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CORRELATION AND PATH ANALYSIS OF EARLY-MATURING RICE (*ORYZA SATIVA* L.) TREATED WITH ZINC AT VARIOUS GROWTH PHASES

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SUMMARY

The concerned study aimed to determine the correlation and direct and indirect effects to estimate the interaction between production parameters and the zinc content of plant tissues of early maturing rice (*Oryza sativa* L.) cultivars. The study comprised the application of zinc at various crop phases, namely, without zinc (Zn0), zinc at the vegetative phase (Zn1), the vegetative and generative phases (Zn2), and the generative phase (Zn3) to three early maturing rice cultivars, Inpari 19, Inpari Cakrabuana, and Inpari Sidenuk. Data analysis used correlation and path analyses. The results revealed that rice grain yield positively correlated with most production parameters. The zinc analysis also showed a positive correlation between zinc content and rice plant tissues. The path analysis indicated that the clumping grain weight had a significant ($P \leq 0.01$) positive direct effect (0.75). Meanwhile, panicle density had a significant ($P \leq 0.05$) positive direct effect (0.51) on rice grain production per hectare. Path analysis of zinc content in tissues signified that zinc content in leaves had a very significant ($P \leq 0.01$) positive direct effect (0.71), In contrast, zinc content in stems had an indirect positive influence (0.33) on zinc content in grain.

Keywords: Early maturing rice (*Oryza sativa* L.), zinc applications, yield and its parameter traits, correlation analysis, path analysis

Key findings: The results revealed that rice grain yield positively correlated with most production parameters. The zinc analysis also showed a positive correlation among the zinc content in rice plant tissues.

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INTRODUCTION

Rice (*Oryza sativa* L.) is a staple crop vital in the economy of Indonesia because it serves as a prime ingredient to meet the country's basic needs. Technology-enhancing rice production uses early-maturing superior cultivars and optimizes inorganic inputs that suit rice crop needs for growth and development (Sianipar and Khadijah, 2021). The contribution of new high-yielding rice cultivars in boosting grain production is considerable. Potential rice genotypes as one of the production components have contributed around 56% (Samrin and Amirullah, 2018). Early maturing rice cultivars have a harvest age of 90–104 days after sowing (DAS).

Zinc is also essential for humans, animals, and crop plants. Zinc deficiency inhibits plant growth, eventually reducing grain yield. Lack of zinc has become a severe problem affecting almost half of the world's population because of growing different crop plants in zinc-deficient soils (Rudani *et al*., 2018; Kolencik *et al*., 2020). Therefore, efforts are ongoing to increase the zinc content in grains by foliar application to the plant biomass.

High-yielding rice cultivars' planting requires efficient fertilization. Farmers generally apply continuous mineral fertilizers that contain macronutrients, especially N, P, and K, with high doses often disrupting the balance between macro- and micronutrients in the soil. That disruption of macro- and micronutrients typically impacts the rice grain yield and quality (Salawati *et al*., 2021). Supplying micronutrients to the paddy fields is unimportant to the farming community, and therefore, farmers rarely use micronutrients in crop plants.

The rice cultivation in flooding irrigated fields is at high risk of Zn deficiency. Flooding regularly increases the soil pH, causing Zn sulfate formation and increasing levels of iron (II) and manganese (II) ions. The activity of these ions greatly influences the Zn uptake by the roots of crop plants (Alloway, 2008; Dobermann and Fairhust, 2000). Past studies also established that Zn deficiency negatively affects plant growth and development, causing stunted plants, shorter internodes, smaller leaves, leaf chlorosis, and delayed maturity. Therefore, sufficient Zn is crucial for optimum crop yield and products quality (Hacisalihoglu, 2020; Vadlamudi *et al*., 2020).

Applying zinc through leaves with a concentration of 0.5% $ZnSO_4$ in 1000 l of water per hectare increases the zinc content in rice grains compared with direct soil application (Rehman *et al*., 2012). Zinc application at a concentration of 0.5% $ZnSO_4$ in 900 l of water per hectare increases the Zn content in rice grains in well-drained and flooded soils (Khampuang *et al.*, 2022). Zinc deficiency can come as some plant symptoms appear on older leaves (Sutarman and Agus, 2019). The timing of zinc application on the leaves and plant biomass is also a critical factor (Stomph *et al*., 2011). Therefore, zinc application to rice plants requires timeliness to enhance rice grain production and its zinc content.

Rice production per hectare and zinc content in grain can correlate with other parameters of rice production. Therefore, correlation analysis helps determine the association among the studied parameters. Path coefficient analysis is also an efficient statistical technique designed to quantify the interrelationship of different components and their direct and indirect effects on grain yield (Wamanrao, 2020). Based on the above description, the presented study aimed to determine the direct and indirect correlation and influence among the rice production parameters and the association among zinc content in rice (*Oryza sativa* L.) plant tissues.

MATERIALS AND METHODS

Plant material and zinc application process

The practical research on rice (*Oryza sativa* L.) commenced in January–April 2023 in Salo Village, District Watang Sawitto, Pinrang Regency, South Sulawesi Province, Indonesia. The meteorological data, including rainfall, temperature, and duration of irradiation at the study site, are available in Figure 1. The research ran on technically irrigated paddy

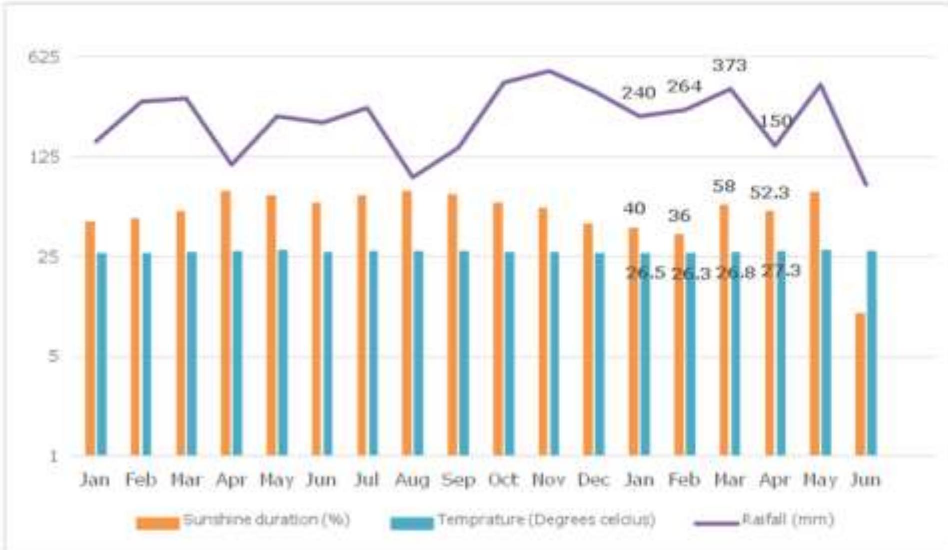

Figure 1. Rainfall, temperature, and sunshine duration for the period of January 2022 – June 2023 in Watang Sawitto Sub-district, Pinrang Regency, South Sulawesi, Indonesia (Source: Meteorological, Climatological and Geophysical Agency. Maros, South Sulawesi, Indonesia).

Table 1. Analysis of soil sample at the study site before rice crop planting.

pH	Texture sand, silt, clay (%)	OM (%)	C/N	N (%)	P (ppm)	K (ppm)	CEC (%)	WS (%)	Zn (ppm)	S (%)
7,5	Clay loam 22, 40, 38	3.51	29.25	0.12	65	59	6.84	100+	62.16	0.04
Neutral	Clay loam	High	Very high	Low	Very high	Very high	Low	Very high	Medium	Very low

OM: organic matter, C/N: carbon and nitrogen ratio, N: nitrogen, P: phosphorus, K: potassium, CEC: cation exchange capacity, WS: wet saturation, Zn: zinc, S: sulfur.

fields. This study had a split-plot design, with the main plots comprising the three rice cultivars, namely, the Inpari 19 (V1), Inpari Cakrabuana (V2), and Inpari Sidenuk (V3). The subplots were zinc (Zn) applications consisting of four applications, i.e., without zinc (Zn0), zinc application at the vegetative phase (Zn1), at the age of 20, 30, and 40 days after sowing (DAS), during vegetative and generative phases (Zn2) at 40, 50, and 60 DAS, and at the generative phase (Zn3) at 60, 70, and 80 DAS. Based on Table 1, the zinc content in the research soil was 62.16 ppm, which means the soil had sufficient zinc content. Hence, the zinc application used a 0.5% zinc sulfate concentration in 1000 L of water per hectare.

Research procedures

The research transpired on irrigated paddy fields. Land management ensued before the tests, then, the experimental subplots prepared had a size of 4 m × 3 m, with a distance of 1.5 m between two main plots, a distance of 1 m between subplots, and a distance of 2 m between replications. Furthermore, planting uses rice sown before with a transplanting age of 15 DAS. The plants and rows' spacings were 12.5 and 25 cm, respectively.

The fertilizers used depended on the soil analysis earlier conducted (Table 1). The first fertilization (100 kg/ha of urea and 150 kg/ha of NPK) applied to the rice plants was at 20 DAS, while the second fertilization (100 kg/ha of ZA and 150 kg/ha of NPK) at 50 DAS. Rice crop maintenance included irrigation, replanting, weeding, and pest and disease management. Harvesting proceeded at the physiological maturity when 90%–95% of the plant panicles had turned yellow (after 103–104 DAS).

Data recording and statistical analysis

The data recorded on randomly selected rice plants for the production parameters included the number of productive tillers, panicle length, number of grains per panicle, panicle density, percentage of grain filled per panicle, grain weight in clumps, and grain yield per hectare. The zinc content analysis progressed for the rice root, stem, leaves, and grain tissues. Analyzing the collected data for correlation used the Pearson product-moment correlation technique equation as given below (Purba and Purba, 2022):

$$r = \frac{\sqrt{\sum xy} - (\sum x \ X \sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2} \ X \sqrt{n\sum y^2 - (\sum y)^2}}$$

Where:
r_{xy} = the relationship between variable x and variable y
x = the variable x value
y = the variable y value

Then, data assessment engaged the path analysis. The cross-sectional analysis relied on the simultaneous equation with the following formula (Singh and Chaudhary, 1979):

$$\underbrace{\begin{pmatrix} R_{11} & R_{12} & \dots & R_{1P} \\ R_{21} & R_{22} & \dots & R_{2P} \\ \dots & \dots & \dots & \dots \\ R_{P1} & R_{P2} & \dots & R_{PP} \end{pmatrix}}_{\mathbf{R_x}} \underbrace{\begin{pmatrix} C_1 \\ C_2 \\ \dots \\ C_P \end{pmatrix}}_{\mathbf{C_x}} \begin{matrix} = \\ = \\ \equiv \\ \equiv \end{matrix} \underbrace{\begin{pmatrix} R_{1y} \\ R_{2y} \\ \dots \\ R_{Py} \end{pmatrix}}_{\mathbf{R_y}}$$

Based on this equation, the value of C (direct effect)'s calculation used the following formula:

$$C = R_x^{-1} \times R_y$$

Where:
R_x = correlation matrix between independent variables
R_x^{-1} = R_x matrix inverse
C = the cross coefficient vector, which shows the direct effect of each independent variable that has become standard on the dependent variable
R_y = the correlation coefficient vector between the Xi variable and the dependent variable

RESULTS AND DISCUSSION

Correlation among production parameters

The correlation analysis revealed that the number of productive tillers had a significant ($P \leq 0.01$) negative correlation with panicle length, a significant ($P \leq 0.05$) negative correlation with the number of seeds per panicle and panicle density, and a nonsignificant negative correlation with the percentage of grain filled panicles, grain weight per clump, and grain yield per hectare in rice (*Oryza sativa* L.) (Table 2). It means that the more productive tillers, the shorter the panicles formed, the number of seeds per panicle, and the panicle density decreased, which were also analogous to the past research on yield and yield components correlation of local rice cultivars in upland and wetland cultivation system (Afza *et al*., 2017; Afa *et al.*, 2021). According to Peng *et al*. (1994), the more tillers formed, the smaller the panicles, and the less optimal grain filling, resulting in fewer grains than optimum.

Panicle length has a significant ($P \leq 0.05$) positive correlation with grain yield per hectare and a highly significant ($P \leq 0.01$) positive correlation with grains per panicle, panicle density, and grain weight per clump, with the same findings also reported by Riyanto *et al*. (2012) and Rajasekhar *et al*. (2022) in their studies on characteristic association and path coefficient analysis in upland rice (*Oryza sativa* L.) for grain yield and quality traits. The number of grains per panicle

Table 2. Correlation analysis among rice production parameters.

Parameters	NPT	PL	NGP	PD	PGF	GWC	GWH
NPT	1	-0.765**	-0.644*	-0.504*	-0.011NS	-0.471NS	-0.491NS
PL		1	0.868**	0.714**	0.034NS	0.661**	0.587*
NGP			1	0.948**	0.323NS	0.763**	0.777**
PD				1	0.526*	0.788**	0.841**
PGF					1	0.660**	0.677**
GWC						1	0.916**
GWH							1

*: Significant at α = 5%, **: Highly significant at α = 1%, NS: Nonsignificant, NPT: number of productive tillers, PL: panicle length, NGP: number of grains per panicle, PD: panicle density, PGF: percentage grain filled, GWC: grain weight per clump, and GWH: grain weight per hectare.

significantly ($P \leq 0.05$) correlates with panicle length, panicle density, grain weight of clump, and grain yield per hectare. According to past research, the grains per panicle positively correlated with grain yield in correlation studies of agronomic attributes with grain yield in brown rice (Prabowo *et al*., 2014; Singh *et al*., 2022). It means that longer panicle affects the number of grains per panicle, the higher it affects the panicle density and grain weight of the clump, and eventually increasing grain yield per hectare. According to Zhang *et al*. (2010), long panicles with more grains can enhance the panicle density.

The results also indicated that panicle density had a significant ($P \leq 0.05$) positive correlation with the percentage of filled grain and a substantial ($P \leq 0.01$) positive relationship with the panicle length, number of grains per panicle, grain weight per clump, and grain yield per hectare. The panicle grain filling percentage had a significant ($P \leq 0.01$) positive correlation with clumping grain weight and grain yield per hectare and a noteworthy ($P \leq 0.05$) positive association with panicle density, and these results aligned with the past research on correlation and path analysis for grain quality trait of lowland rice (*Oryza sativa* L.) (Limbongan *et al*., 2010; Abdala *et al*., 2016). The grain weight in the clump also has a very significant positive correlation with panicle length, number of grains per panicle, percentage of filled grain, and grain yield per hectare, which also follows the past research on correlation and cross-characteristics of hybrid rice (Kartina *et al*., 2017).

Grain yield per hectare showed a meaningful ($P \leq 0.01$) positive correlation with the number of unhusked grains, panicle density, the percentage of grain filled per panicle, and grain weight per clump, and significantly ($P \leq 0.05$) correlated with panicle length. Early maturing rice applied with zinc in various phases showed that the production per hectare had close association with the length of panicles, the number of grains per panicle, the density of panicles, the percentage of filled grains per panicle, and the weight of grain per hectare. The strength of the relationship between essential plant traits plays a vital role in predicting yield responses concerning variations associated with a particular character (Malek *et al*., 2014; Bagati *et al*., 2016; Jumaa *et al*., 2020).

Correlation between zinc content in plant tissues

The correlation analysis revealed that the zinc content in rice plant tissues and zinc content in roots have a significant ($P \leq 0.05$) positive association with leaf zinc content and a nonsignificant positive correlation with zinc content in stems and grains (Table 3). It indicated that the zinc content in the roots had a closer connection to the zinc stored in the leaves. The zinc content in stems has a significant ($P \leq 0.01$) positive correlation with zinc content in the leaves and grains. However, the zinc content in stems had nonsignificant positive correlations with the zinc in roots. The zinc content in the stem also showed near

Table 3. Correlation analysis among zinc content in the plant tissue.

Parameters	Root	Stem	Leaf	Grain
Root	1	0.386^{NS}	0.502*	0.222^{NS}
Stem		1	0.798**	0.796**
Leaf			1	0.843**
Grain				1

*: Significant at α = 5%, **: Highly significant at α = 1 %, NS: Nonsignificant.

associations with the zinc content in the leaves and grains. The zinc content in the leaves showed a significant ($P \leq 0.01$) positive correlation with the zinc content in the stems and grain. The zinc content in the leaves also correlated to the zinc content in the roots, stems, and leaves. This occurrence might be due to foliar application of zinc through the leaves and plant biomass. Zinc content in grains showed a significant ($P \leq 0.01$) positive correlation with stems and leaves, but not a significantly positive correlation with roots in the zinc nutrition in the rice production system (Rehman *et al*., 2012).

In plant tissues, there was a positive correlation among the zinc content. Presumably, it is because zinc translocation occurs through the symplast and apoplast from roots to the plant tissues, and increased zinc levels can exist in the blast. Translocation of the metals mostly happens through plant and blast tissues in crop plants. Controversial reports have stated that Zn uptake manifested to take care of active or passive techniques. A reduced Zn absorption is barely at the root level, under the presence of anaerobic conditions, by decreasing temperatures and metabolic activities suggests elements uptake by the plant roots to the leaves by an active method in crop plants (Vadlamudi *et al*., 2022). Therefore, if there is a deficiency of Zn nutrients in plants, it can cause leaf degeneration, the appearance of macules on the leaf veins, small leaf deformation, and slow growth. However, fulfilling the zinc needs of crop plants can be better through foliar application on the leaf surface, which the leaf epidermis can absorb easily for transport to other parts of the plant through the rice xylem and phloem (*Oryza sativa* L.) (Hu *et al*., 2023).

Path analysis of yield traits and grain yield

The correlation values signified the nature and extent of association between pairs of characteristics. Path analysis provides an applicable means to partition correlation coefficients into unidirectional and alternative pathways, thus critically analyzing the specific trait that produced a given correlation, which can be employed to formulate an effective selection program (Jain *et al*., 2015). The path analysis showed the direct and indirect effects of the observed production parameters in rice (Table 4). The parameter of grain weight of clumps provided a very significant positive direct effect on grain yield per hectare with a direct influence of 0.7482. A significant positive direct effect on grain yield per hectare was indicative in the panicle density parameter (0.5052). Grain weight per clump gave the highest direct effect value on grain yield per hectare, which means that the grain weight per clump highly enhanced grain yield per hectare in early maturing rice cultivars applied with zinc in various growth phases. The second significant positive direct effect was on the panicle density, contributing to grain yield per hectare. Gravois and Helms (1992) also observed that panicle density and per panicle grain weight directly affected grain yield in the path analysis of rice yield and yield components, as affected by seeding's rate.

The parameters of the productive tillers, panicle length, number of grains per panicle, and the percentage of filled grain showed nonsignificant negative direct effects with the values of the direct outcome of the number of productive tillers at -0.2077, panicle length at -0.3417, number of panicles at -

Table 4. Path analysis of rice production traits with grain yield per hectare.

Parameters	Direct effects	Indirect effects						Total effects
		NPT	PL	NGP	PD	PGF	GWC	
NPT	-0.2077^{NS}	-	0.2614	0.0622	-0.2548	0.0005	-0.3527	-0.4912
PL	-0.3417^{NS}	0.1589	-	-0.0838	0.3605	-0.0015	0.4949	0.5873
NGP	-0.0966^{NS}	0.1337	-0.2965	-	0.4789	-0.0138	0.5712	0.7770
PD	0.5052*	0.1048	-0.2438	-0.0915	-	-0.0225	0.5893	0.8414
PGF	-0.0428^{NS}	0.0024	-0.0117	-0.0312	0.2657	-	0.4942	0.6765
GWC	0.7482**	0.0979	-0.2260	-0.0737	0.3979	-0.0282	-	0.9160
Residual	0.30							-

*: Significant at α = 5%, **: Highly significant at α = 1%, NS: Nonsignificant, NPT: number of productive tillers, PL: panicle length, NGP: number of grains per panicle, PD: panicle density, PGF: percentage grain filled, and GWC: grain weight per clump.

Table 5. Path analysis of zinc content in rice plant tissues with zinc content in grains.

Parameters	Direct effects	Indirect effects			Total effects
		Root	Stem	Leaf	
Root	-0.262^{NS}	-	0.127	0.358	0.222
Stem	0.329^{NS}	-0.101	-	0.568	0.796
Leaf	0.712**	-0.132	0.263	-	0.843
Residual	0.44				-

**: Highly significant at α = 1%, NS: Nonsignificant.

0.0966, and the percentage filled grain at -0.0428. Panicle length has no significant negative direct effect on grain yield per hectare, and these results agreed with past findings on the correlation and cluster analysis of yield and yield-related traits in rice germplasm (Rashid *et al*., 2014; Sarangi *et al*., 2022). The percentage of filled seeds per panicle has a negative direct effect and was nonsignificant for grain yield in rice genotypes (Faysal *et al*., 2022). The number of productive tillers and the number of seeds per panicle have a direct negative effect and were nonsignificant for production per hectare. However, these results were contrary to previous research, which showed that the percentage of filled seeds per panicle and the number of seeds per panicle positively affected rice production (Singh *et al*., 2022; Ratnam *et al*., 2023). The differences between the current and past results might also be due to the diverse genetic makeup of the rice cultivars and environmental conditions. Factors that influence the growth and production of rice plants are genotypes, environments, and genotype-by-environment interactions. Rice genotypes with a high-yield potential can also experience biotic and abiotic stress conditions during their lifetime (Jaenuristy *et al*., 2022).

The path analysis of this research revealed a residual value of 0.30. The residual value is the total unaccounted-for direct effect on parameters for identification. However, the residual values close to zero indicate that the path analysis effectively explains the causation of the observed correlation values and characters from direct and indirect influence values (Rohaeni and Permadi, 2012; Widyaningtias *et al*., 2020).

Path analysis of zinc content in plant tissues and grains

Path analysis showed direct and indirect effects of zinc content in rice plant tissues and grains (Table 5). The zinc content in the leaves had a substantial positive direct influence (0.712) on zinc in the grains. The zinc content in stems also had a direct positive and insignificant effect (0.329) on the zinc content in the grains, and the zinc content in the roots had a negative direct result (-0.262) on the zinc content in grains, with a residue value of 0.44. The direct effect of zinc content in stems also correlated positively with the zinc in grains. In contrast, the zinc content in roots has a negative direct effect on the grains' zinc content, which means that zinc content in leaves directly affects its content in grains compared with soil absorption through roots. It is likely because, in this study, zinc application ensued through the leaves. The leaf epidermis can absorb Zn sprayed on the leaf surface and transport it to other parts of the plant via the xylem and phloem. Migration from nutrient tissue to grains is an essential pathway for zinc accumulation in grains. Rice is a plant that is sensitive to Zn. The zinc fertilizer application can significantly increase Zn concentration, reduce Zn deficiency, and increase grain yield (Hu *et al*., 2023). The findings of Rehman *et al*. (2012) revealed that increased grain zinc concentration is parallel with increased remobilization of zinc in leaves during the grain-filling phase.

Leaf zinc application parallels the advantages of rapid and effective utilization of nutrients and reduction of losses through washing, fixation, and regulating the plant nutrient uptake (Saikh *et al*., 2022). Foliar application can avoid the problem of zinc fixation in soil; however, the time of zinc application should be around flowering to increase the granular Zn concentration. Applying foliar zinc in the generative phase increases the zinc content in grains compared with the vegetative phase in rice (Cakmak *et al*., 2010; Boonchuay *et al*., 2013).

CONCLUSIONS

The parameters of grain weight of clump and panicle density can be an eminent indication in increasing production per hectare in early maturing rice (*Oryza sativa* L.) cultivars, along with the foliar application of zinc. The zinc content in the leaves is vital in mobilizing the zinc nutrients in rice plants to enhance the grains' zinc content.

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