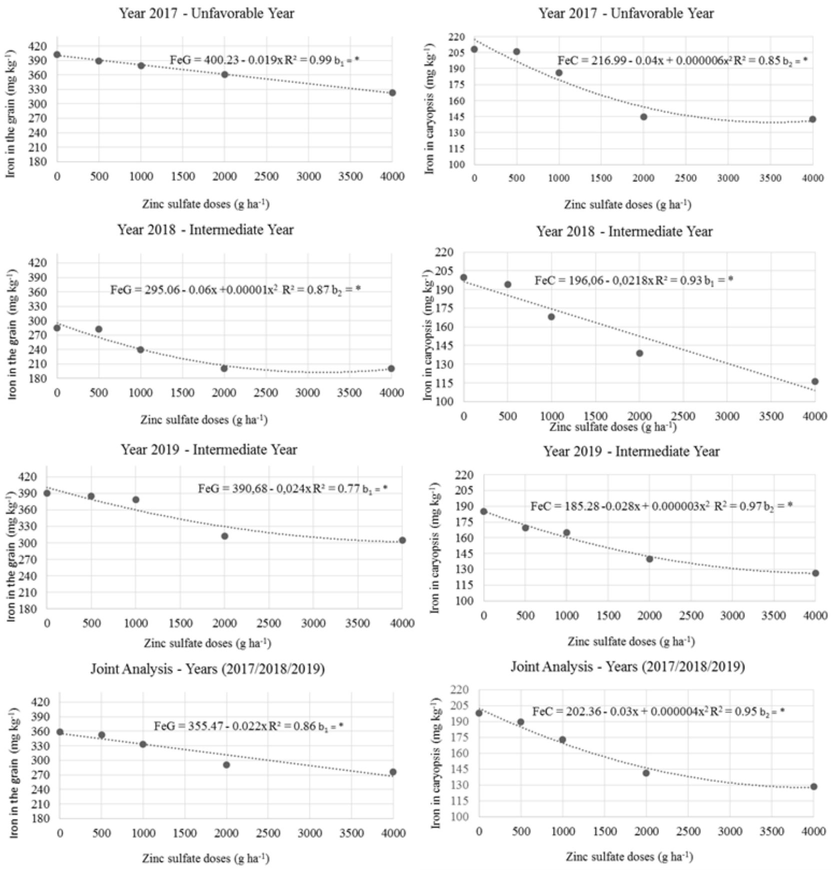

Fig 3. Regression models for the average values of iron in grain and oat caryopsis as a function of zinc sulfate doses. FeG_Iron in the grain; FeC_Iron in caryopsis; R^2_Coefficient of determination; b_n _Significance of the angular parameter of the regression equation at 0.05 error probability

Table 4. Average values, relative contribution and correlation of doses of the compound with zinc on indicators of the organic composition of oat grains.

Zn Dose	Organic Chemical Composition Indicators (y)					
	CP	CF	ST	FND	AS	EN
(g ha^{-1})	(g kg^{-1})					(MJ kg^{-1})
	2017 (UY)					
0	111.67 a	131.67 a	434.33 a	341.67 a	32.33 a	11.67 a
500	111.75 a	128.67 a	437.00 a	320.00 a	28.67 a	11.77 a
1000	111.33 a	133.50 a	442.67 a	345.33 a	22.50 a	11.50 a
2000	112.67 a	134.33 a	436.00 a	348.67 a	26.00 a	11.57 a
4000	110.00 a	135.67 a	429.00 a	355.00 a	29.67 a	11.53 a
$r_{(dose\ x\ y)}$	-0.18	0.49*	-0.45*	0.52*	0.04	-0.27
CR (%)	4.21	1.29	42.12	30.66	11.08	10.64
	2018 (IY)					
0	118.33 a	132.33 a	428.00 a	335.00 ab	35.33 a	11.80 a
500	118.00 a	130.67 a	426.67 a	330.67 ab	33.33 a	11.83 a
1000	121.33 a	126.67 a	426.67 a	312.33 c	36.33 a	11.97 a
2000	121.00 a	127.67 a	425.00 a	318.00 c	37.33 a	11.97 a
4000	114.33 a	136.67 a	421.67 a	356.67 a	36.00 a	11.67 a
$r_{(dose\ x\ y)}$	-0.32	0.45*	-0.45*	0.47*	0.20	-0.39
CR (%)	1.00	50.13	12.42	32.06	0.01	4.38
	2019 (IY)					
0	114.33 a	127.67 a	450.33 a	255.00 a	34.67 a	12.43 a
500	114.42 a	123.00 a	444.87 a	269.00 a	29.83 a	12.23 a
1000	118.33 a	123.10 a	444.62 a	256.33 a	34.33 a	12.37 a
2000	118.00 a	121.67 a	443.70 a	261.33 a	33.33 a	12.33 a
4000	115.72 a	121.33 a	438.52 a	288.00 a	34.17 a	12.13 a
$r_{(dose\ x\ y)}$	0.13	-0.31	-0.60*	0.46*	0.11	-0.28
CR (%)	12.69	30.78	41.47	0.33	1.36	13.37

r – Pearson's correlation; CR_Relative contribution (Mahalanobis); Grouping - Grouping by Tocher; Zn Dose_Biofortification dose by zinc sulfate (g ha-1); CP_Crude protein; CF_Crude fiber; ST_ Starch; FND_Fiber in neutral detergent; AS_Ashes; EN_Energy; IY_Intermediate year to cultivation; UY_Unfavorable year for cultivation, * – Significant at p ≤ 0.05 by the F test; In each dose, averages followed by the same letter do not differ from each other by Fischer's test at a level of 0.05 error probability

Table 5. Average values, relative contribution and correlation of doses of the compound with zinc on the content of zinc and iron in oat grains and caryopsis.

Zn Dose	Inorganic Chemical Composition Indicators (y)			
	ZnG	ZnC	FeG	FeC
(g ha^{-1})	(mg kg^{-1})			
2017 (UY)				
0	30.52 d	30.42 e	402.62 a	208.30 a
500	30.92 d	34.35 d	389.37 b	205.92 b
1000	34.05 c	38.30 c	379.02 c	186.12 c
2000	40.55 b	41.07 b	360.82 d	144.87 d
4000	43.57 a	46.32 a	322.82 e	142.85 e
$r_{(dose\ x\ y)}$	0.95*	0.95*	-0.99*	-0.90*
CR (%)	8.81	1.25	43.33	46.61
2018 (IY)				
0	36.25 d	44.20 d	284.50 a	199.82 a
500	37.35 d	48.30 c	282.10 a	193.85 b
1000	41.45 c	49.10 c	239.97 b	168.00 c
2000	45.00 b	51.25 b	200.42 c	139.10 d
4000	51.60 a	54.45 a	201.07 c	116.00 e
$r_{(dose\ x\ y)}$	0.97*	0.92*	-0.86*	-0.96*
CR (%)	14.67	15.32	26.88	43.13
2019 (IY)				
0	36.05 d	48.27 e	390.08 a	185.12 a
500	37.17 d	51.57 d	385.25 b	169.65 b
1000	41.30 c	53.32 c	379.30 c	164.95 c
2000	46.87 b	55.10 b	312.77 d	139.87 d
4000	56.15 a	62.17 a	304.82 e	126.57 e
$r_{(dose\ x\ y)}$	0.99*	0.98*	-0.91*	-0.96*
CR (%)	1.59	2.99	80.64	14.78

r – Pearson's correlation; CR_Relative contribution (Mahalanobis); Grouping - Grouping by Tocher; Zn Dose_Biofortification dose by zinc sulfate (g ha^{-1}); ZnG_Zinc in oat grains; ZnC_Zinc in oat caryopsis; FeG_Iron in oat grains; FeC_Iron in oat caryopsis; IY_Intermediate year to cultivation; UY_Unfavorable year for cultivation; * – significant at p ≤ 0.05 by the F test; In each dose, averages followed by the same letter do not differ from each other by Fischer's test at a level of 0.05 error probability

In the analysis of relative the variables content of total fiber and starch stand out, as most influenced by biofortification with the compound with zinc. Although statistical differences have been detected, the expressiveness of the change is very small, not bringing changes on organic chemical variables in the oat grains that could make the biofortification technique unfeasible.

In Table 5, regardless of the crop year condition, the biofortification doses by the compound with zinc modified the zinc and iron content in oat grains and caryopsis, showing a strong relationship of the compound dose on these variables. The increase in the dose applied via foliar increases the zinc concentration in the structures, showing a strong positive correlation, however, reducing the iron concentration in grains and oat caryopsis, confirming a high negative correlation.

Regression of biofortification doses

In the study involving a joint analysis of variables, the results of relative contribution (Table 5) show greater alteration by the doses of the compound with zinc on the iron content in oat grains and caryopsis, indicating a greater magnitude of iron reduction than the increase in zinc concentration. This analysis corroborates the information obtained from Figures 2 and 3, in which the expression behavior of these elements as a function of biofortification doses, confirm the significant behavior of zinc elevation and iron reduction, with significance of the regression parameters. The results confirm that the foliar application of the compound with zinc brings effective results of nutrient increment in oat grains and caryopsis. Therefore, giving support in enriching foods with low concentration of this nutrient or even easier access to the population. The possibility of including a nutraceutical food such as oats enriched with zinc is highlighted, thinking of foods aimed at school lunch.

Agronomic biofortification is considered an immediate and effective management technique to increase nutrient concentrations in edible agricultural products (Szerement et al., 2022). In corn, biofortification by zinc sulfate with foliar spray and directed to the soil caused an increase in the concentrations of zinc and proteins in the grains. Also, a correlation between zinc and protein concentrations was confirmed, ranging from 22.3 to 41.9 mg kg^{-1} and from 9 to 12%, respectively (Imran and Rehim, 2017). Foliar application with 0.5% $ZnSO_47H_2O$ increased the zinc content in bread and triticale wheat grains of different varieties, ranging from 31.0 to 63.0, 29.3 to 61.8 and 30.2 to 62.4 mg kg^{-1}, respectively. A study reports that the grain yield of bread, triticale and durum wheat increased with the use of zinc biofortification technology (Dhaliwal et al., 2019). In another study with wheat, using foliar biofortification by zinc at doses of 0, 800, 1600, 2400 and 3200 g ha^{-1}, they promoted concentrations of 30.3; 33.9; 34.1; 38.7 and 40.0 mg kg^{-1} of zinc in the grains, respectively (Jalal et al., 2020). In rice, the effects of biofortification with zinc via foliar+soil and use only in soil at doses 0 and 3000 g ha^{-1} of $ZnSO_47H_2O$ were evaluated. Biofortification showed no change on grain yield, however, its concentration in brown rice (whole reased about 30% in zinc applications via foliar+soil, and 2.4% by application only in soil. The zinc concentration in rice without husk was increased by 66% by foliar+soil application, indicating a possible penetration of zinc into the husk of the inner layers of the rice endosperm (Phattarakul et al., 2012). In soybean, the use of biofortification via foliar zinc showed a concentration of 44.17 mg kg^{-1} of zinc in the control grains in the cultivar Williams to 58.5 mg kg^{-1} of zinc in the grains using the dose of 1800 g ha^{-1} of zinc. In the Sahar cultivar, a concentration of 34.25 mg kg^{-1} of zinc was observed in the control grains to 55.51 mg kg^{-1} of zinc in the grains with a dose of 1800 g ha^{-1} of zinc. The results also showed that there are genetic differences in the greater efficiency of the increase in zinc in grains by biofortification (Malakooti et al., 2017). In arugula, biofortification via foliar zinc was evaluated using doses of 0, 500, 1000 and 1500 g ha^{-1} applied at 15, 20, 25, 15 and 20 and 15, 20 and 25 days after emergence. The results showed no effect of application on physiological variables, as well as on height, leaf area and shoot mass of the plant. The application of a dose of 1.5 kg ha^{-1} of zinc at 25 days after emergence provided the highest zinc content in the leaves, representing an increase of 279% compared to the control (Rugeles-Reyes et al., 2019). However, in all the studies analyzed, no results were found showing the effects of biofortification with zinc on the range of characteristics of agronomic, industrial and consumer interest, especially when it comes to relating the effect of the increase in zinc in grains by technology and the reflections on iron content.

Materials and Methods

Crop area description

The experiment was carried out in the years 2017, 2018 and 2019, in the municipality of Augusto Pestana, RS, Brazil (28° 26' 30'' latitude S and 54° 00' 58'' longitude W). The soil of the experimental area is classified as a typical dystroferric red latosol and the climate of the region, according to the Köppen classification, is Cfa, with hot summers without a dry season. In the study, twenty days before sowing, soil analysis was carried out, and the following chemical characteristics were determined: (pH = 6,2; P = 33,9 mg dm^{-3}; K = 200 mg dm^{-3}; MO = 3,0%; Al = 0 cmol$_c$ dm^{-3}; Ca = 6,5 cmol$_c$ dm^{-3} and Mg = 2,5 cmol$_c$ dm^{-3}).

Experimental design

Sowing was carried out in the third week of June with a seeder-fertilizer in the composition of the plot with 5 lines of 5 m in length and spacing between lines of 0.20 m, forming the experimental unit of 5 m^2. The population density used was 400 viable seeds m^{-2}. During the execution of the study, applications of tebuconazole fungicide were carried out at a dose of 0.75 L ha^{-1}. Weed control was performed with metsulfuron-methyl herbicide at a dose of 4 g ha^{-1}. At sowing, 45 and 30 kg ha^{-1} of phosphorus and potassium, respectively, and nitrogen (urea) were applied in coverage at the phenological stage of 4th expanded leaf, configuring a fertilization for grain yield expectation of 4 t ha^{-1}.

The foliar zinc biofortification experiment was carried out in a randomized block design with eight replications at five levels of the $ZnSO_45H_2O$ compound (0, 500, 1000, 2000 e 4000 g ha^{-1}), applied at the beginning of oat grain filling. For the application, a 20-liter backpack sprayer was used at a constant pressure of 30 lb in^{-2}, with cone-type jet tips. The dimensioned volume of water was considering the application of 500 liters ha^{-1}. Prior to the application in the field, tests were carried out to size the volume in each experimental unit, with a time of 21 seconds being conditioned inent to the laboratory to correct the grain moisture to 13%, to estimate grain yield (GY, kg ha^{-1}).

Prior to grain harvest, ten panicles were randomly collected from each plot to analyze the inflorescence indicators, which were: panicle length (PL, cm), measured with the aid of a ruler, excluding the edges; number of spikelets per panicle

(NSP, n) and number of grains per panicle (NGP, n), measured by counting; panicle mass (PM, g), obtained by weighing on a precision scale; panicle grain mass (PGM, g), threshed panicle grains and weighed on a precision balance; panicle harvest index (PHI, g g^{-1}), obtained by the ratio of panicle grain mass to panicle mass (PHI = PGM/PM).

In the indicators of industrial interest, the following were analyzed: mass of a thousand grains (MTG, g), by counting 250 grains and weighing them on a precision scale, subsequently multiplied by four; mass of hectoliter (MH, kg hl^{-1}) obtained by the mass of grains from a cube of known volume of 250 cm³, and converted to kg hl^{-1}; number of grains larger than two millimeters (NG>2mm, n) determined by counting one hundred grains, which are placed in a 2mm mesh sieve and those above this dimension are counted; mass of grains greater than 2 mm (MG, n), determined by weighing on a precision scale of 50 grains with a dimension greater than 2 mm; caryopsis mass greater than 2 mm (CM, n), obtained by weighing in a precision scale of 50 grains larger than 2 mm without husk; husking index (HI, g g^{-1}) determined by the ratio between the caryopse mass of 50 grains larger than 2 mm and its grain mass; industrial productivity (IP, kg ha^{-1}) obtained by the product of grain yield with the number of grains greater than 2 mm and the husking index (IP= GY x NG>2mm x HI).

In the indicators of chemical quality of grains, the contents of crude protein (CP, g kg^{-1}), crude fiber (CF, g kg^{-1}), starch (ST, g kg^{-1}), fiber in neutral detergent (FND, g kg^{-1}), ash (AS, g kg^{-1}) and energy (EN, kcal) were evaluated, which were obtained by the sample of unhusked grains performed with the NIR (Near Infrared Reflectance) spectrometer device, through near-infrared spectrophotometry. The Near Infrared Reflectance Spectrometer (NIRS) by Perten, model Diode Array DA7200.

In the direct evaluation of zinc concentration in oat grains, 20 grams of hulled and unhulled grains (caryopsis) were weighed on a precision scale. Subsequently, they were placed in an oven at a temperature between 70 and 80 ºC, to correct for weight variation; each sample ground in the mill for about 90 seconds. After milling, the samples were sieved with a 270-mesh sieve, with a size of 53 microns, where each sample resulted in a mass of 5 to 6 grams. The samples were properly identified and submitted to analysis via atomic absorption spectrometry to analyze the concentration of zinc in oat grains and caryopsis. In addition, knowing the importance that iron plays for the proper functioning of the human organism, such as participation in enzymatic and metabolic activities, respiratory chain reactions and nucleic acid synthesis, it was also decided to analyze the iron content in grains and caryopsis of oat, to the point of confirming that zinc biofortification does not promote competition in reducing the iron content in these structures. The information on air temperature (ºC) and rainfall (mm) for the analysis of the meteorological conditions of the agricultural years were obtained by the Automatic Total Station installed 500 meters from the experiment.

Statistical analysis

Analysis of variance, comparison of means and polynomial regression were performed to estimate the behavior and possible definition of the optimal dose for biofortification. Also, analysis of relative contribution and correlation of zinc biofortification doses on grain yield and quality variables. All these analyzes were performed with the help of the GENES software (**Cruz**, 2006).

Conclusion

Biofortification with foliar zinc sulfate does not compromise the productivity and industrial quality of oat grains, as well as the elements of organic composition. The foliar biofortification process developed promotes a significant increase of zinc in oat grains and caryopsis, however, reducing the iron content in these structures. Foods enriched with zinc, especially in a species of recognized nutraceutical function such as oats, can reduce the rates of many diseases and health expenses. Even as a suggestion to include biofortified oats in food preparation in schools and hospitals.

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