International Journal of Agriculture and Biosciences 2025 14(1): 136-144.
https://doi.org/10.47278/journal.ijab/2024.197

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

A Novel Approach to Evaluate the Interaction Effects of Nano Silica Bokashi Fertilizer on Several Rice Varieties Using Multivariate Analysis

Abd Haris Bahrun[1], Muhammad Fuad Anshori[1*], Muh Riadi[1], Yunus Musa[1], Muh Farid[1], Nuniek Widiayani[1], Nurlela Nurlela[2], Andi Isti Sakinah[3], Achmad Kautsar Baharuddin[2], Yi Cheng Huang[4] and Madonna Casimero[5]

[1]Hasanuddin University, Department of Agronomy, Faculty of Agriculture, Jl. Perintis Kemerdekaan Km 10, Makassar 90245, South Sulawesi, Indonesia
[2]Hasanuddin University, Agrotechnology Study Program, Faculty of Agriculture, Jl. Perintis Kemerdekaan Km 10, Makassar 90245, South Sulawesi, Indonesia
[3]Hasanuddin University, Agricultural Science Study Program, Graduate School, Makassar 90245, Indonesia
[4]Taiwan International Cooperation and Development Fund (TaiwanICDF), 111047, Taipei, Taiwan
[5]International Rice Research Institute, University of the Philippines Los Baños, 4031, Los Baños, Philippines
*Corresponding author: fuad.anshori@unhas.ac.id

ABSTRACT

The assembly of superior rice varieties requires growth environmental engineering as a motor in optimizing its production. One uses a specific type of fertilizer known as nano silica bokashi. This technology involves the application of nano-sized silica particles, which are encapsulated in a bokashi carrier, to the soil. Evaluating the interaction between this nano silica bokashi fertilizer and several high-yielding varieties is necessary. However, the effectiveness of these technologies must be systematically assessed, so the application of multivariate and index analysis concepts can be a solution in considering fertilizer technology. This study, conducted at the greenhouse of the agricultural faculty at Hasanuddin University from September to December 2023, by using a split-plot design. The main plot factor consisted of nano silica bokashi dosage (four dosages), the subplot being varieties (seven varieties), and three replications, resulting in 96 experimental units. Based on this study, evaluation indices based on flowering age, percentage of filling grain, and yield can give an idea of the potential for responsibility and adaptability in parallel. Notably, early maturing rice varieties, namely Cakrabuana, Padjajaran, and M70D, have shown promising results with adaptive evaluation index (positive index values) and a determination above 0.5. With their potential for early maturation and high yield, these varieties are recommended as effective options for developing nano silica bokashi fertilizer. The optimal dose of the fertilizer ranged from 400-600kg.ha^{-1}.

Keywords: Early-maturity, Nano silica, Organic fertilizer, Orthogonal-polynomials, *Oryza sativa*

Article History
Article # 24-869
Received: 06-Oct-24
Revised: 26-Oct-24
Accepted: 15-Nov-24
Online First: 06-Dec-24

INTRODUCTION

Rice is a crop that belongs to the Gramineae family and is one of the main foodstuffs in the world. This is also true in Indonesia, where Indonesia ranks in the top 5 in world rice production and consumption (Patunru and Ilman, 2019; World Bank Group and Asian Development Bank, 2021). Rice production in Indonesia in the last five years has fluctuated around 54 million tons (Indonesian Statistic, 2024). The dynamics of production are not in line with the increase in population, which continues to increase every year. According to Busari et al. (2022), Indonesia's population growth reaches 1.17% every year, so the government continues to import rice to meet the needs of rice in Indonesia. This reliance on imports presents a significant future risk if domestic rice production challenges are not addressed. Therefore, intensification efforts are essential in boosting national rice production.

Cite this Article as: Bahrun AH, Anshori MF, Riadi M, Musa Y, Farid M, Widiayani N, Nurlela N, Sakinah AI, Baharuddin AK, Huang YC and Casimero M, **2025**. A novel approach to evaluate the interaction effects of nano silica bokashi fertilizer on several rice varieties using multivariate analysis. International Journal of Agriculture and Biosciences 14(1): 136-144. https://doi.org/10.47278/journal.ijab/2024.197

A Publication of Unique Scientific Publishers

Using superior varieties is one of the efforts to increase rice productivity. Several reports have shown the potential of varieties that can support national production, especially in the face of global warming (Hidayat et al., 2020; Paiman et al., 2020; Dar et al., 2021; Sutardi et al., 2023; Singh et al., 2024). Early maturing and functional varieties are some options for optimizing rice production. In general, early maturing varieties have a short vegetative life, but they also have yield potential that does not differ much from that of moderate maturing varieties in Indonesia (Noviana et al., 2021; Musa et al., 2023; Yun et al., 2023; Anshori et al., 2024; Li et al., 2024). Functional varieties improve rice quality and adapt well to climate change (Kobayashi et al., 2023; Rezvi et al., 2023; Haruni et al., 2024). Both types of varieties are considered adaptive in responding to the challenges of an uncertain climate (Rezvi et al., 2023; Haruni et al., 2024). However, to fully leverage the potential of these varieties, additional intensification strategies, such as optimized fertilization, are essential.

Fertilization is the main thing in efforts to engineer the growing environment to increase the productivity of rice plants. Various fertilizers can support this production (Abduh et al., 2021; Dungga et al., 2023). Chemical fertilizers are the main fertilizers in increasing productivity (Hindersah et al., 2022; Musa et al., 2023; Sung et al., 2023; Yassi et al., 2023; Haruni et al., 2024). However, these fertilizers cannot cover all the needs required by plants, especially the unique needs of plants (Siedt et al., 2021; Hindersah et al., 2022; Urmi et al., 2022). Therefore, the use of other types of fertilizers as a support for chemical fertilizers is needed to increase production. One of the supporting fertilizers that plants can give is nano silica bokashi fertilizer.

Nano silica bokashi fertilizer is a combination of bokashi fertilizer and nano-silica. In general, bokashi fertilizer is a composted organic fertilizer that plays a role in improving soil properties, both physically, chemically, and biologically (Gashua et al., 2022; Gebiola et al., 2023; Panday et al., 2024). This role will support sustainable growth and productivity in crops, including rice (Quiroz and Céspedes, 2019; Gashua et al., 2022; Panday et al., 2024). Several studies have also reported the effectiveness of using biofertilizers in rice cultivation. According to Wu et al. (2023), applying biochar has been shown to effectively reduce the negative impacts of drought stress. In addition, according to Kakar et al. (2019), applying biochar fertilizer to rice can increase rice's amylose content, which correlates with its productivity. This indicates that manure can help the role of chemical fertilizers in supporting rice productivity. However, it can also be combined with other fertilizers to expand its potential for crop production. Several research reports have reported the effectiveness of such combinations (Ansar et al., 2021; Novianto et al., 2021; Kruker et al., 2023; Sung et al., 2023). One combination that can be applied is nano silica fertilizer.

Nano silica fertilizer is a fertilizer with silica as the essential element. In general, silica is not crucial to rice plants (Engku Abdullah et al., 2021; Taskin et al., 2023; Pavlovic et al., 2021). However, This fertilizer enhances rice growth by strengthening cell walls, making plant cells more resilient to pathogens and better adapted to environmental changes (Tayade et al., 2022; Cheng et al., 2021; Engku Abdullah et al., 2021; Pavlovic et al., 2021; Ulfianida and Rachmawati, 2024). The utilization of nanotechnology further supports the role of the silica element. According to Shang et al. (2019), de Moraes et al. (2021), Júnior et al. (2022), and Al-Khayri et al. (2023), the use of nanotechnology can change the structure of these elements to be simpler so that these particles can be utilized by plants effectively to improve plant growth and production. Several studies have also reported the successful use of nano fertilizers. According to Cheng et al. (2021), applying nano silica increases the formation of lignin and silica cells that act as plant cell barriers against planthoppers attacks. According to Jiang et al., (2022), nano silica application can also increase root development and photosynthetic efficiency, which supports rice growth. In addition, according to Wu et al. (2023), and Larkunthod et al. (2022), Applying nano silica can enhance inorganic phosphorus levels and reduce peroxide concentration in rice plants under salinity stress. This minimizes the adverse effects of stress, which is linked to the plant's tolerance to salinity. Consequently, nano silica is expected to boost rice productivity, particularly when used effectively in combination with fertilizers. Therefore, evaluating the impact of nano silica bokashi fertilizer on the growth and productivity of various high-yielding rice varieties is a noteworthy area of study. A systematic approach is essential for evaluating the interaction of various technologies on the growth and yield of multiple crop varieties. This concept is also explained by Boomsma and da Costa (2019) and Musa et al. (2023), where the effectiveness of a crop evaluation depends on the systematic analysis concept. This is also inseparable from the many variables in crop evaluation with relatively high interconnectedness (Dey et al., 2024). The situation will be more complex if the evaluation is focused on their interactions, so systematic analyses, such as multivariate analysis, are needed in such evaluations (Abduh et al., 2021; Momen et al., 2021; Musa et al., 2023; Yassi et al., 2023). Multivariate analysis is a powerful approach for managing complex datasets by organizing, summarizing, and reducing numerous variables into a more simplified form, facilitating a clearer interpretation of results (Maione and Barbosa, 2019; Landler et al., 2022). Several studies have reported the effective use of multivariate analysis in rice evaluation (Sushmitharaj et al., 2020; Shrestha et al., 2021; Yassi et al., 2023; Anshori et al., 2024). Therefore, multivariate analysis must be used to evaluate the interaction of nano silica bokashi fertilizer with several high-yielding rice varieties.

This research aims to identify the effective approach in assessing the interaction of nano silica bokashi fertilizer to several superior rice varieties by multivariate analysis. In addition, this research is also expected to determine the best dosage of nano silica fertilizer and its interaction with the growth and productivity of superior rice varieties.

MATERIALS & METHODS

Experimental Design

The research was meticulously conducted at the Green House Centre of Excellence (CoE) Experimental Garden of the Department of Plant Cultivation, Faculty of Agriculture, Hasanuddin University, Makassar City. The research took place from September to December 2023 with a temperature greenhouse according to Fig. 1. The research was arranged in a split-plot design, with the main plot being the dose of nano silica bokashi fertilizer (Table 1) and the subplots being the varieties. Doses of nano silica fertilizer consisted of 4 doses, namely 0g/pot, 1g/pot (200kg ha^{-1}), 2g per pot (400kg ha^{-1}), and 3g per pot (600kg ha^{-1}). Meanwhile, the varieties (V) used consisted of 8 varieties, namely Cakrabuana (v1), Padjajaran (v2), Inpari 19 (v3), Inpari 42 (v4), Baroma (v5), Pamelen (v6), Arumba (v7) and M70D (v8). Based on their combination, there were 32 treatment combinations, and each treatment combination was repeated three times, resulting in 96 experimental units. Each experimental unit consisted of three pots, producing 288 plant pot samples.

Table 1: Chemical composition of nano silica bokashi

Measurable Parameters	Unit	Values
C-organic	%	12.03
N-Total	%	0.53
C/N Ratio	%	23
P_2O_5	%	3.68
K_2O	%	0.8
Ca	%	1.05
Mg	%	4.35
Mn	ppm	92.36
Zn	ppm	16.55
B	ppm	28.07
S	%	0.22
Si	%	12

Notes: C=carbon, N=nitrogen, P2O5: phosphate pentoxide to explain phosphate contains, K2O=potassium oxide to explain potassium contains.

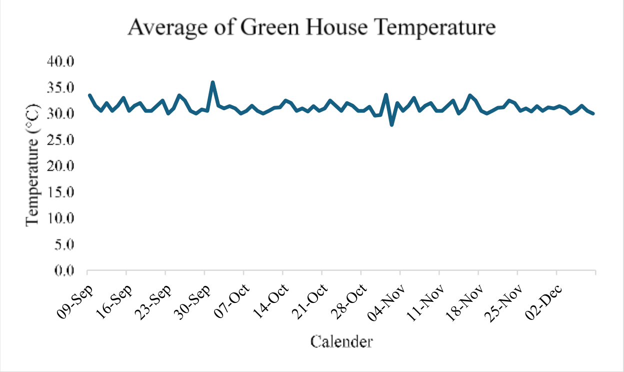

Fig. 1: Temperature in the greenhouse of Hasanuddin University.

Experimental Procedure

The study used Anshori et al. (2018, 2022) approach to cultivate rice in the greenhouse. The study started with container preparation. The bucket is a growth container with a volume of 10L or a topsoil weight of 10kg in each bucket. Before use, the soil was first homogenized and analyzed in the laboratory (Table 2). Furthermore, 4L of water was added to the media and stirred to form mud to prepare the soil for planting. Planting preparation also involves the concept of seedbeds. The seeds are soaked in warm water for 15 minutes and then tended for 24 hours. After the seeds have been soaked, the germinated seeds are sown in soil and compost media with a volume ratio of 1:1 to the volume of the germination container, which is 1kg. After the seeds were 15 days after sowing (DAS), they were planted in buckets and treated with standard operating procedures (SOPs), according to Anshori et al. (2022). Rice maintenance activities in the bucket include watering, weeding, fertilizing, and pest control. Watering is done every day until the soil conditions in the plants are saturated. Irrigation of the plants continues, and at the age of 95 days after planting (DAP), the land is dried until harvest. Weeding is done conventionally by pulling weeds around the plants, especially before organic and non-organic fertilizing. Fertilization of rice plants was carried out three times for chemical fertilizers, namely 10 DAP with NPK fertilizer of 5g bucket^{-1}, 21 DAP with urea fertilizer of 3g bucket^{-1}, and 42 DAP with KNO_3 fertilizer of 3g bucket^{-1}. In contrast, organic fertilizer is adjusted to the treatment randomized in the field. The last maintenance activity is pest control, carried out almost every week and adjusted to integrated pest control. Meanwhile, the final harvesting activity is carried out in stages according to the harvest criteria. Plants are harvested when the seeds have entered the physiological maturity phase with the criteria that 80% of the plants have turned yellow and the rice grains at the base of the panicle have hardened.

Observation and Data Analysis

Data collection focused on morphological and physiological characters. Morphological characters observed included plant height (cm), number of total tillers (stems), number of productive tillers (stems), days to flowering (DAP), days to harvesting (DAP), flag leaf length (cm), panicle length (cm), number of total grains (grains), percentage of filled grain (%) per panicle, weight of 100 grain (g), shoot dry weight (g) and yield per pot (g). The anatomical and physiological characters include stomatal density (n mm^{-2}), chlorophyll a (μmol m^{-2}), chlorophyll b (μmol m^{-2}), and total (μmol m^{-2}), and Leaf area index (LAI) (m2 m^{-2}). The chlorophyll parameter used CCM plus 200+, Opti-Sciences, Inc., Hudson, NH, USA.

Table 2: Analysis of soil components

Variable	Parameter										
	Texture	Clay (%)	Dust (%)	Sand (%)	C-Organic (%)	Total nitrogen (%)	pH-Water	C/N (%)	P Olsen (ppm)	K (cmol (+)kg^{-1})	cation exchange (me/100g)
Value	Dusty Clay	44	46	10	0.98	0.1	5.19	10	8.14	0.19	22.27

Notes: C=carbon, N=nitrogen, P: phosphate, K=potassium

Data analysis was carried out systematically, starting with analysis of variance (ANOVA). ANOVA used a standard alpha of 5%. The evaluation criteria for companion production were determined by significant characteristics. In general, yield is the primary selection character in rice research, so determining other evaluation criteria requires multivariate analysis in stages (Musa et al., 2023; Yassi et al., 2023). Correlation, factor, and path analysis are potential analyses to be combined into an analysis system. In general, correlation analysis can roughly select the alleged relationship of a growth character to yield potential (Abduh et al., 2021; Anshori et al., 2022, 2023; Yassi et al., 2023). The selection results become the basis for factor analysis and path analysis as advanced analyses that identify specific diversity among growth characters (Anshori et al., 2022; Musa et al., 2023; Yassi et al., 2023). Factor analysis can reduce characters by reducing the variance of a variable that does not have a significant internal correlation to a dimension (Shrestha, 2021; Anshori et al., 2022). Meanwhile, path analysis can identify secondary evaluation criteria by partitioning the correlation diversity to obtain the direct influence that plays a role in the diversity of the main evaluation criteria, such as the yield (Thuy et al., 2023; Yassi et al., 2023). Based on this, a combination of all three has the potential to be conducted in this study.

The selection criteria obtained will be used as the basis for a thorough interaction analysis. Index-based interaction analysis can be done by adjusting the weighting value on each selection criterion. The weighting can be based on path analysis (Anshori et al., 2022). The index results are the basis for forming orthogonal-polynomial response curves (Musa et al., 2023). The results of the curve formed are the basis for the effectiveness of the responsiveness and adaptability of a technology package.

RESULTS

Determination and Development of Evaluation Index

The ANOVA results for silica fertilizer and plant varieties are shown in Table 3. Silica fertilizer significantly impacted only the 100-grain weight, harvest age and number of seeds per panicle. In contrast, both the plant varieties and the interaction between nano silica and the varieties significantly affected all agronomic and physiological traits.

The correlation analysis focused on yield characteristics. According to Table 4, the following traits had strong positive correlations with yield: percentage of filled grain (0.80), chlorophyll a (0.40), chlorophyll b (0.39), and total chlorophyll (0.40). Conversely, the following traits showed significant negative correlations with yield: plant height (-0.41), flowering age (-0.72), harvesting age (-0.52), flag leaf length (-0.50), panicle length (-0.46), number of seeds per panicle (-0.51), and shoot dry weight (-0.67). The strongest correlation with yield was the percentage of filled grain. The flowering age had the highest negative correlation and was also significantly correlated with total tiller number (0.34), stomatal density (-0.40), and leaf area index (LAI) (0.34).

The factor analysis revealed 82% of the diversity in the data, with each character having a commonality level of over 50% (Table 5). Factor 1 includes flowering age, harvesting age, number of seeds per panicle, percentage of grain content, and shoot dry weight, all with factor loading values above 0.50. Factor 2 is characterized by chlorophyll a, b, and total. Factor 3 best describes plant height and panicle length.

The results of the path analysis indicated that the coefficient of determination reached 44% (Table 6). The study revealed that flowering age (-0.41) had a significant negative direct effect on productivity. Conversely, the percentage of filled grain (0.57) emerged as the only character with a significant positive direct effect on yield. Additionally, harvest age, the number of seeds per panicle, and shoot dry weight displayed insignificant direct effects. Both characters will be considered in the corrected multivariate interaction analysis of the impact of silica bokashi fertilizer on various growth responses of rice varieties. Based on this approach, the evaluation index formed was:

Index=the yield – 0.41*0.44 days to flowering + 0.57*0.44 percentage of filling grain

Or

Index=the yield - 0.18 days to flowering + 0.25 percentage of filling grain

Table 3: Analysis of variance in the growth of rice characteristics, nano silica Bokashi fertilizer dosage, and various treatments

Characters	Nano silica bokashi (N)	Error a	Variety (V)	N x V	Error b
PH (cm)	61.05	56.14	484.91**	19.89*	9.48
NTT (stems)	25.09	6.24	52.33**	13.90**	3.59
NPT (stems)	39.45*	5.03	39.80**	10.70**	4.47
DF (DAP)	2.54	1.99	333.77**	7.02**	3.01
DH (DAP)	20.57**	0.31	271.64**	8.62**	1.67
FLL (cm)	5.80	16.31	480.57**	13.39*	7.43
PL (cm)	1.09	0.73	12.60**	1.46**	0.66
NTG (grains)	1536.20**	84.46	11667.13**	466.18**	92.37
PFG (%)	63.69	18.67	2156.40**	179.00**	13.58
W100G (g)	0.13*	0.03	0.08**	0.05**	0.01
Yield per pot (g)	69.17	60.87	695.65**	107.23*	54.34
SD (n mm^{-2})	25.51	119.09	212.01*	216.13**	90.26
Chl a (μmol m^{-2})	8.51	15.76	95.79**	46.04**	9.16
Chl b (μmol m^{-2})	1.42	2.96	16.72**	8.32**	1.63
Chl total (μmol m^{-2})	17.31	31.34	190.50**	91.58**	18.22
SDW (g)	12.73	24.79	585.32**	129.86**	5.42
LAI (m2 m^{-2})	0.19	0.21	0.26*	0.23**	0.10

Notes: * Significant effect AT 5% error level, ** significant effect AT 1% error level, PH=plant height, NTT=number of total tillers, NPT=number of productive tillers, DF=days to flowering, DH=days to harvesting, FLL=flag leaf length, PL=panicle length, NTG=number of total grain, PFG=percentage of filled grains, W100G=weight of 100 grains, SD=stomata density, CHL A=chlorophyll A, CHL B=chlorophyll B, CHL TOT=chlorophyll total, SDW=shoot dry weight, LAI=leaf area index.

Table 4: Correlation analysis of growth characteristics in rice with respect to nano silica bokashi fertilizer dosage and variety treatments.

	PH	NTT	NPT	DF	DH	FLL	PL	NTG	PFG	YP	W100G	SC	Chl a	Chl b	Chl tot	SDW
PH (cm)	0.09															
NTT (stems)	0.03	0.87														
NPT (stems)	0.46	0.34	0.13													
DF (DAP)	0.36	0.35	0.14	0.84												
DH (DAP)	0.72	0.35	0.25	0.58	0.58											
FLL (cm)	0.84	0.01	-0.06	0.59	0.42	0.62										
PL (cm)	0.50	0.01	-0.09	0.54	0.42	0.55	0.39									
NTG (grains)	-0.56	-0.37	-0.12	-0.76	-0.61	-0.67	-0.56	-0.61								
PFG (%)	**-0.40***	-0.03	0.21	**-0.72****	**-0.52****	**-0.50****	**-0.46***	**-0.51****	**0.80****							
W100G (g)	-0.01	-0.09	0.00	-0.27	-0.20	-0.07	0.12	-0.33	0.18	0.27						
Yield per pot (g)	-0.09	-0.11	-0.03	-0.40	-0.29	-0.21	-0.18	-0.30	0.27	0.22	0.00					
SD (n mm^{-2})	-0.45	-0.25	-0.04	-0.51	-0.38	-0.35	-0.40	-0.30	0.56	**0.40***	0.16	0.12				
Chl a (µmol m^{-2})	-0.44	-0.25	-0.04	-0.50	-0.36	-0.33	-0.40	-0.29	0.56	**0.39***	0.14	0.12	1.00			
Chl b (µmol m^{-2})	-0.45	-0.25	-0.03	-0.51	-0.38	-0.35	-0.40	-0.30	0.56	**0.40***	0.16	0.12	1.00	1.00		
Chl total (µmol m^{-2})	0.33	0.27	0.09	0.79	0.59	0.53	0.45	0.51	-0.70	**-0.67****	-0.23	-0.50	-0.38	-0.38	-0.39	
SDW (g)	-0.14	0.12	0.01	0.34	0.30	-0.08	-0.11	0.25	-0.04	-0.12	-0.51	-0.11	-0.21	-0.20	-0.21	0.36

Notes: * significant correlation at 5% error level, ** significant correlation at 1% error level, PH=plant height, NTT=number of total tillers, NPT=number of productive tillers, DF=Days to flowering, DH=days to harvesting, FLL=Flag leaf length, PL=Panicle length, NTG=number of total grain, PFG=percentage of filled grains, YP= Yield per pot, W100G=Weight of 100 grains, SD=stomata density, Chl a=chlorophyll a, Chl b=chlorophyll b, Chl tot=chlorophyll total, SDW=shoot dry weight, LAI=Leaf area index.

Table 5: Factor analysis among rice growth characters that correlated with yield per pot

Variable	Factor1	Factor2	Factor3	Communality
PH (cm)	0.168	0.256	-0.924	0.947
DF (DAP)	0.858	0.283	-0.256	0.882
DH (DAP)	0.778	0.166	-0.186	0.666
FLL (cm)	0.492	0.096	-0.71	0.754
PL (cm)	0.282	0.206	-0.825	0.802
NTG (grains)	0.562	0.074	-0.442	0.516
PFG (%)	-0.743	-0.341	0.385	0.817
YP (g)	-0.785	-0.195	0.216	0.701
Chl a (µmol m^{-2})	-0.235	-0.953	0.182	0.997
Chl b (µmol m^{-2})	-0.22	-0.957	0.179	0.996
Chl tot (µmol m^{-2})	-0.235	-0.953	0.182	0.997
SDW (g)	0.842	0.169	-0.154	0.762
Variance (Var)	4.0429	3.1454	2.6495	9.8378
% Var	0.337	0.262	0.221	0.82

Notes: PH=plant height, DF=Days to flowering, DH=days to harvesting, FLL=Flag leaf length, PL=Panicle length, NTG=number of total grains, PFG=percentage of filled grains, YP= Yield per pot, Chl a=chlorophyll a, Chl b=chlorophyll b, Chl tot=chlorophyll total, SDW=shoot dry weight

Table 6: Path analysis of selected growth characteristics in rice based on factor analysis.

Characters	Direct effect	Indirect effect					Correlation
		DF	DH	NTG	PFG	SDW	
DF (DAP)	**-0.41***		0.18	0.00	-0.43	-0.06	-0.72
DH (DAP)	0.22	-0.34		0.00	-0.35	-0.05	-0.51
NTG (grains)	0.01	-0.22	0.09		-0.35	-0.04	-0.51
PFG (%)	**0.57****	0.31	-0.13	-0.01		0.05	0.80
SDW (g)	-0.08	-0.32	0.13	0.00	-0.40		-0.67

Notes: * significant direct effect at 5% error level, ** significant direct effect at 1% error level DF=days to flowering, DH=days to harvesting, NTG=number of total grains, PFG=percentage of filled grains, SDW=shoot dry weight, determination value (R^2)=0.44.

Interaction Analysis Based on Evaluation Index

The interaction analysis results shown in Fig. 2 examine the responses of various rice varieties to a silica binder fertilization technology package. This potential is captured in an index illustrated in the figure, which identifies four distinct patterns of varietal response to silica binder fertilizer dosage. The first pattern is a downward-facing quadratic response, with optimal performance reached at a dosage of 400kg ha-1. The varieties exhibiting this response are Cakrabuana (v1), Arumba (v7), and M70D (v8). The second pattern is also a downward-facing quadratic response, but it performs optimally at 0 grams per pot; the variety corresponding to this pattern is Inpari 42 (v4). The third pattern demonstrates an upward-facing quadratic response, with optimization at 600kg ha-1, including varieties Padjajaran (v2), Inpari 19 (v3), and Baroma (v5). The fourth pattern is another upward-facing quadratic response optimized at 0 grams per pot, which is uniquely exhibited by Pamelen (v6). Additionally, the figure outlines three patterns of adaptability of rice varieties to silica bokashi fertilizer dosage. Some varieties, including Padjajaran, Pamelen, and M70D, consistently display an adaptive response. Other varieties, such as Cakrabuana and Inpari 19, are responsive to silica fertilizer application. Finally, certain varieties demonstrate low adaptability, specifically Inpari 42, Baroma, and Arumba.

DISCUSSION

The analysis of variance showed that the variety and its interaction with nano silica fertilizer significantly affected rice growth characters. This is attractive because the independent treatment of nano silica bokashi fertilizer did not significantly affect almost all these growth characteristics. According to Yassi et al. (2023) and Musa et al. (2023), applying bokasi or compost will impact

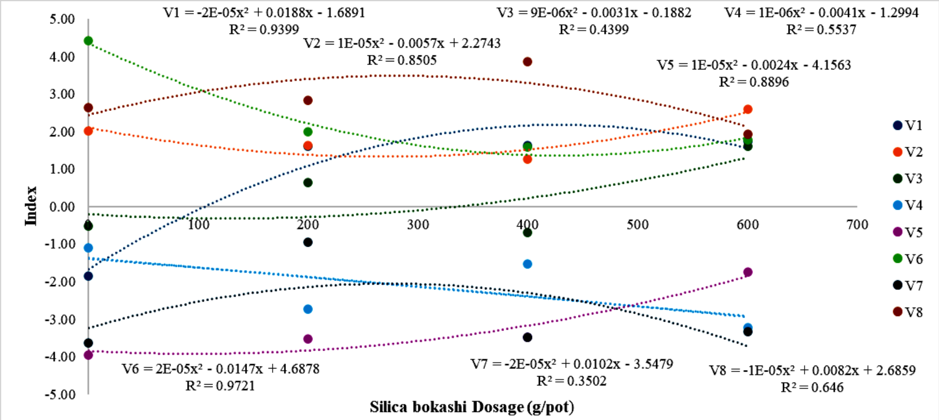

Fig. 2: Index-based orthogonal-polynomial interaction analysis. (V1= Cakrabuana, V2=Padjajaran, V3=Inpari 19, V4=Inpari 42, V5=Baroma, V6=Pamelen, V7=Arumba and V8=M70D).

increasing growth with a clear pattern. In addition, according to Gopal et al. (2024) and Elshayb et al. (2021), Nano silica application consistently affects the growth of rice plants; however, this effect was not seen in this study.In general, the rice varieties used have specific backgrounds. They can be classified into three groups, namely early-maturing white rice varieties (Cakrabuana (v1), Padjajaran (v2), Inpari 19 (v3), and M70D (v8)), medium-maturing white rice varieties (Inpari 42 (v4)) and functional varieties (Baroma (v5), Pamelen (v6), and Arumba (v7). Variations among these groups lead to different response patterns between the varieties. This aligns with the research of He et al. (2024) and Musa et al. (2023), where different variety groups show different response patterns to fertilizer technology. In addition, the fertilizer treatment used in this study combines bokashi and nano-silica fertilizer, so the plant has a specific combination pattern. This is also confirmed by Jiang et al. (2022) and Benavides-Mendoza et al. (2024), where there are differences in plant-specific responses to nano fertilizer technology, including nano-silica. Therefore, the analysis pattern in this study will focus on the interaction between varieties and doses of nano silica bokashi. However, evaluating such interactions requires effective criteria, especially when dealing with significant variables such as this study. This is the essential proof that this study should use multivariate analysis.

Based on the results of multivariate analysis, there are two potential characters to accompany the yield as evaluation criteria. These characters are the percentage of filled grain and flowering age. The percentage of filled grain is a key agronomic factor influencing yield potential (Zhao et al., 2020; He et al., 2024; Liu et al., 2024). The effectiveness of a variety in nutrient distribution and assimilate transport is evident in the percentage of filled grains (Fukai and Mitchell, 2023; Padhan et al., 2023). In addition, using several varieties with different classes will show different responses to the effectiveness of assimilate translocation. This percentage character is often used as a selection or evaluation criteria in controlled experiments, such as this study (Zhao et al., 2020; Sadimantara et al., 2021; Tirtana et al., 2021). Meanwhile, flowering age has the opposite orientation to the percentage of filled grains, which influences yield variation. This is reflected by the tested varieties, which also consist of early maturing varieties, so including this character is a reasonable consideration in analyzing the interaction of varieties and nano fertilizer binder doses. The effectiveness of using plant age as a rice evaluation criterion was also reported by Aristya et al. (2021), Musa et al. (2023), and Anshori et al. (2024). Based on these results, these two criteria are feasible to be used as evaluation criteria for the yield companion in analyzing the interaction index between varieties and doses of nano silica fertilizer.

Interaction analysis is generally carried out through the concept of independent one-by-one character. This concept was also reported by Hastini et al. (2019), Musa et al. (2023), and Yassi et al. 2023) on rice crop evaluation. However, independent assessment is less practical for orthogonal-polynomial interaction analysis with multiple varieties. In addition, the orientation of the evaluation criteria in this study is different, making independent interaction analyses very complex to explore further. This also proves the importance of the index approach in this evaluation. The index approach requires consideration of orientation and weighting. In general, this research focuses on the yield, so the formation of the index will ensure that the weighting of the yield should be higher than that of other selection criteria. This can be approached through the direct effect on the analysis pathway. Direct effect is a description of how much influence a character has on the total variance of the main character (the yield) so that the weighting value based on direct effect can describe the objective weight in the formation of the selection index. This concept is also supported by Alsabah et al. (2019), Akbar et al. (2019), and Anshori et al. (2022), who used this concept as a consideration in forming the orientation and weighting of the index. This indicates that path analysis can also be applied to this study. Path analysis focuses on the value of the direct effect corrected by determination (R^2). Alsabah et al. (2019) and Anshori et al. (2022) also do this.

The index-based interaction analysis reveals distinct patterns of responsiveness and adaptability among genotypes. Ideally, the desired genotypes exhibit strong positive responsiveness and adaptability, characterized by high determination and consistently positive index values, particularly at fertilizer doses of 400 and 600 grams per pot. This assessment is reflected in the genotypes Cakrabuana (v1), Padjajaran (v2), and M70D (v8). However, some varieties experienced a negative response pattern due to an increase in silica fertilizer dose but were still adaptive because they were above the index threshold (Pamelen (v6)). Meanwhile, other varieties are considered less adaptive because they are below the threshold and or have a determination value below 0.5. The concept of index assessment is considered very informative because it can combine the assessment of responsiveness and adaptability to the application of nano silica bokasi fertilizer. Adaptability assessment is one of the keys to a technology being applied and accepted in the farmer's environment (Aryal et al., 2020; Stringer et al., 2020; Anshori et al., 2024). The concept makes the assessment more synergized, informative, and simple, leading to a more accurate interpretation of the results. This differs from the independent concept, which only focuses on the assessment of responsibility and has no connection with other evaluation criteria, making the assessment more complicated to conclude. Therefore, this indexing approach is considered adequate and recommended in evaluating the response of rice varieties to nano silica fertilizer doses.

Based on the overall results, Cakrabuana, Padjajaran, and M70D have good growth and production potential when applied with nano silica fertilizer. However, the Pamelen variety can still be recommended for this fertilizer technology. The three varieties, Cakrabuana, Padjajaran, and M70D, are part of the early-maturing rice group. Early maturing rice varieties generally have a relatively short vegetative life, producing a low potential number of spikelets (Musa et al., 2023; Anshori et al., 2024; Haruni et al., 2024). This potential differs from the new type of rice varieties with many grains per panicle (Abbasi et al., 2022; Nurhidayah et al., 2023), so optimizing the percentage of filled grains is crucial in increasing the production of early maturing rice. The application of nano silica fertilizer is thought to improve the effectiveness of the process of translocation of assimilates to spikelets, resulting in an increase in the percentage of the number of filled grains in early maturing rice (Jiang et al., 2022; Larkunthod et al., 2022). In this study, the optimal nano silica fertilizer dosage for early maturing rice varieties ranged from 400 to 600kg ha^{-1}. However, the dosage cannot be a definite recommendation. The research is still on a controlled environment scale, so information about plant interactions and responses to the natural environment has not been studied. Nevertheless, the results of this study can be a rough reference for further development, especially information on optimal rice varieties for the development of nano silica fertilizer. Therefore, assessing nano silica fertilizer on early maturing rice varieties in the field is recommended for further research development.

Conclusion

Multivariate analysis and index development are adequate for evaluating nano silica bokashi fertilizer dosage on several rice varieties. The results of the multivariate analysis recommended days to flowering and percentage of filling grain as evaluation criteria accompanying the yield in this study. Based on these criteria, the evaluation index is the yield - 0.18 days to flowering + 0.25 percentage of filling grain. The index approach can give an idea of the potential of responsibility and adaptability in parallel. Based on the potential of responsibility and adaptability, early maturing rice varieties Cakrabuana, Padjajaran, and M70D are recommended as effective varieties for developing nano silica bokashi fertilizer. Meanwhile, the optimum nano silica bokashi fertilizer dosage ranges from 400-600kg ha^{-1}. However, the dose cannot be a definite recommendation. However, the results of this dose can be a rough reference for further development, especially information on optimal rice varieties for the development of nano silica fertilizer. Therefore, assessing nano silica fertilizer on early maturing rice varieties in the field is recommended for further research development.

Conflict of Interest: The authors declare there is no conflict of interest.

Acknowledgement: We thank the International Cooperation and Development Fund (ICDF) Taiwan, the International Rice Research Institute and the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia for funding this study over two seasons. Furthermore, we are also thankful for the International Collaboration Research (I-CORE) Program Equity World Class University Indonesia Endowment Fund for Agency (WCU LPDP) 2023-2024 scheme (grant number: 04966/UN4.22/PT.01/.03/2023) in supporting for validation of this study.

Author's Contribution: AHB, MFA, MR, YM, and MF led the project's conceptualization. AHB, MFA, and MF handle data curation. AHB, MFA, and MR carried out formal analysis. Funding acquisition was the responsibility of YCH. NN, AIS, AKB, and NW conducted the investigation. AHB and MFA developed the methodology. MFA and MC were in charge of project administration. YCH, MC, and MFS provided resources. MFA and MR managed the software. YM and MF do the supervision. YM, MR, and NW performed validation. Visualization by MFA and AIS. Writing the original draft involved AHB, MR, NN, and MFA. YM, MF, NW, AIS, AKB, YCH, and MC did review and editing.

REFERENCES

Abbasi, M.F., Din, A.U., & Abbasi, F.M. (2022). Development of new rice strain with improved sink size and source capacity using a multi-parent advanced generation intercross (MAGIC) approach. *SABRAO Journal of Breeding and Genetics*, 54(5), 963–975. http://doi.org/10.54910/sabrao2022.54.5.1

Abduh, A.D.M., R. Padjung, M. Farid, A.H. Bahrun, M.F. Anshori, Nasaruddin, I. Ridwan, A. Nur, & M. Taufik (2021). Interaction of genetic and cultivation technology in maize prolific and productivity increase. *Pakistan Journal of Biological Sciences*, 24, 716–723. https://doi.org/10.3923/pjbs.2021.716.723

Akbar, M.R., Purwoko, B.S., Dewi, I.S., & Suwarno, W.B. (2019). Selection of doubled haploid lines of rainfed lowland rice in preliminary yield trial. *Biodiversitas Journal of Biological Diversity*, 20(10), 2796-2801. https://doi.org/10.13057/biodiv/d201003

Al-Khayri, J. M., Rashmi, R., Surya Ulhas, R., Sudheer, W. N., Banadka, A., Nagella, P., Aldaej, M. I., Rezk, A. A. -S., Shehata, W. F., & Almaghasla, M. I. (2023). The role of nanoparticles in response of plants to abiotic stress at physiological, biochemical, and molecular levels. *Plants*, 12, 292. https://doi.org/10.3390/plants12020292

Alsabah, R., Purwoko, B.S., Dewi, I.S., & Wahyu, Y. (2019). Selection index for selecting promising doubled haploid lines of black rice. *SABRAO Journal of Breeding and Genetics,* 51(4), 430-441. https://research.ebsco.com/linkprocessor/plink?id=2d0b23a7-c83f-33cc-b3cb-10a5b96c55c8

Ansar, M., Darman, S., Thaha, A. R., Angka, A. W and Rahmadanih. (2021). Application of bokashi goat manure and organic liquid fertilizer to improve the growth and yield of Lembah Palu shallot variety. *IOP*

Conference Series: Earth and Environmental Science, 681, 012047. https://doi.org/10.1088/1755-1315/681/1/012047

Anshori, M. F., Musa, Y., Farid, M., Jayadi, M., Bahrun, A. H., Yassi, A., Sulaiman, A. A., Huang, Y. C., Casimero, M., Llorca, L., Suwarno, W. B., Putra, M. M., Sembiring, H., Purwoko, B. S., Wasonga, D. O., & Seleiman, M. F. (2024). A new concept in assessing adaptability index for superior potential cropping intensity in early-maturing rice. *Frontiers in Sustainable Food Systems*, 8. https://doi.org/10.3389/fsufs.2024. 1407880

Anshori, M.F., Purwoko, B.S., Dewi, I.S., Ardie, S.W., Suwarno, W.B., & Safitri, H. (2018). Determination of selection criteria for screening of rice genotypes for salinity tolerance. *SABRAO Journal of Breeding and Genetics,* 50, 279-294. https://research.ebsco.com/linkprocessor/plink?id=0d1df286-b7fa-39d7-976f-8f64cc94d55a

Anshori, M.F., Purwoko, B.S., Dewi, I.S., Suwarno, W.B., & Ardie, S.W. (2022). Salinity tolerance selection of doubled-haploid rice lines based on selection index and factor analysis. *AIMS Agriculture and Food*, 7, 520–535. https://doi.org/10.3934/agrfood.2022032

Anshori, M.F., Purwoko, B.S., Dewi, I.S., Suwarno, W.B., & Ardie, S.W. (2023). Systematic selection to adaptive doubled haploid rice lines under different environments of submergence screening methods. *Journal of Agriculture and Food Research*, 14. https://doi.org/10.1016/j.jafr.2023. 100775

Aristya, V., Trisyono, Y., Mulyo, J., & Taryono, T. (2021). Participatory Varietal Selection for Promising Rice Lines. *Sustainability*, 13, 6856. https://doi.org/10.3390/su13126856

Aryal, J.P., Sapkota, T.B., Khurana, R., Khatri-Chhetri, A., Rahut, D.B., & Jat, M.L. (2020). Climate change and agriculture in South Asia: adaptation options in smallholder production systems. *Environment, Development and Sustainability*, 22, 5045–5075. https://doi.org/10.1007/s10668-019-00414-4

Benavides-Mendoza, A., Juárez-Maldonado, A., Tortella, G., Ojeda-Barrios, D. L., & Fuentes-Lara, L.O. (2024). Differences in crop responses to fertilizers and nanofertilizers. *Nanofertilizer Delivery, Effects and Application Methods*, 16, 299-329. https://doi.org/10.1016/B978-0-443-13332-9.00014-9

Boomsma, C.R., & da Costa, V.A. (2019). Systematic evaluation of field crop performance using modern phenotyping tools and techniques. *Transgenic Plants: Methods and Protocols*, 419-440. https://doi.org/10.1007/978-1-4939-8778-8_26

Busari, A., Rochaida, E., Hasid, Z., & Kurniawan, A. (2022). Population and economic growth nexus: evidence from Indonesia. *Economic Alternatives*, 4, 697–710. https://www.unwe.bg/doi/eajournal/2022.4/EA.2022.4.08.pdf

Cheng, B., Chen, F., Wang, C., Liu, X., Yue, L., Cao, X., Wang, Z., & Xing, B. (2021). The molecular mechanisms of silica nanomaterials enhancing the rice (Oryza sativa L.) resistance to planthoppers (Nilaparvata lugens Stal). Science of The Total Environment, 767, 144967. https://doi.org/10.1016/j.scitotenv.2021.144967

Dar, M. H., Bano, D. A., Waza, S. A., Zaidi, N. W., Majid, A., Shikari, A. B., Ahangar, M. A., Hossain, M., Kumar, A., & Singh, U. S. (2021). Abiotic stress tolerance-progress and pathways of sustainable rice production. *Sustainability*, 13(4), 2078. https://doi.org/10.3390/su13042078

de Moraes, A.C.P., Ribeiro, L. da S., de Camargo, E.R., & Lacava, P.T. (2021). The potential of nanomaterials associated with plant growth-promoting bacteria in agriculture. *3 Biotech*, 11(7), 318. https://doi.org/10.1007/s13205-021-02870-0

Dey, B., Ferdous, J., & Ahmed, R. (2024). Machine learning based recommendation of agricultural and horticultural crop farming in India under the regime of NPK, soil pH and three climatic variables. *Heliyon*, 10(3), e25112. https://doi.org/10.1016/j.heliyon.2024.e25112

Dungga, N.E., Kasim, N., Anshori, M.F., & Muryadi, C.G. (2023). Enhancement of butternut squash (*Cucurbita moschata*) growth and yield through sugarcane waste and banana hump extract application. *Asian Journal of Plant Sciences*, 22, 610–617.

Elshayb, O.M., Nada, A.M., Ibrahim, H.M., Amin, H.E., & Atta, A.M. (2021). Application of silica nanoparticles for improving growth, yield, and enzymatic antioxidant for the hybrid rice EHR1 Growing under Water Regime Conditions. *Materials*, 14(5), 1150. https://doi.org/10.3390/ma14051150

Engku Abdullah, E.H., Misran, A., Yaapar, M.N., Yusop, M.R., & Ramli, A. (2021). The potential of silicon in improving rice yield, grain quality, and minimising chalkiness: A Review. *Pertanika Journal of Tropical Agricultural Science*, 44(3), 655-672. https://doi.org/10.47836/pjtas.44. 3.09

Fukai, S., & Mitchell, J. (2023). Grain yield and protein concentration relationships in rice. *Crop and Environment*, 3(1), 12-24. https://doi.org/10.1016/j.crope.2023.11.002

Gashua, A.G., Sulaiman, Z., Yusoff, M.M., Samad, M.Y.A., Ramlan, M.F., & Salisu, M.A. (2022). Assessment of fertilizer quality in horse waste-based bokashi fertilizer formulations. *Agronomy*, 12(4), 937. https://doi.org/10.3390/agronomy12040937

Gebiola, M., Rodriguez, M. V., Garcia, A., Garnica, A., Tomberlin, J. K., Hopkins, F. M., & Mauck, K. E. (2023). Bokashi fermentation of brewery's spent grains positively affects larval performance of the black soldier fly *Hermetia illucens* while reducing gaseous nitrogen losses. *Waste Management*, 171, 411–420. https://doi.org/10.1016/j.wasman.2023. 09.033

Gopal, D., Prasad, T.N.V.K.V., Pradeep, T., Reddy, C.B.R., NirmalKumar, A.R., Naseeruddin, R., & Naidu, M.V.S. (2024). Effects of nanoparticulate delivery of silicon on the growth and yield of rice (*Oryza sativa* L.). *Silicon*, 16(1), 253-263. https://doi.org/10.1007/s12633-023-02673-3

Haruni, S.A., Padjung, R., Musa, Y., Farid, M., Anshori, M.F., & Fadhilah, A.N. (2024). Functional food biofortification in increasing red and black rice production through the use of nano silica organic fertilizer. *Chilean Journal of Agricultural Research*, 84(3), 362–371. http://dx.doi.org/10.4067/S0718-58392024000300362

Hastini, T., Suwarno, W.B., Ghulamahdi, M., & Aswidinnoor, H. (2019). Correlation and regression among rice panicle branches traits. *Biodiversitas Journal of Biological Diversity*, 20(4), 1140-1146. https://doi.org/10.13057/biodiv/d200428

He, H., Song, L., Wang, W., Zheng, H., & Tang, Q. (2024b). Critical yield components for achieving high annual grain yield in ratoon rice. *Scientific Reports*, 14(1), 23190. https://doi.org/10.1038/s41598-024-74836-0

He, X., Zhu, H., Shi, A., & Wang, X. (2024a). Optimizing nitrogen fertilizer management enhances rice yield, dry matter, and nitrogen use efficiency. *Agronomy*, 14(5), 919. https://doi.org/10.3390/agronomy14050919

Hidayat, R.A., Iskandar, J., Gunawan, B., & Partasasmita, R. (2020). Impact of green revolution on rice cultivation practices and production system: A case study in Sindang Hamlet, Rancakalong Village, Sumedang District, West Java, Indonesia. *Biodiversitas Journal of Biological Diversity*, 21(3). https://doi.org/10.13057/biodiv/d210354

Hindersah, R., Kalay, A.M., & Talahaturuson, A. (2022). Rice yield grown in different fertilizer combination and planting methods: Case study in Buru Island, Indonesia. *Open Agriculture*, 7(1), 871-881. https://doi.org/10.1515/opag-2022-0148

Indonesian Statistic, (2024). Harvest and Production Area Rice in Indonesia 2023. Available at: https://bps.go.id/pressrelease/2023/10/16/2037/Luas-Panen-dan-Produksi-Padi-di-Indonesia-Rilis-16-Oktober-2023.html (Accessed May 1, 2024).

Jiang, Y., Yang, J., Li, M., Li, Y., Zhou, P., Wang, Q., Sun, Y., Zhu, G., Wang, Q., Zhang, P., Rui, Y., & Lynch, I. (2022). Effect of silica-based nanomaterials on seed germination and seedling growth of rice (*Oryza sativa* L.). *Nanomaterials*, 12(23), 4160. https://doi.org/10.3390/nano12234160

Júnior, L. M., Jamróz, E., de Ávila Gonçalves, S., da Silva, R. G., Alves, R. M. V., & Vieira, R. P. (2022). Preparation and characterization of sodium alginate films with propolis extract and nano-SiO2. *Food Hydrocolloids for Health*, *2*, 100094. https://doi.org/10.1016/j.fhfh.2022.100094

Kakar, K., Nitta, Y., Asagi, N., Komatsuzaki, M., Shiotsu, F., Kokubo, T., & Xuan, T. D. (2019). Morphological analysis on comparison of organic and chemical fertilizers on grain quality of rice at different planting densities. *Plant Production Science*, 22(4), 510–518. https://doi.org/10.1080/1343943X.2019.1657777

Kobayashi, K., Wang, X., & Wang, W. (2023). Genetically modified rice is associated with hunger, health, and climate resilience. *Foods*, 12(14), 2776. https://doi.org/10.3390/foods12142776

Kruker, G., Guidi, E.S., Santos, J.M. da S. dos, Mafra, Á.L., & Almeida, J.A. de (2023). Quality of bokashi-type biofertilizer formulations and its application in the production of vegetables in an ecological system. *Horticulturae*, 9(12), 1314. https://doi.org/10.3390/horticulturae9121314

Landler, L., Ruxton, G.D., & Malkemper, E.P. (2022). The multivariate analysis of variance as a powerful approach for circular data. *Movement Ecology*, 10(1), 21. https://doi.org/10.1186/s40462-022-00323-8

Larkunthod, P., Boonlakhorn, J., Pansarakham, P., Pongdontri, P., Thongbai, P., and Theerakulpisut, P. (2022). Synthesis and characterization of silica nanoparticles from rice husk and their effects on physiology of rice under salt stress. *Chilean Journal of Agricultural Research*, 82(3), 412–425. http://dx.doi.org/10.4067/S0718-58392022000300412

Li, J., Yang, C., Zhang, X., Wu, S., Chi, H., Zhang, X., & Wei, C. (2024). Soil nitrogen distribution affects nitrogen utilization and yield of drip-irrigated rice. *Agronomy*, 14(3), 593. https://doi.org/10.3390/agronomy14030593

Liu, K., Zhang, K., Zhang, Y., Cui, J., Li, Z., Huang, J., Li, S., Zhang, J., Deng, S., Zhang, Y., Huang, J., Ren, L., Chu, Y., Zhao, H., & Chen, H. (2024).

Optimizing the total spikelets increased grain yield in rice. *Agronomy*, 14(1), 152. https://doi.org/10.3390/agronomy14010152

Maione, C., & Barbosa, R.M. (2019). Recent applications of multivariate data analysis methods in the authentication of rice and the most analyzed parameters: A review. *Critical Reviews In Food Science and Nutrition,* 59(12), 1868–1879. https://doi.org/10.1080/10408398.2018.1431763

Momen, M., Bhatta, M., Hussain, W., Yu, H., & Morota, G. (2021). Modeling multiple phenotypes in wheat using data-driven genomic exploratory factor analysis and Bayesian network learning. *Plant Direct,* 5(1), 1–12. https://doi.org/10.1002/pld3.304

Musa, Y., Farid, M., Nasaruddin, N., Anshori, M. F., Adzima, A. F., Maricar, M. F., Sulaiman, A., Huang, Y. C., Iswoyo, H., Bahrun, A. H., & Adnan, A. (2023). ustainability approach in cropping intensity (CI) 400 through optimizing the dosage of compost and chemical fertilizers to early-maturing rice varieties based on multivariate analysis. *Journal of Agriculture and Food Research*, 14. https://doi.org/10.1016/j.jafr.2023.100907

Noviana, I., Haryati, Y., Sari, R., & Sunandar, N. (2021). Adaptation to climate change by using drought tolerant and early maturing rice varieties in Majalengka Regency. *IOP Conference Series: Earth and Environmental Science,* 648(1), 012118. https://doi.org/10.1088/1755-1315/648/1/012118

Novianto, E.D., Husen, M.A., & Sugiyarto, S. (2021). The effect of rabbit urine and bokashi addition on the stem growth of shallots (*Allium ascalonicum* L.). *Journal of Natural Sciences and Mathematics Research,* 7(1), 22–27. https://doi.org/10.21580/jnsmr.2021.7.1.11205

Nurhidayah, S., Purwoko, B.S., Dewi, I.S., Suwarno, W.B., & Lubis, I. (2023). Agronomic performance and selection of green super rice doubled haploid lines from anther culture. *Biodiversitas Journal of Biological Diversity,* 24(2). https://doi.org/10.13057/biodiv/d240218

Padhan, B.K., Sathee, L., Kumar, S., Chinnusamy, V., & Kumar, A. (2023). Variation in nitrogen partitioning and reproductive stage nitrogen remobilization determines nitrogen grain production efficiency (NUEg) in diverse rice genotypes under varying nitrogen supply. *Frontiers in Plant Science*, 14, 1093581. https://doi.org/10.3389/fpls.2023.1093581

Paiman, A., Ansar, M., Effendy, I., & Sumbodo, B.T. (2020). Rice cultivation of superior variety in swamps to increase food security in Indonesia. *Reviews in Agricultural Science,* 8, 300–309. https://doi.org/10.7831/ras.8.0300

Panday, D., Bhusal, N., Das, S., & Ghalehgolabbehbahani, A. (2024). Rooted in nature: The rise, challenges, and potential of organic farming and fertilizers in agroecosystems. *Sustainability,* 16(4), 1530. https://doi.org/10.3390/su16041530

Patunru, A., & Ilman, A.S. (2019). *Political economy of rice policy in Indonesia: A perspective on the ASEAN economic opportunity*. Jakarta: Center for Indonesian Policy Studies (CIPS). Available at: https://hdl.handle.net/10419/249429

Pavlovic, J., Kostic, L., Bosnic, P., Kirkby, E.A., & Nikolic, M. (2021). Interactions of silicon with essential and beneficial elements in plants. *Frontiers in Plant Science,* 12. https://doi.org/10.3389/fpls.2021.697592

Quiroz, M., & Céspedes, C. (2019). Bokashi as an amendment and source of nitrogen in sustainable agricultural systems: A review. *Journal of Soil Science and Plant Nutrition,* 19, 237–248. https://doi.org/10.1007/s42729-019-0009-9

Rezvi, H. U. A., Tahjib-Ul-Arif, M., Azim, M. A., Tumpa, T. A., Tipu, M. M. H., Najnine, F., Dawood, M. F. A., Skalicky, M., & Brestič, M. (2022). Rice and food security: Climate change implications and the future prospects for nutritional security. *Food Energy Security*, 12(1), e430. https://doi.org/10.1002/fes3.430

Sadimantara, G.R., Yusuf, D.N., Febrianti, E., Leomo, S., & Muhidin, (2021). The performance of agronomic traits, genetic variability, and correlation studies for yield and its components in some red rice (*Oryza sativa*) promising lines. *Biodiversitas Journal of Biological Diversity,* 22(9), 3994–4001. https://doi.org/10.13057/biodiv/d220947

Shang, Y., Hasan, M.K., Ahammed, G.J., Li, M., Yin, H., & Zhou, J. (2019). Applications of nanotechnology in plant growth and crop protection: A review. *Molecules*, 24(14), 2558. https://doi.org/10.3390/molecules24142558

Shrestha, J., Subedi, S., Singh Kushwaha, U.K., & Maharjan, B. (2021). Evaluation of growth and yield traits in rice genotypes using multivariate analysis. *Heliyon*, 7(9), e07940. https://doi.org/10.1016/j.heliyon.2021.e07940

Shrestha, N. (2021). Factor analysis as a tool for survey analysis. *American Journal of Applied Mathematics and Statistics*, 9(1), 4-11. https://doi.org/10.12691/ajams-9-1-2

Siedt, M., Schäffer, A., Smith, K.E. C., Nabel, M., Roß-Nickoll, M., & van Dongen, J.T. (2021). Comparing straw, compost, and biochar regarding their suitability as agricultural soil amendments to affect soil structure, nutrient leaching, microbial communities, and the fate of pesticides. *Science of the Total Environment*, 751, 141607. https://doi.org/10.1016/j.scitotenv.2020.141607

Singh, P., Sundaram, K. T., Vinukonda, V. P., Venkateshwarlu, C., Paul, P. J., Pahi, B., Gurjar, A., Singh, U. M., Kalia, S., Kumar, A., Singh, V. K., & Sinha, P. (2024). Superior haplotypes of key drought-responsive genes reveal opportunities for the development of climate-resilient rice varieties. *Communications Biology*, 7(1), 89. https://doi.org/10.1038/s42003-024-05769-7

Stringer, L., Fraser, E., Harris, D., Lyon, C., Pereira, L., Ward, C., & Simelton, E. (2019). Adaptation and development pathways for different types of farmers. *Environmental Science & Policy*, 104, 174–189. https://doi.org/10.1016/j.envsci.2019.10.007

Sung, J., Kim, W., Oh, T.K., & So, Y.S. (2023). Nitrogen (N) use efficiency and yield in rice under varying types and rates of N source: Chemical fertilizer, livestock manure compost, and food waste-livestock manure compost. *Applied Biological Chemistry*, 66(1), 4. https://doi.org/10.1186/s13765-022-00766-y

Sushmitharaj, D.V., Arunachalam, P., Vanniarajan, C., Souframanien, J., & Subramanian, E. (2020). Multivariate analysis in rice (*Oryza sativa* L.) mutant families from Anna (R) 4 cultivar. *Indian Journal of Agricultural Research*, 54(6), 769–774. https://doi.org/10.18805/IJARe.A-5348

Sutardi, N., Apriyana, Y., Rejekiningrum, P., Alifia, A. D., Ramadhani, F., Darwis, V., Setyowati, N., Setyono, D. E. D., Gunawan, N., Malik, A., Abdullah, S., Muslimin, N., Wibawa, W., Triastono, J., Yusuf, N., Arianti, F. D., & Fadwiwati, A. Y. (2022). The transformation of rice crop technology in Indonesia: Innovation and sustainable food security. *Agronomy*, 13(1), 1–14. https://doi.org/10.3390/agronomy13010001

Taskin, M.B., Akca, H., Babar, S.K., Kadioglu, Y.K., Deniz, K., Kan, S., & Gunes, A. (2023). Evaluating the comparative effects of acid modified rice husk and nano-silicon derived from rice husk on phosphorus use efficiency in wheat and lettuce plants with differing silicon contents. *Journal of Plant Nutrition*, 46(10), 2329-2341. https://doi.org/10.1080/01904167.2022.2155535

Tayade, R., Ghimire, A., Khan, W., Lay, L., Attipoe, J.Q., & Kim, Y. (2022). Silicon as a smart fertilizer for sustainability and crop improvement. *Biomolecules*, 12(8), 1027. https://doi.org/10.3390/biom12081027

Thuy, N.P., Trai, N.N., Khoa, B.D., Thao, N.H.X., Phong, V.T., & Thi, Q.V.C. (2023). Correlation and path analysis of association among yield, micronutrients, and protein content in rice accessions grown under aerobic condition from Karnataka, India. *Plant Breed and Biotechnology*, 11(2), 117–129. https://doi.org/10.9787/PBB.2023.11.2. 117

Tirtana, A., Purwoko, B.S., Dewi, I.S., & Trikoesoemaningtyas, (2021). Selection of upland rice lines in advanced yield trials and response to abiotic stress. *Biodiversitas Journal of Biological Diversity*, 22(10, 4694–4703. https://doi.org/10.13057/biodiv/d221063

Ulfianida, D., & Rachmawati, D. (2024). Effect of silicon priming on germination and growth of rice (*Oryza sativa* L.) in drought condition. *BIO Web of Conferences*, 94, 06007. https://doi.org/10.1051/bioconf/20249406007

Urmi, T. A., Rahman, M. M., Islam, M. M., Islam, M. A., Jahan, N. A., Mia, M. a. B., Akhter, S., Siddiqui, M. H., & Kalaji, H. M. (2022). Integrated nutrient management for rice yield, soil fertility, and carbon sequestration. *Plants*, 11(1), 1–17. https://doi.org/10.3390/plants11010138

World Bank Group, & Asian Development Bank (2021). Indonesia climate risk country profile. Available at: www.worldbank.org

Wu, Y., Wang, X., Zhang, L., Zheng, Y., Liu, X., & Zhang, Y. (2023). The critical role of biochar to mitigate the adverse impacts of drought and salinity stress in plants. *Frontiers in Plant Science*, 14, 1163451. https://doi.org/10.3389/fpls.2023.1163451

Yassi, A., Farid, M., Anshori, M.F., Muchtar, H., Syamsuddin, R., & Adnan, A. (2023). The integrated minapadi (rice-fish) farming system: Compost and local liquid organic fertilizer based on multiple evaluation criteria. *Agronomy*, 13(4), 978. https://doi.org/10.3390/agronomy13040978

Yun, Y., Kim, G., Cho, G., Lee, Y., Yun, T., & Kim, H. (2023). Effect of nitrogen application methods on yield and grain quality of an extremely early maturing rice variety. *Agriculture*, 13(4), 832. https://doi.org/10.3390/agriculture13040832

Zhao, H., Mo, Z., Lin, Q., Pan, S., Duan, M., Tian, H., Wang, S., & Tang, X. (2020). Relationships between grain yield and agronomic traits of rice in southern China. *Chilean Journal of Agricultural Research*, 80(1), 72–79. http://dx.doi.org/10.4067/S0718-58392020000100072