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RESEARCH ARTICLE

Functional food biofortification in increasing red and black rice production through the use of nano silica organic fertilizer

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ABSTRACT

Increasing paddy consumption can be done through efforts to increase yields by improving production technology, one of which is using organic nano silica fertilizer. Food biofortification efforts in paddy are also considered a solution for improving nutrition to help improve community nutrition. This research aims to determine the colour cultivar and dosage of nano silica organic fertilizer and the interaction between the two, which provide high growth and production and determine the nutritional quality of functional paddy. Functional paddy planting occurred in Manakku Village, Labakkang District, Pangkep Regency, South Sulawesi, from May to August 2023. The research was arranged in a separate plot design with the main plot varying doses (kg ha^{-1}) of nano silica organic fertilizer consisting of control (d0), 500 (d1), 1000 (d2), and 1500 (d3), as well as subplots of four cultivars of red rice (*Oryza sativa* L.), namely Inpari 24 (v1), Pamelen (v2), Pamera (v3) and Inpago 7 (v4) as well as one cultivar of black rice Jeliteng (v5). The results were that the interaction of 1000 kg ha^{-1} organic nano silica fertilizer and red rice 'Inpago 7' (d2v4) provides the best yield of 5.62 t ha^{-1}. Characters that have a significant positive correlation with yield are plant height (0.64**), number of productive tiller (0.74**), grain total (0.54*), and weight of 1000 grains (0.88**). The quality of functional rice based on glycaemic index (GI) analysis showed that the black rice 'Jeliteng' with a dose of organic nano silica fertilizer of 1000 kg ha^{-1} (58.9%) had the lowest GI value.

Key words: Biofortification, black rice, glycemic index, nano silica, *Oryza sativa*, red rice.

INTRODUCTION

Paddy is a rice (*Oryza sativa* L.)-producing commodity that is the main source of carbohydrates for some of the world's population (FAO, 2018). This causes the need for paddy to continue to increase every year, along with the increase in population. Paddy demand in 2025 is projected at 65.9 million tons of dry unhusked paddy (DUP), with an average population growth rate of 1.17% (CBS, 2022). As a staple food, paddy contributes 63% energy, 38% protein, and 21.5% Fe (Safitri et al., 2019). This potential can be combined with the high yields in cultivating varieties potential, one of which is through food biofortification efforts on superior varieties. Biofortification is a new paradigm in agriculture that can help improve community nutrition. Biofortification of paddy through the assembly of functional paddy itself aims to obtain superior varieties that have the potential for high yields and contain microelements, vitamins, and other important nutrients for health. The results can be passed on to the next plant, so it is considered more efficient than fortification, which requires increased nutrients every time.

Rice has white, red, purple, and black colours based on its pigment. Pigmented rice contains anthocyanins, which have the potential to be used as a source of antioxidants apart from being a source of starch (Hosoda et al., 2018). Nowadays, red and black rice are known as functional food sources, which not only act as a source of carbohydrates but also as a source of fibre, which is good for health (Purwanto et al., 2018). Red and black rice contains anthocyanins, which act as antioxidants to ward off free radicals and prevent human disease (Priska et al., 2018; Suarni et al., 2020). This potential influences the demand for pigmented rice, which is increasing along with changes in people's lifestyles towards health, especially having a low glycaemic index (GI) suitable for people with diabetes (Mutiyani et al., 2020). The effect of consuming brown rice on decreasing the glycaemic response is thought to be due to the anthocyanin content in brown rice (Cosomn et al., 2017). However, red and black rice development has several obstacles, including low yields and long plant life, so this rice is less popular with farmers (Putri et al., 2017). The introduction of red and black rice varieties with high productivity and a short lifespan is still being introduced. In contrast, red rice cultivars include Inpari 24, Pamelen, Pamera, Inpago 7, and black rice, the Jeliteng type. Each cultivar has a high average DUP yield with a short harvest time (Margaret and Ruskandar, 2020; CRR, 2022; Husna et al., 2022).

The yield potential of a superior variety can be achieved under optimal environmental conditions to contribute to increasing production through fertilization (Damiri et al., 2022). The use of high levels of inorganic fertilizer without being balanced with the provision of organic fertilizer can result in an imbalance of nutrients in the soil. In contrast, organic material plays an important role in improving the soil's physical, chemical, and biological properties (Syawal et al., 2017). Low nutrient levels in organic fertilizers cause their use to be quite large and impact increasing production costs, so new technology is needed to increase productivity.

Nanotechnology can be used for fertilization because it can reduce the size of fertilizer to 1 nm (nanometre) so that absorption by plants is more complete (Rohaeni et al., 2015). Microfertilizers are available in the form of nanoparticles, one of which is silica (Larkunthod et al., 2022). Although silica is not an essential nutrient for plants, it is beneficial mineral that, if present, would be useful for plant growth, especially paddy (Sabatini et al., 2021). Silica fertilizer, especially in nano form, has the advantage of being more reactive, directly reaching the target because of its small size, and only needed in small quantities (Putri et al., 2017).

Nano silica granule plus fertilizer is small granules, so it is easy to spread without being carried by the wind. This is a solid organic fertilizer that improves and rehabilitates the soil in terms of physical, chemical, and biological soil. Made from 30% manure, 20% agricultural waste, 15% silica powder made from straw and another 35% consisting of dolomite and clay powder, it can reduce environmental pollution. Nano silica organic fertilizer is starting to be developed and is expected to increase production cost efficiency and reduce the potential for ecological pollution while increasing paddy production. The Si fertilization can increase phenols, flavonoid, compounds, and phenylalanine ammonia-lyase (PAL) activity, the main key to phenylpropanoid biosynthesis (Jafari et al., 2016). Anthocyanins can be formed from increased synthesis of these flavonoid compounds. The higher concentration of nano silica fertilizer treatment aligns with the increase in anthocyanin content in red rice (Sabatini et al., 2021). Here must be clearly stated objective of the study. Based on this description, this research was conducted to determine the effect of the dose of organic nano silica fertilizer as a source of Si on the growth, yield and quality of various functional paddy. This research is expected to provide recommendations for the right dosage of organic nano silica fertilizer for the best functional paddy cultivar to increase the productivity and quality of functional paddy.

MATERIALS AND METHODS

Functional paddy production

The research was conducted in Manakku Village (4°46'11" S, 119°31'17" E), Labakkang District, Pangkep Regency, South Sulawesi, from May to August 2023. The study was arranged in a split-plot design with randomized complete block, the main plot being various doses of nano silica organic fertilizer consisting of 500 (d1), 1000 (d2), 1500 kg ha^{-1} (d3) and control (d0), as well as subplots of several red rice (*Oryza sativa* L.) cultivars consisting of Inpari 24 (v1), Pamelen (v2), Pamera (v3), Inpago 7 (v4) and the black rice cultivar Jeliteng (v5).

Each treatment was repeated three times to obtain 60 treatment plots. The parameters observed were plant height, flag leaf length, flag leaf width, panicle length, number of productive tillers, grain total, weight of 1000 grains, leaf chlorophyll index, yield, and anthocyanin content. Data analysis was carried out using ANOVA with the least significant difference (LSD) test at a confidence level 0.05. Correlation analysis was carried out using the Pearson Product Moment equation to find out the relationship between characters.

Anthocyanin and proximate analysis

Anthocyanin analysis was carried out based on the method of Lee et al. (2005) and Suzery et al. (2010), which consists of several stages, namely (1) extraction of anthocyanin pigments by crushing the object, then centrifuging for 10 min and taking 5 mL water or extract juice and (2) determining total anthocyanins, using the differential pH method at pH 1.0 and 4.5 to measure the anthocyanin content. Determination of total anthocyanins is carried out by making a solution of pH 1.0 and 4.5 (stock solution), creating an anthocyanin solution by dissolving 5 mL of the object extract in 50 mL each stock solution in a measuring flask, then measuring and calculating the total anthocyanin content at a wavelength of 520 and 700 nm after incubation for 1 h at room temperature and in the dark. Then, the results of the spectrophotometer analysis are calculated using the formula $A = (A_{510} - A_{700})_{pH1.0} - (A_{510} - A_{700})_{pH4.5}$.

Proximate analysis of rice samples includes analysis of ash content (%), water content (%), fat content (%), protein content (%), crude fibre (%) and carbohydrates (%).

Determination of the glycaemic index

This test was carried out after obtaining permission from the Faculty of Public Health, Hasanuddin University’s ethics commission regarding Ethical Approval Number: 6078/UN4.14.1/TP.01.02/2023. The glycaemic index (GI) was determined using five treatment combinations with the highest anthocyanin content and white rice as a comparison, which was cooked and then given to six people as subjects with inclusion criteria aged >18 yr and in good health (not diabetics). The food requirements for each sample are equivalent to 50 g carbohydrates or 50 g pure glucose. Pure glucose is used as a comparison and is consumed as a drink dissolved in 200 mL warm water. Each subject underwent testing with two types of treatment within 1 wk, namely pure glucose on the first day and coloured rice on the seventh day. Subjects fasted (8-10 h) before undergoing testing. The test is conducted by consuming coloured rice and 250 mL water within 10-15 min. Blood was drawn via the capillary blood vessels at the subject’s fingertips (finger-prick capillary) to measure blood glucose levels using HemoCue (HemoCue AB, Ängelholm, Sweden) at 0, 15, 30, 45, 60, 90 and 120 min. The GI obtained is categorized into high (≥ 70), medium (56-69), and low (≤ 55).

RESULTS

The ANOVA results show that all observed characters have a low coefficient of variation with values ranging from 1.84-9.33 (Table 1). Variation in the dose of organic nano silica fertilizer significantly affected almost all observed characteristics except for plant height and 1000 grain weight, while varietal diversity significantly affected almost all observed characteristics except for flag leaf area. Meanwhile, the source of variation in interactions between doses of nano silica organic fertilizer and varieties also had a significant effect on all observed characters. Characters not influenced by the diversity of interactions between the two treatments were not subjected to further analysis in this study.

The results of the correlation analysis in Table 2 are focused on the character of grain production per hectare as the main character. Characters that had a significant positive correlation with the main characters were plant height (0.64**), number of productive tillers (0.74**), total grain number (0.54*), and weight of 1000 grains (0.88**), characters that had a significantly negative correlation namely the character of the leaf chlorophyll index (-0.45*), while the characters that do not correlate with the main character are the character of flag leaf length, flag leaf area, panicle length and anthocyanin content.

Table 1. ANOVA of some growth characters based on split plot design. *Significant effect on 5% level; ns: nonsignificant; D: doses of nano silica organic fertilizer; C: paddy functional cultivar; PH: plant height; FLL: flag leaf length; FLW: flag leaf width; PL: panicle length; NPT: number of productive tillers; GT: grain total; W1000: weight of 1000 grains; LCI: leaf chlorophyll index; Y: yield; AC: anthocyanin content.

Characters	D	Error D	C	D×C	Error C	CV D	CV C
PH	15.22^{ns}	27.82	131.52*	26.56*	9.58	5.18	3.04
FLL	17.38*	3.29	64.92*	12.39*	1.48	5.58	3.75
FLW	0.24*	0.01	0.02^{ns}	0.05*	0.01	5.63	7.58
PL	1.83*	0.21	104.32*	1.89*	0.82	1.84	3.62
NPT	15.73*	3.18	17.43*	6.01*	1.59	7.13	5.05
GT	450.21^{ns}	804.25	11026.91*	830.96*	312.89	16.98	10.59
W1000	2.14^{ns}	1.40	33.62*	1.93*	0.38	5.11	2.66
LCI	1270.7*	231.05	4728*	636.41*	152.08	5.15	4.18
Y	1095688.27*	26823.73	28603016.20*	1689503.86*	9029.58	5.00	2.90
AC	175.20*	2.52	78.23*	68.46*	0.89	9.33	5.55

Table 2. Pearson correlation of selected characters of yield. **Significant effect on 1% level; *significant effect on 5% level; ns: nonsignificant; PH: plant height; FLL: flag leaf length; FLW: flag leaf width; PL: panicle length; NPT: number of productive tillers; GT: grain total; W1000: weight of 1000 grains; LCI: leaf chlorophyll index; Y: yield.

	PH	FLL	FLW	PL	NPT	GT	W1000	LCI	Y
PH	1.00								
FLL	0.02^{ns}	1.00							
FLW	0.07^{ns}	0.34^{ns}	1.00						
PL	0.54*	0.02^{ns}	0.07^{ns}	1.00					
NPT	0.51*	0.29^{ns}	0.37^{ns}	0.06^{ns}	1.00				
GT	0.49*	0.31^{ns}	0.12^{ns}	0.65**	0.38^{ns}	1.00			
W1000	0.57**	0.32^{ns}	0.23^{ns}	0.39^{ns}	0.63**	0.66**	1.00		
LCI	-0.56**	-0.02^{ns}	-0.07^{ns}	-0.56*	-0.15^{ns}	-0.40^{ns}	-0.45*	1.00	
Y	0.64**	0.07^{ns}	0.14^{ns}	0.29^{ns}	0.74**	0.54*	0.88**	-0.45*	1.00

Testing of blood glucose levels used samples of pure glucose and white rice as a comparison, as well as four red rice cultivars (Inpari 24, Pamelen, Pamera and Inpago 7) and one black rice cultivar (Jeliteng) with a dose of organic nano silica fertilizer of 1000 kg ha^{-1} (d2) based on the best anthocyanin content. The percentage increase or decrease in blood glucose levels was calculated seven times, namely initial testing and testing at 15, 30, 45, 60, 90 and 120 min. Based on the results (Figure 1), all test samples experienced increased blood glucose levels from initial testing to testing at 45 min, decreasing until 120 min. In the comparison sample, namely pure glucose, the rise in glucose levels up to 45 min was 33.3 and decreased by 47.5, while in white rice, the increase in glucose levels up to 45 min was 9.1 and decreased by 21.

Testing samples of five cultivars of coloured rice showed that the largest increase in glucose levels from the initial test to 45 min test, respectively, were red rices 'Pamelen' (33.0), 'Pamera' (20.0), 'Inpari 24' (18.0), 'Inpago 7' (16.0) and black rice 'Jeliteng' (12.0), while the largest decrease in glucose levels from 45 to 20 min of testing respectively were red rices 'Pamelen' (29.0), 'Inpari 24' (23.0), 'Inpago 7' (18.0), 'Pamera' (16.0) and 'Jeliteng' black rice (4.0).

The area under the curve and GI of each test sample (Table 3) shows that GI of seven test samples consisting of comparison samples (pure glucose and white rice) and five coloured rice (four cultivars of red rice and one of black rice) which ranged from 58.9%-100.0% with 'Jeliteng' as the test sample with the lowest GI.

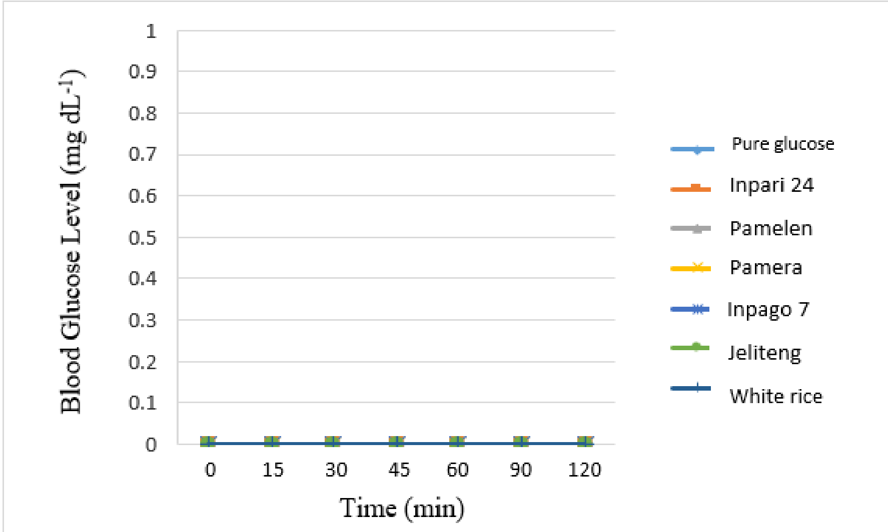

Figure 1. Graph of changes in blood glucose levels.

Table 3. Glycaemic index of studied paddy cultivars.

Sample	Under curve area	Glycemic index (GI)	Category
	Square unit	%	
Pure glucose	723.9	100.0	Comparison standard
Inpari 24	481.5	66.5	Medium
Pamelen	495.0	68.4	Medium
Pamera	478.0	66.0	Medium
Inpago 7	444.1	61.3	Medium
Jeliteng	426.5	58.9	Medium
White rice	522.0	72.1	Comparison

The proximate analysis results (Table 4) show the percentage of proximate content analysis values for the 10 samples' ash, water, fat, protein, crude fibre and extract materials without N (carbohydrate) content. The average weight of ash content ranges 1.01%-1.6%, with the highest ash content by the black rice 'Jeliteng' (control) (1.6%) and the lowest by red rice 'Inpari 24' (nano-silica) (1.01%). The average value of water content ranged 10.10%-10.71%, with the highest water content being black rice 'Jeliteng' (control) (10.71%) and the lowest being red rice 'Pamelen' (control) (10.10%). The average value of fat content ranges 1.34%-1.95%, with the highest fat content of the red rice 'Pamera' (control) (1.95%) and the lowest of the red rice 'Inpari 24' (control) (1.34%). The average value of protein content ranges 7.62%-13.83%, with the highest protein content of black rice 'Jeliteng' (nano silica) (13.83%) and the lowest by red rice 'Inpari 24' (nano silica) (7.62%). The average value of fibre content ranged 1.05%-1.63%, with the highest fibre content of the red rice 'Pamelen' (control) (1.63%) and the lowest by the black rice 'Jeliteng' (control) (1.05%). The average value of carbohydrate content ranges 71.52%-78.20%, with the highest carbohydrate content of the red rice 'Inpari 24' (nano silica) (78.20%) and the lowest by the black rice 'Jeliteng' (nano silica) (71.52%).

Table 4. Value of proximate content analysis of studied rice cultivars. BETN: Extract materials without N (carbohydrate).

Sample	Ash	Water	Fat	Proteins	Coarse fibre	BETN
		%				
Inpari 24 (without nano silica)	1.11	10.48	1.36	9.32	1.37	76.36
Inpari 24 (with nano silica)	1.01	10.69	1.34	7.62	1.14	78.20
Pamelen (without nano silica)	1.22	10.33	1.87	10.10	1.63	74.85
Pamelen (with nano silica)	1.25	10.22	1.78	10.88	1.47	74.40
Pamera (without nano silica)	1.46	10.43	1.95	10.83	1.44	73.89
Pamera (with nano silica)	1.47	10.10	1.91	10.78	1.12	74.62
Inpago 7 (without nano silica)	1.27	10.38	1.68	10.14	1.55	74.98
Inpago 7 (with nano silica)	1.3	10.54	1.74	10.67	1.36	74.48
Jeliteng (without nano silica)	1.6	10.71	1.89	12.26	1.22	72.11
Jeliteng (with nano silica)	1.4	10.37	1.80	13.83	1.05	71.52

DISCUSSION

Efforts to increase production are carried out by providing optimal production technology, one of which is improving the inputs provided. High use of inorganic fertilizers without being balanced with the use of organic fertilizers can result in an imbalance of nutrients in the soil. In contrast, organic materials play an essential role in improving the soil's physical, chemical and biological properties. However, low nutrient levels in organic fertilizer can cause its use to be quite extensive. They will impact increasing production costs, so new technology is needed in providing appropriate plant fertilizer inputs, one of which is the use of nano silica organic fertilizer, which can reduce the fertilizer size to nanometre size so that its absorption by plants is more complete.

Based on the overall cultivar test results, the interaction between the dose of nano silica organic fertilizer and the cultivar had a real to authentic influence on all observed characters. This is also to the results of previous research by Hayati et al. (2021), Sabatini et al. (2021), and Yuniarti et al. (2021). Interaction between doses of organic fertilizer nano silica 1000 kg ha^{-1} and 'Inpago 7' (d2v4) was the interaction between the two most dominant treatments that gave the best results in almost all observed parameters.

The different doses of nano silica organic fertilizer also significantly affected almost all of the observed characters. They were dominated by the 1000 kg ha^{-1} dose of nano silica organic fertilizer as the best dose. These results show that a higher dose of nano silica organic fertilizer can provide better growth than without nano silica organic fertilizer. High silica fertilizer levels affect photosynthesis activities, which are closely related to cell division to produce the best plant growth (Yohana, 2013; Kharisun et al., 2019; Tang et al., 2022). Frasetya et al. (2021) also added that the Si element in nano silica can improve plant growth patterns by influencing the straightness of stems and leaves, which is needed for cell elongation and increasing photosynthesis activities.

Apart from the influence of different nano silica organic fertilizer doses, which is considered crucial in the resulting production, using the suitable cultivar also affects increasing production and the characteristics that support production. Genetic differences in each cultivar can influence the resulting production, whereas, in this study, the red rice 'Inpago 7' (v4) gave the best results in almost all the observed characters. So, adding the correct dose of nano silica organic fertilizer to 'Inpago 7' red rice can increase the best production in this research. Seed weight or production is influenced by genetic factors, making it possible for the results obtained by each treatment to be different because a plant's ability is influenced by the genetic factors of the plant itself (Hayati, 2021).

Biofortification efforts increase the content of micronutrients in staple crops that are widely consumed, one of which is through agronomic practices, namely fertilization (Hartoyo, 2022). Biofortification efforts are carried out from the start of planting through environmentally friendly cultivation by adding nano silica fertilizer made from agricultural and livestock waste in the form of manure, which can increase the availability of nutrients in the soil that plants need so that the nutritional content of rice can be increased even higher. Jafari et al. (2016) added that silica could increase phenol compounds, flavones and PAL activity, which is the primary key in the biosynthesis of phenylpropanoids, and anthocyanins can be formed from increasing the synthesis of these flavonoid compounds. Based on the analysis of anthocyanin content, it was found that the variation in the interaction of nano silica organic fertilizer doses and varieties significantly affected the anthocyanin content. The interaction of 1000 kg ha^{-1} nano silica organic fertilizer dose and black rice 'Jeliteng' (d2v5) was the interaction with the best results, compared to other red rice cultivars. This is thought to be due to the tendency that the blacker the outer skin colour of the rice, the higher the anthocyanin content (Mackon et al., 2021).

Rice colour is genetically regulated due to gene differences that regulate the colour of aleurone, endosperm and starch composition in the endosperm. Brown rice has aleurone, which contains genes that produce anthocyanin as a source of red and purple colour. In contrast, in black rice, the aleurone and endosperm produce a high intensity of anthocyanin, so the rice's colour becomes deep purple, approaching black (Mbanjo et al., 2020). Black rice has high antioxidant and free radical scavenging effects and is very important as a source of natural antioxidant development (Das et al., 2023), while red rice is rich in secondary metabolites such as phenolic acids and quinoline alkaloids and tool compounds (tocopherol and tocotrienol) (Nandhini et al., 2023). The anthocyanin content is closely related to reducing blood glucose levels, in which there are the active compounds cyanidin-3-glucoside which functions to improve insulin resistance and pelargonidin-3-galactoside, which can increase insulin secretion, reduce inflammation and reduce histamine which plays a role as trigger inflammation and reduce levels of the inflammatory factor triggering C-reactive protein (CRP) (Anjani et al., 2018; Angriani, 2019; Ockermann et al., 2021).

Evaluation of the results of a treatment given is closely related to the results of the characters involved. However, using more selection characters causes a more significant error rate and effectiveness of an evaluation, especially if a character has a different direction of variation (Oliveira et al., 2016; Nardino et al., 2020). Correlation analysis can be further used to obtain characters that are considered to have a solid relationship with the main character (Fadhilah et al., 2022). Based on the correlation analysis (Table 2), the results showed that the characteristics of plant height, number of productive tillers, total grain number and weight of 1000 grains had a significant positive correlation with the characteristics of grain production per hectare as the main character. A strong relationship can be shown from a real correlation value, not due to chance but caused by a relationship between the two variables (Schober et al., 2018).

The glycaemic index (GI) concept is closely related to blood sugar levels, where foods with low GI will produce a less steep rise and fall in blood sugar levels shortly after the food is digested and metabolized by the body (Augustin et al., 2015). The effect of consuming pigmented rice on the decreased GI response is thought to be due to the anthocyanin content (Cosomn et al., 2017). Based on the results of GI (Table-6), the black rice 'Jeliteng' (v4) had the lowest GI with an average value of 58.9%. This is thought to be because the amylose content of 'Jeliteng' black rice is higher than that of other coloured rice varieties; this is characterized by the hard/springy nature of the rice. According to Pereira-Caro et al. (2013), the lower the GI, the higher the amylose content, so coloured rice has a lower GI than white rice. The GI of white rice obtained has an average value of 72.1%, higher than that of other coloured rice varieties. Mutiyani et al. (2020) added that white rice has a relatively higher GI than coloured rice because the fibre in coloured rice, such as red and black rice, is higher. A high GI value can quickly increase glucose in the blood.

The GI value is influenced by carbohydrate content, type of carbohydrate, food processing, and other components such as fat, protein, fibre, antinutrients, and organic acids (Kumar and Pandey, 2020). The influence of these factors generally needs to be made clear. Still, there are interactions, so it is difficult to determine the most dominant factor that can influence the final GI value. The highest protein content of the black rice 'Jeliteng' (v4) treated with nano silica fertilizer was 13.83%, causing the GI value to be lower than that of other varieties. This is thought to be because protein can slow down the rate of gastric emptying so that the rate of digestion and absorption in the small intestine becomes slow (Li et al., 2023). The lower the carbohydrate content, the lower the glycaemic load; this is also shown by the black rice 'Jeliteng' (v4), which has the lowest carbohydrate content. In this case, the GI concept only describes how fast and high blood sugar levels rise after consuming coloured rice without paying attention to the number of carbohydrates and their impact on blood sugar levels. Fat content can also influence the GI value of foodstuffs. In this study, the fat content of 'Jeliteng' black rice (v4) treated with nano silica fertilizer was lower than that of 'Pamera' red rice (v3), which had the highest fat content but with a high protein content of 'Jeliteng' has a lower GI value. The crude fibre content in all varieties is low because it is less than 36%, which is the ideal limit (Hussain et al., 2020). The low crude fibre content is thought to be due to the grinding and polishing processes, which reduce the proximate composition (Reddy et al., 2017).

CONCLUSIONS

The research showed that the interaction between the dose of organic nano silica fertilizer was 1000 kg ha^{-1} and red rice 'Inpago 7' (d2v4) provides the best yield of 5.62 t ha^{-1}. Characters that have a significant positive correlation with yield are plant height (0.64**), number of productive tiller (0.74**), grain total (0.54*), and weight of 1000 grains (0.88**). The quality of functional rice based on glycaemic index (GI) analysis showed that the black rice 'Jeliteng' with a dose of organic nano silica fertilizer of 1000 kg ha^{-1} (58.9%) had the lowest GI value.

Author contribution

Conceptualization: R.P., M.F. Methodology: M.F. Software: M.F-A. Validation: Y.M. Formal analysis: R.P. Investigation: S.A-H. Resources: M.F. Data curation: M.F. Writing-original draft: S.A-H. Writing-review & editing: M.F-A. Visualization: Y.M. Supervision: Y.M. Project administration: A.N-F. Funding acquisition: R.P. All co-authors reviewed the final version and approved the manuscript before submission.

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