PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.4840

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Effect of integrated nutrient management practices on nutrient uptake, yield and quality of improved black kavuni rice variety (CO57)

A. Udhaya[1], S Radhamani[1*], G Senthil Kumar[1], V Ravichandhran[2], P Janaki[3] & S Manonmani[4]

[1]Department of Agronomy, TNAU, Coimbatore, Tamil Nadu - 641 003, India
[2]Department of Crop Physiology, TNAU, Coimbatore, Tamil Nadu - 641 003, India
[3]Nammazhvar Organic Farming, Research Centre, TNAU, Coimbatore, Tamil Nadu - 641 003, India
[4]Department of Rice, CPBG, TNAU, Coimbatore, Tamil Nadu - 641 003, India

*Email: subhamythili@yahoo.co.in

OPEN ACCESS

ARTICLE HISTORY
Received: 28 August 2024
Accepted: 16 September 2024
Available online
Version 1.0 : 29 September 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Udhaya A, Radhamani S, Kumar GS, Ravichandhran V, Janaki P, Manonmani S. Effect of integrated nutrient management practices on nutrient uptake, yield and quality of improved black kavuni rice variety (CO57). Plant Science Today (Early Access).https:/doi.org/10.14719/pst.4840

Abstract

The rising demand for high-quality rice and rice products motivates farmers to produce traditional rice varieties. Rice production needs to be substantially increased with suitable nutrient management practices to meet the demand. Hence, the present study was carried out to evaluate the influence of integrated nutrient management practices on nutrient uptake, yield and quality of improved black kavuni rice. The research was conducted during the *Early kar* (April-August 2023) and *Late samba* (September-January 2023-24) seasons in a randomized block design (RBD) with three replications and twelve treatments consisting of N in equivalent basis with organic manure and inorganic fertilizers and one control. Based on an N equivalent basis, the required quantity of inorganic fertilizer, farmyard manure (FYM), vermicompost (VC) and poultry manure (PM) were applied to rice. Observations on nutrient uptake, yield and quality were recorded and the data were analyzed using LSD at a 5% probability level for significance differences. The results revealed that higher nutrient uptake, yield and quality parameters of rice were recorded with 50% recommended dose of nitrogen through inorganic fertilizer + 50% recommended dose of nitrogen through VC + foliar spray of 0.5% $ZnSO_4$ & 1% $FeSO_4$ at tillering, panicle initiation (PI) and flowering stage (T_{11}).

Keywords

Improved kavuni; nutrient uptake; quality; yield

Introduction

In Asia, rice is one of the significant stable food crops. The majority of people consume white rice, which has been linked to a higher risk of diabetes. Its high glycemic index increases blood glucose levels (1). Considering this issue, the consumer prefers traditional rice varieties. The medicinal and nutritional properties of each kind of conventional rice are unique. Traditional rice varieties are high in fibre and rich in nutrients like calcium, riboflavin, thiamine, vitamin D and glutamic acids. They are low in fat, sugar and gluten. It contains oryzanol, a compound that reduces fat production in the body, making it an excellent dietary choice for diabetics (2).

According to (3,4), there are approximately 1200 different types of traditional rice in Tamil Nadu, including Mappillai Samba, Karuppu kavuni, Karunguruvai, Atthur Kichali Samba, Thanga Samba, Vadan Samba, Iluppaipoo Samba, Garudan Samba, Anai komban, Ganda Sali, Chinnar, Kala Namak, Kattuyanam, Kudavazhi, Kuzhiyadichan, Kottara Samba, Kothamallisamba, Singinikar, Seeraga Samba, Surakurvai, Sempalai, Salem Sanna, Thuyamalli, Thengaipoo Samba, Bhavani, Basumathi, Poongar, Kullakkar, Kuruvikkar, Ponni, Manjal Ponni, Muttrinasannam, Maraththondi, Rasakkadam and Rattha Sali, *etc.* Karuppu kavuni has higher anthocyanin content, phenolic acids, flavonoids and carotenoids and it has lower total soluble sugar, fat, and protein than traditional rice varieties. It also contains Fe, Mn, Zn, Cu, salt, K and Mg minerals. It has anti-arthritic, anti-diabetic and antioxidant properties (5).

Despite its favourable nutritional quality, kavuni rice is not widely cultivated among farmers due to its phenological properties such as photosensitivity, long duration, poor tillering and lower yield than current varieties (6). Meanwhile, the improved black kavuni rice variety CO 57 released from TNAU in 2023 is photoinsensitive and suitable for all seasons. It gives more yield (55.74 %) than traditionally cultivated black kavuni rice. Its high fibre, protein and low carbohydrate content give it excellent nutritional value. It inhibits a rise in blood sugar levels because of its lower glycemic index. Due to the presence of flavonoids, it also has an anticancer property (7). These high-yielding varieties require more nutrients to boost productivity (8).

High-yielding rice varieties remove higher amounts of macro and micronutrients from the soil (9). Nutrient management is a crucial component of the soil and plant management system. Farmers have recently relied on chemical fertilizers, particularly macronutrients, to boost rice yields. It leads to many problems, mainly rapidly declining soil fertility, which damages soil physicochemical properties and soil and water quality, resulting in global environmental issues (10, 11). Thus, applying organic manures restores soil health and sustains productivity over time. Using organic manures with chemical fertilizers may have reduced N loss and increased availability for extended periods (12).

Using organic manures offers numerous benefits because it provides a balanced nutrient supply. According to (13), the balanced application of nutrients from various organic sources such as farmyard manure (FYM), poultry manure (PM) and vermicompost (VC) along with inorganic fertilizers is essential to maintain soil fertility and achieve optimal crop yields. (14) stated that appropriate nutrient management techniques are now a crucial part of recent rice production technology to ensure productivity. An appropriate combination of inorganic and organic nutrient sources can increase rice productivity and quality without harming the ecosystem. With this view, the present study was planned to evaluate the effect of INM practices on nutrient uptake, yield and quality of improved black kavuni rice.

Materials and methods

Experimental site

The field experiment was conducted at Wetland Farm, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, during the *Early kar* (April - August 2023) and *Late samba* (September - January 2023-24) seasons. It was located at 11°01'06" N Latitude, 76°58'21" E Longitude and 426.7 m above MSL. The soil of the experimental field was clay loam in texture with a pH range of 8.12 and 8.00, and EC was 0.47 and 0.45 dsm^{-1}. The soil nutrient status was low in available $KMnO_4$- nitrogen (215 and 226 kg ha^{-1}, respectively) (15), medium in Olsen available phosphorus (20.8 and 21.9 kg ha^{-1}, respectively) (16) and high in available NH_4O Ac- potassium (569 and 585 kg ha^{-1}, respectively) (17).

Experimental design and treatments

The experimental design consisted of twelve treatments with three replications, laid out in a Randomized Block Design. The treatment details of the experiment are provided in Table 1. Before application, the N content was analyzed in different organic manures and the quantity was determined. The nitrogen content of FYM, PM and VC were 0.43, 2.92 and 2.26 per cent, respectively.

Crop management

The rice variety CO 57 (Improved black kavuni) was used in this experiment. Organic manures are applied basally per the treatment schedule before transplanting rice seedlings. The recommended dose of N (150 kg ha^{-1}) was used per the treatment schedule. N and K were applied at basal, tillering, panicle initiation and heading stages. Full dose of P was applied at basal. N content in different organic manures was analyzed and the required quantity was determined.

Nutrient uptake analysis

Plant samples were analyzed for different nutrients. The total nitrogen, phosphorus, potassium and micronutrients were estimated following the Kjeldahl distillation (18), Spectrophotometer (18), Flame photometer (18) and Inductively Coupled Plasma Optical Emission spectroscopy (ICP - OES) (19), respectively at 90 DAT.

Table 1. Treatment details

	Treatments
T_1	Control (Without fertilizer)
T_2	100 % RDN* through inorganic fertilizer
T_3	50 % RDN through inorganic fertilizer + 50 % RDN through FYM
T_4	50 % RDN through inorganic fertilizer + 50 % RDN through PM
T_5	50 % RDN through inorganic fertilizer + 50 % RDN through VC
T_6	50 % RDN through inorganic fertilizer + 25 % RDN through PM + 25 % RDN through VC
T_7	T_4+ Foliar application of 0.5 % $ZnSO_4$ + 1 % $FeSO_4$ at Tillering and PI stage
T_8	T_5+ Foliar application of 0.5 % $ZnSO_4$ + 1 % $FeSO_4$ at Tillering and PI stage
T_9	T_6+ Foliar application of 0.5 % $ZnSO_4$ + 1 % $FeSO_4$ at Tillering and PI stage
T_{10}	T_4+ Foliar application of 0.5 % $ZnSO_4$ + 1 % $FeSO_4$ at Tillering, PI and Flowering stage
T_{11}	T_5+ Foliar application of 0.5 % $ZnSO_4$ + 1 % $FeSO_4$ at Tillering, PI and Flowering stage
T_{12}	T_6+ Foliar application of 0.5 % $ZnSO_4$ + 1 % $FeSO_4$ at Tillering, PI and Flowering stage

Yield

Grain yield from the net plots was calculated and expressed in kg ha^{-1} at a grain moisture content of 14 per cent. After sun drying, the weight of straw from each net plot was recorded and represented in kg ha^{-1}.

Physical Quality

Rice length and breadth were measured using a vernier calliper and expressed in mm (20). The ratio between length and breadth was used to determine the grain shape, as suggested by (20).

Cooking quality

Kernel length and breadth after cooking were measured using graduated cardboard and expressed in mm (21). The linear elongation ratio was calculated using the following formula (21).

$$\text{LER} = \frac{\text{Length of cooked rice (mm)}}{\text{Length of raw rice (mm)}}$$

Breadth wise expansion ratio of rice was calculated using the following formula, as proposed by (21).

$$\text{BER} = \frac{\text{Breadth of cooked rice (mm)}}{\text{Breadth of raw rice (mm)}}$$

The known weight of the rice sample was cooked in boiling water until its optimum cooking time. To determine water absorption ratio, the cooked rice was weighed and wiped to remove any remaining water without losing solids (22).

$$\text{Water absorption ratio} = \frac{\text{Weight of cooked rice (g)}}{\text{Weight of raw rice (g)}}$$

The water displacement method measured the initial rice volume in a graduated measuring cylinder. After that, the rice was cooked in boiling water and its volume was measured again using the water displacement method (22).

$$\text{Volume expansion ratio} = \frac{\text{Volume of cooked rice (ml)}}{\text{Volume of raw rice (ml)}}$$

Biochemical quality

Anthocyanin content was estimated using the pH difference method, as proposed by (23). The following formula is used to determine the total anthocyanin content.

$$\text{Total anthocyanin (mg/g)} = \frac{AxMWxDFx10^3}{Ex1}$$

The amylose content was estimated using the (24) simplified method.

To determine the total nitrogen content, the grain sample was first digested using a digestion mixture, followed by 0.1 N sulfuric acid distillation. The crude protein content was then calculated from the N content by multiplying the total N by 6.25 (25).To determine true protein content, use the (26) method.

Statistical analysis

To test for significant differences among the 12 treatment means, data were analyzed using R software version 4.2.0 (R Studio 2022.02.3 + 492). The significance difference was found at the 5% level. The relationship between nutrient uptake and rice yield was assessed by Pearson correlation analysis.

Results

Nutrient uptake

During *Early kar* and *Late samba* seasons, among the various treatments the highest N (94.3 and 96.4 kg ha^{-1}), P (17.2 and 18.3 kg ha^{-1}), K (90.0 and 96.7 kg ha^{-1}), Zn (261 and 295 g ha^{-1}) and Fe (1469 and 1502 g ha^{-1}) uptake was noticed in plot supplied with 50% RDN through inorganic fertilizer + 50% RDN through VC + foliar application of nutrients (0.5% $ZnSO_4$ & 1% $FeSO_4$ at tillering, PI and flowering stage) (T_{11}). It was comparable with 50% RDN through inorganic fertilizer + 50% RDN through VC + foliar application of nutrients (0.5% $ZnSO_4$ & 1% $FeSO_4$ at tillering and PI stage) (T_8). Unfertilized control (T_1) recorded lower N, P, K, Fe and Zn uptake (Fig. 1 and 2).

Grain yield

During *Early kar* and *Late samba* seasons, grain yields were influenced by INM practices are presented in Fig. 3. Higher grain yields (3972 and 4114 kg ha^{-1}, respectively) were recorded with the combined application of 50% RDN through inorganic fertilizer + 50% RDN through VC + foliar application of nutrients (0.5% $ZnSO_4$ & 1% $FeSO_4$ at tillering, PI and flowering stage) (T_{11}). However, treatment

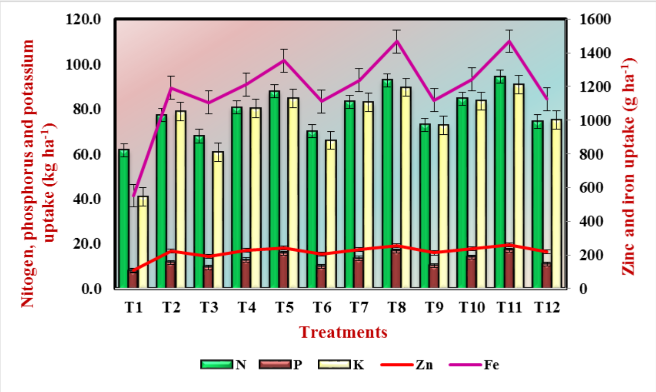

Fig. 1. Effect of INM practices on nutrient uptake of improved traditional black kavuni rice (*Early kar*, 2023)

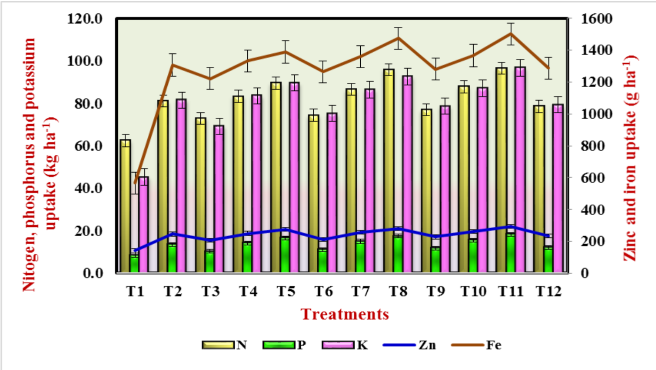

Fig. 2. Effect of INM practices on nutrient uptake of improved traditional black kavuni rice (*Late samba*, 2023-24)

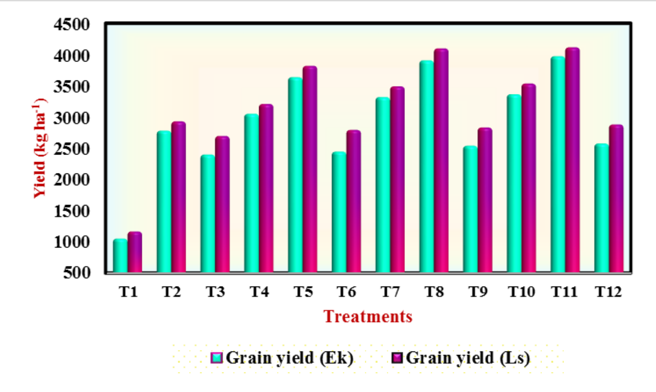

Fig 3. Effect of INM practices on grain yield (kg ha^{-1}) of improved traditional black kavuni rice (*Eary Kar*, 2023 and *Late Samba*, 2023-24) Ek- *Eary Kar*; Ls - *Late Samba*

T_{11} was on par with treatment T_8, where foliar spraying was done twice at the tillering and PI stages. The lowest grain (1052 and 1166 kg ha^{-1}, respectively) were recorded under treatment without application of nutrients, control (T_1) in both *Early kar* and *Late samba* seasons.

Physical and cooking quality

Among different INM practices, there was no significant difference in physical and cooking quality characters during the *Early kar* and *Late samba* seasons, presented in Tables 2, 3 & 4. The maximum kernel length and kernel breadth before and after cooking, length breadth ratio, linear elongation ratio, breadth-wise expansion ratio, water absorption ratio and volume expansion ratio were recorded under plot received with 50% RDN through inorganic fertilizer + 50% RDN through VC + foliar application of nutrients (0.5% $ZnSO_4$ & 1% $FeSO_4$ at tillering, PI and flowering stage) (T_{11}). The minimum physical and cooking quality characters were recorded in the control plot (T_1). The kernel length of more than 5 mm was classified as medium size.

Biochemical quality

Different nutrient sources significantly influenced the biochemical characteristics of rice grain in both seasons, as shown in Table 5. During *Early kar* and *Late samba* seasons,

Table 2. Effect of INM practices on physical quality characters of improved traditional black kavuni of rice (*Early kar*, 2023 and *Late samba*, 2023-24)

Treatments	Physical quality*					
	Early kar (2023)			*Late samba* (2023-24)		
	KLBC (mm)	KBBC (mm)	LBR	KLBC (mm)	KBBC (mm)	LBR
T_1	5.69	2.02	2.82	5.71	2.03	2.81
T_2	6.35	2.13	2.98	6.40	2.14	2.99
T_3	6.22	2.10	2.96	6.23	2.10	2.97
T_4	6.37	2.13	2.99	6.42	2.15	2.99
T_5	6.47	2.16	3.00	6.50	2.17	3.00
T_6	6.24	2.10	2.97	6.29	2.11	2.98
T_7	6.40	2.14	2.99	6.46	2.16	2.99
T_8	6.51	2.17	3.00	6.54	2.18	3.00
T_9	6.27	2.11	2.97	6.32	2.12	2.98
T_{10}	6.42	2.15	2.99	6.46	2.16	2.99
T_{11}	6.54	2.18	3.00	6.58	2.19	3.00
T_{12}	6.29	2.11	2.98	6.32	2.12	2.98
SEd	0.15	0.11	0.15	0.32	0.11	0.15
CD (P=0.05)	NS	NS	NS	NS	NS	NS

*KLBC- Kernel length before cooking / KBBC- Kernel breadth before cooking /LBR - Linear breadth ratio

Table 3. Effect of INM practices on cooking quality characters of improved traditional black kavuni of rice (*Early kar*, 2023)

Treatments	Cooking quality*					
	KLAC (mm)	KBAC (mm)	LER	BER	WAR	VER
T_1	7.00	2.40	1.23	1.19	2.47	1.96
T_2	7.96	2.60	1.25	1.22	2.60	2.10
T_3	7.71	2.54	1.24	1.21	2.51	2.00
T_4	8.02	2.63	1.26	1.23	2.62	2.14
T_5	8.20	2.68	1.27	1.24	2.70	2.20
T_6	7.75	2.55	1.24	1.21	2.54	2.03
T_7	8.05	2.64	1.26	1.23	2.66	2.17
T_8	8.24	2.70	1.27	1.24	2.73	2.25
T_9	7.86	2.56	1.25	1.21	2.57	2.06
T_{10}	8.07	2.65	1.26	1.23	2.68	2.18
T_{11}	8.29	2.71	1.27	1.24	2.75	2.27
T_{12}	7.88	2.58	1.25	1.22	2.58	2.08
SEd	0.39	0.13	0.06	0.06	0.13	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS

*KLAC- Kernel length after cooking/ KBAC - Kernel breadth after cooking/ LER - Linear Elongation Ratio/ BER- Breadth Wise Elongation Ratio/ WAR- Water Absorption Ratio/ VER- Volume Expansion Ratio

Table 4. Effect of INM practices on cooking quality characters of improved traditional black kavuni of rice (*Late samba*, 2023-24)

Treatments	Cooking quality*					
	KLAC (mm)	KBAC (mm)	LER	BER	WAR	VER
T_1	7.01	2.42	1.23	1.19	2.50	1.99
T_2	8.00	2.63	1.25	1.23	2.65	2.13
T_3	7.72	2.55	1.24	1.21	2.54	2.04
T_4	8.04	2.64	1.25	1.23	2.67	2.15
T_5	8.26	2.70	1.27	1.24	2.75	2.23
T_6	7.78	2.56	1.24	1.21	2.57	2.06
T_7	8.09	2.65	1.25	1.23	2.70	2.18
T_8	8.30	2.74	1.27	1.26	2.78	2.27
T_9	7.87	2.57	1.25	1.21	2.59	2.09
T_{10}	8.12	2.67	1.26	1.24	2.72	2.20
T_{11}	8.33	2.75	1.27	1.26	2.79	2.29
T_{12}	7.90	2.59	1.25	1.22	2.61	2.11
SEd	0.39	0.13	0.06	0.06	0.13	0.11
CD (P=0.05)	NS	NS	NS	NS	NS	NS

* KLAC- Kernel length after cooking/ KBAC - Kernel breadth after cooking /LER- Linear Elongation Ratio/ BER- Breadth Wise Elongation Ratio / WAR- Water Absorption Ratio /VER- Volume Expansion Ratio

Table 5. Effect of INM practices on biochemical quality characters of improved traditional black kavuni of rice (*Early kar*, 2023 and *Latesamba*, 202324)

Treatments	Biochemical quality							
	***Early kar* (2023)**				***Late samba* (2023-24)**			
	Anthocyanin (mg g^{-1})	Amylose (%)	Crude protein (%)	True protein (%)	Anthocyanin (mg g^{-1})	Amylose (%)	Crude protein (%)	True protein (%)
T_1	115.7^{d}	17.20^{g}	6.00^{d}	4.60^{e}	118.8^{d}	18.20^{f}	6.25^{e}	4.60^{e}
T_2	131.0^{bc}	20.10^{cdef}	7.59^{c}	5.30^{cd}	133.9^{c}	21.50^{cd}	7.73^{cd}	5.40^{bcd}
T_3	125.5^{c}	18.90^{f}	7.34^{c}	5.00^{d}	128.7^{c}	20.00^{e}	7.45^{d}	5.10^{d}
T_4	131.6^{bc}	20.30^{bcdef}	7.67^{bc}	5.30^{cd}	134.6^{c}	21.80^{bcd}	7.88^{cd}	5.40^{bcd}
T_5	136.1^{ab}	21.10^{bc}	7.90^{abc}	5.50^{abc}	137.0^{bc}	22.30^{bc}	8.08^{bc}	5.60^{abc}
T_6	126.7^{c}	19.10^{ef}	7.41^{c}	5.10^{cd}	131.5^{c}	20.70^{de}	7.57^{cd}	5.20^{cd}
T_7	132.9^{bc}	20.50^{bcde}	7.70^{bc}	5.40^{bcd}	135.7^{c}	22.00^{bcd}	7.94^{cd}	5.50^{abcd}
T_8	143.6^{a}	21.80^{ab}	8.22^{ab}	5.70^{ab}	145.6^{ab}	23.10^{ab}	8.61^{ab}	5.70^{ab}
T_9	129.5^{bc}	19.50^{def}	7.49^{c}	5.20^{cd}	132.4^{c}	20.80^{cde}	7.64^{cd}	5.20^{cd}
T_{10}	134.2^{bc}	20.90^{bcd}	7.76^{bc}	5.40^{bc}	136.3^{c}	22.10^{bcd}	8.00^{cd}	5.50^{abcd}
T_{11}	145.0^{a}	22.70^{a}	8.51^{a}	5.80^{a}	147.1^{a}	23.90^{a}	8.72^{a}	5.90^{a}
T_{12}	129.8^{bc}	19.90^{cdef}	7.55^{c}	5.20^{cd}	133.0^{c}	21.00^{cde}	7.69^{cd}	5.30^{bcd}
SEd	4.5	0.74	0.28	0.18	4.72	0.73	0.28	0.18
CD (P=0.05)	9.33	1.53	0.58	0.37	9.78	1.52	0.58	0.38

Same alphabets are on par with each other.

combined application of 50% RDN through inorganic fertilizer + 50% RDN through VC + foliar application of nutrients (0.5% $ZnSO_4$ & 1% $FeSO_4$ at tillering, PI and flowering stage) (T_{11}) recorded higher anthocyanin content (145.0 and 147.1 mg g^{-1}, respectively), amylose content (22.7 and 23.9%, respectively), crude protein (8.51 and 8.72%, respectively) and true protein (5.80 and 5.90%, respectively) content. It was at par with 50% RDN through inorganic fertilizer + 50% RDN through VC + foliar application of 0.5% $ZnSO_4$ & 1% $FeSO_4$ at tillering and PI stage (T_8). The lowest biochemical quality was recorded under the control plot (T_1).

Correlation analysis

Correlation analysis was carried out to assess rice's nutrient uptake and yield. Results showed that uptake of nitrogen (0.97 and 0.97), phosphorous (0.95 and 0.96), potassium (0.96 and 0.97), zinc (0.96 and 0.98) and iron (0.97 and 0.95) of rice were positively correlated with grain yield in both *Early kar* and *Late samba* seasons, respectively (Fig. 4).

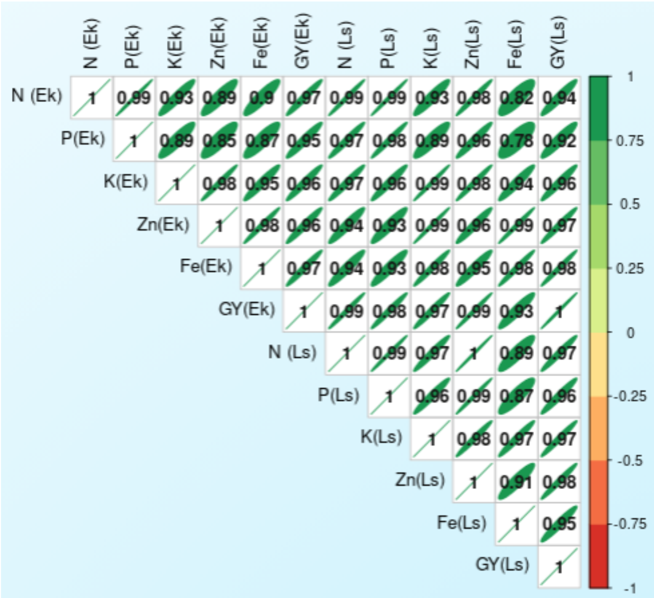

Fig. 4. Correlation between nutrient uptake and grain yield (kg ha^{-1}) of improved traditional black kavuni rice (*Early Kar*, 2023 and *Late Samba*, 2023 -24)

Discussion

Nutrient uptake

Higher nutrient uptake could be attributed to increased dry matter production by combining organic and inorganic fertilizers. The improved performance under the combined application of inorganic fertilizer and vermicompost may also result from a favourable soil environment, which might have promoted better root proliferation and ensured higher nutrient uptake (27, 28).

The higher nitrogen uptake might have increased due to the steady availability of nutrients from inorganic sources at earlier stages and the slower release from VC. Additionally, nitrogen is a vital component of the chlorophyll molecule, enabling the plant to absorb sunlight for photosynthesis. This drives vegetative growth and ultimately, greater nitrogen uptake, leading to higher yields (29). Nitrogen uptake is determined by nitrogen content and biomass production. The notable increase in nitrogen content, combined with higher yield under the application of inorganic fertilizer and VC, boosted the overall nitrogen uptake. This is because plants absorb more nitrogen due to the increased pool of available nitrogen in the soil from the applied nutrients. These results are closely conformed with the findings of (30).

The increased availability of phosphorus could result from the solubilization of native phosphorus by organic acids produced during the decomposition of organic manure. This process leads to better utilization of available phosphorus. Additionally, the organic manure, which contains nitrogen, may have boosted the soil's organic phosphorus content, thereby enhancing phosphorus availability and resulting in higher phosphorus uptake by rice plants. These results align with the findings of (31). INM practices improve the efficiency of phosphorus absorption mechanisms and promote root growth, enhancing phosphorus uptake. VC increases microbial activity in the soil, leading to higher availability of phosphorus and its uptake. Combining inorganic and organic nutrient sources facilitates the synthesis of DNA and RNA, the fundamental genetic materials. It promotes the development, maintenance, and repair of all tissues and cells in crop plants (32). This process boosts phosphorus uptake in crops.

The increase in potassium uptake can be attributed to the enhancement of photosynthesis, energy transfer and nutrient movement within plants, facilitated by proper fertilization through organic and inorganic nutrient sources. Additionally, this could enhance crop plants' absorption of various minerals. This results in increased carbohydrate mineralization, which might have contributed to higher plant potassium uptake. These results confirm the results of (33, 34).

The increase in Zn and Fe uptake with the application of these micronutrients is likely due to their enhanced bioavailability. The combined application of Zn, Fe and nitrogen sources might further boost Zn and Fe levels by promoting the synthesis of Zn and Fe regulator proteins, which facilitate their translocation in crops potentially due to improved root growth, leading to increased uptake by root tips and transfer to the phloem. Similar findings were observed by (35, 36). Foliar application of $ZnSO_4$ and $FeSO_4$ combined with organic and inorganic fertilizers enhanced and balanced the availability of essential plant nutrients. Organic fertilizers contributed to sustained nutrient release over a prolonged period. The simultaneous release of organic acids, acting as chelating agents, might have facilitated micronutrient availability and absorption, which might have resulted in increased micronutrient uptake. These results conform to the findings of (37).

Grain yield

The highest grain yield might be due to the combined effects of yield attributes, enhanced photosynthetic efficiency, and improved capacity of reproductive sinks to utilize incoming assimilates due to the foliar application of Zn and Fe. Additionally, it enhances protoplasmic elements and supports physiological functions such as chlorophyll and protein synthesis, thereby increasing straw yield (38). Due to the slow release and continuous supply of nutrients in balanced quantities throughout various growth stages, rice plants can assimilate sufficient photosynthetic products. This leads to an increase in dry matter and source capacity, producing more panicles with a higher number of fertile grains, increased test weight and higher grain and straw yields. These results agree with the findings of (39, 40). The combined application of N-based inorganic and organic manures increased grain and straw yield. This could be attributed to enhanced photosynthesis rates, as nitrogen is a crucial component of chlorophyll. This process led to the accumulation of photosynthate in the vegetative parts of the plants, thereby improving growth and yield. These results corroborate the findings of (41).

Physical and cooking quality

The application of different sources of nutrients could not cause much variation in rice's physical and cooking quality. (42, 43) reported that combined application of organic and inorganic nutrients could not cause much variation in the physical (Kernel length (7.19), kernel breadth (2.42) and length breadth ratio (2.97)) and cooking quality (Kernel length (9.90) and breadth (2.67) after cooking, water absorption ratio (3.27), linear elongation ratio (1.37), breadth wise elongation ratio (1.10), volume expansion ratio (3.12) of rice due to various nitrogen management practices.

Biochemical quality

Anthocyanins are crucial secondary metabolites and constitute a significant subclass of flavonoids responsible for the colouration of rice plant tissues. The buildup of anthocyanin in plants serves various roles, including UV radiation protection, involvement in hormone regulation and response to both biotic and abiotic stresses. The highest anthocyanin content might be due to the combined application of inorganic and organic nitrogen sources. The nitrogen application has been linked to increased grain anthocyanin content, which could be a crucial factor in promoting protein synthesis within the anthocyanin synthesis pathway in plant tissues (44). Foliar -sprayed Zn and Fe significantly influenced gene expression in phenolic biosynthesis pathways, increasing anthocyanin content. These results align with the findings of (45).

The amylose content is the most crucial biochemical indicator of rice quality. Improved and adequate nutrition from organic manure, ensuring a steady supply of nutrients, may have increased total amylose content (46). The improvement in rice amylose content could be attributed to the enhanced availability of both macro and micronutrients, balanced fertilization and a continuous supply of nutrients achieved through the combined use of organic manure and inorganic fertilizers (47). Greater availability, absorption, and uptake of nutrients through INM practices lead to increased nutrient levels in the grain, which results in higher amylose content. The use of organic nutrients, particularly VC, resulted in higher amylose content, which is positively linked to the desirable texture of cooked rice (48).

INM practices led to higher protein content due to increased soil nitrogen availability and subsequent plant uptake. Micronutrients enhance the chemical composition of grain and act as catalysts, promoting essential organic reactions within the plants, thus improving protein content in rice grain (49). Nitrogen is a critical component of protein. It is vital in synthesizing amino acids and accumulating protein in plants (50). The consistent supply of nitrogen and its effective translocation to the grain altered the proportion of grain components by increasing the nitrogen levels. The higher nitrogen level within the grain enhances the plant's metabolic activities and increases the protein content. These results are consonant with the findings of (51).

Correlation analysis

Higher grain yield could be attributed to enhanced nutrient uptake by the plant, promoting optimal growth of plant components and metabolic processes such as photosynthesis. This results in increased accumulation and translocation of photosynthate to the economically valuable parts of the plant, thereby leading to higher yields (52). Food nutrient uptake by crops is directly proportional to dry matter production and grain and straw yield. The increased grain yield has resulted due to higher nutrient uptake in rice (53). Applying organic manures enhances microbial activity, releasing various organic acids that solubilize native soil nutrients and making them available for plant macro and micronutrient uptake, resulting in higher productivity. These results confirm the results of (54).

Conclusion

The results revealed that INM practices, *viz.,* application of inorganic fertilizers along with VC and foliar application of $ZnSO_4$ and $FeSO_4$ at tillering, PI and flowering stage, are a practical approach for enhancing nutrient uptake, productivity and quality of improved traditional black kavuni rice. INM is essential for achieving sustained and high-quality rice production. This approach promotes the careful and balanced use of organic and chemical inputs to enhance soil health and boost yield in an eco-friendly manner, thereby mitigating nutrient depletion issues.

Acknowledgements

The authors express their gratitude to Tamil Nadu Agricultural University for furnishing the necessary facilities for conducting the research on integrated nutrient management in rice, which will culminate in this research.

Authors' contributions

Udhaya A: Wrote the first draft of the paper. Radhamani S: Conceptualized, reviewed and edited the research paper holistically. Senthil Kumar G, Ravichandhran V, Janaki P and Manonmani S: Reviewed the paper and shared their inputs for upscaling.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None.

References

1. Bhavadharini B, Mohan V, Dehghan M, Rangarajan S, Swaminathan S, et al. White rice intake and incident diabetes: A Study of 132,373 Participants in 21 Countries. Diabetes Care. 2020; 43: 2643-650. https://doi.org/10.2337/dc19-2335 .
2. Kowsalya P, Sharanyakanth PS, Mahendran R. Traditional rice varieties: A comprehensive review on its nutritional, medicinal, therapeutic and health benefit potential. J Food Compos Anal. 2022; 114. https://doi.org/10.1016/j.jfca.2022.104742
3. Karpagalakshmi S, Brindha KA. Study on farmer's production of traditional rice varieties in Thanjavur District of Tamil Nadu. Journal of Electronics Information Technology Science and Management. 2020; 14:540-46
4. Jalapathi E, Jerlin R, Raja K, Raveendran M, Thiruvengadam V. Evaluation of biochemical properties of traditional rice varieties of Tamil Nadu. International Journal of Plant & Soil Science. 2020; 34: 39-46. https://doi.org/10.9734/ijpss/2022/v34i1731034
5. Jency JP, Sangeetha VR. Traditional rice grains as functional food. Food and Scientific Reports. 2023; 4:36-39.
6. Theiventhiran T, Vasantha S, Amutha S, Hemalatha G, Vellaikumar S, Umamaheswari T. Nutrient content for newly improved breeding rice lines from parentage of the Kavuni and CO_{50}. Curr J Appl Sci Technol. 2021; 40: 41-49. https://doi.org/10.9734/cjast/2021/v40i331283
7. TNAU Agritech Portal. 2023. https://agritech.tnau.ac.in/agriculture/CO%2057.html
8. Batabyal S, Gangopadhyay S, Das N, Pal S, et al. Effect of integrated nutrient management on the growth and productivity of four high-yielding rice varieties of Eastern India. J Environ Biol. 2024; 45: 465-75. https://doi.org/10.22438/jeb/45/4/MRN-5214
9. Saleque MA, Abedin MJ, Bhuiyan NI, Saman SK, Panaullah GM. Long-term effects of inorganic and organic fertilizer sources on yield and nutrient accumulation of low land rice. Field Crops Res. 2004; 86: 53-65. https://doi.org/10.1016/S0378-4290(03)00119-9.

10. Maruthupandi K, Jayanthi C. Integrated nutrient management in rice-gingelly-maize cropping system yield and system economics through integrated farming system. Int J Curr Microbiol App Sci. 2018; 7: 3564-74. https://doi.org/10.20546/ijcmas.2018.709.442

11. Selim M. Potential role of cropping system and integrated nutrient management on nutrients uptake and utilization by maize grown in calcareous soil. Egyptian Journal of Agronomy. 2018; 40: 297-12. https://doi.org/10.21608/agro.2018.6277.1134 .

12. Swamy GVVSN, Masina S, Tanmoy S, Sagar M, et al. Various approaches for nutrient management in rice (*Oryza sativa* L.). Agro Economist - An International Journal. 2020; 7: 123-27.

13. Ramesh S, Vaiyapuri V. Yield potential and economic efficiency of rice (*Oryza sativa*) as in influenced by organic nutrition under Cauvery deltaic region of Tamil Nadu. Plant Archives. 2008; 8: 621-22.

14. Shamal S, Kumar, Ashraf Sultan, Adiba Ejaz, Radha Krishna J. Integrated nutrient management in rice- A Critical Review. Global Scientific Journal. 2021; 9: 1385-400.

15. Asija G, Subbiah B. A rapid procedure for the estimation of available nitrogen in soils. Current Science. 1956; 25: 259-60.

16. Olsen S, Cole C, Watanabe F. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA. Circ. 1954; 939-43.

17. Stanford G, English L. Use of the flame photometer in rapid soil tests of K. Canadian Journal of Agronomy. 1949; 41: 446-47. https://doi.org/10.2134/agronj1949.00021962004100090012x .

18. Jackson ML. Prentice Hall of India Ltd. New Delhi, 1973; 100.

19. Lindsay WL, Norvell W. Development of a DTPA soil test for zinc, iron manganese and copper. Soil Sci Soc Am J. 1978; 42: 421-28. https://doi.org/10.2136/sssaj1978.03615995004200030009x

20. Kaul AK. Earlier generation testing for quality characters II, Rice. Indian J. Genet., 1970; 303: 237-43.

21. Azzez MA, Shafi M. Quality in rice. West Pakistan Tech. Bulletin. 1966; 13: 50.

22. Juliano BO. Rice Starch: Production, Properties and Uses. In: Whistler RL, BeMiller JN and Paschall EF, Eds, Starch Chemistry and Technology, Academic Press, Orlando. 1985;507-28. https://doi.org/10.1016/B978-0-12-746270-7.50022-7

23. Giusti MM, Rodriguez-Saona LE, Wrolstad RE. Spectral characteristics, molar absorptivity and color of pelargonidin derivatives. J Agric Food Chem. 1999; 47: 4631-637. https://doi.org/10.1021/jf981271k

24. Juliano BO. The Rice caryopsis and its composition. In: Houston DF (ed) Rice chemistry and technology, American Association of Cereal Chemists, Philippines. 1972; 16-74

25. Humphries E. Mineral components and ash analysis. Moderne methoden der Pflanzenanalyse/Modern methods of plant analysis: Erster band/volume I. 1956; 468-02. https://doi.org/10.1007/978-3-662-25300-7_17

26. Lowry OC, Rosebrough N, Farr A, Randall R. Protein measurement with the Folin phenol reagent. J Biol Chem. 1951; 193:265-75. https://doi.org/10.1016/S0021-9258(19)52451-6

27. Kumar S, Agrawal S, Jilani N, Kole P, et al. Effect of integrated nutrient management practices on growth and productivity of rice: A review. J Pharm Innov. 2023; 12:2648-662.

28. Sangothari A, Radhamani S, Janaki P, Ravichandran V, et al. Effect of arbuscular mycorrhizal fungi and different combination of foliar application of nutrients on nutrient uptake and yield of aerobic rice. Agricultural Science Digest. 2024; 44: 265-69. https://doi.org/10.18805/ag.D-5814 .

29. Singh M, Deokaran Mishra JS, Bhatt BP. Effect of integrated nutrient management on production potential and quality of summer mungbean (*Vigna radiata* L.). J Krishi Vigyan. 2019; 5:39-45. https://doi.org/10.5958/2349-4433.2017.00009.5

30. Kantwa CR, Saras PK, Vyas KG, Chaudhari HL, et al. Effect of wheat varieties and integrated nutrient management practices on nutrient content, uptake and soil nutrient status. Indian Journal of Agricultural Research. 2023; 1. https://doi.org/10.18805/IJARe.A-6050

31. Ajaykumar R, Sivakumar SD. Effect of integrated nutrient management on growth, physiological, nutrient uptake, root and yield parameters of transplanted lowland rice. Current Journal of Applied Science and Technology. 2020; 39:35-43. https://doi.org/10.9734/cjast/2020/v39i4031110

32. Barkha MK, Arvadia N, Joshi, Vaghela TD. Effect of integrated nutrient management on growth, yield, nutrient uptake and soil nutrient status of summer green gram (*Vigna radiata* L.) under south Gujarat conditions. Int J Chem Stud. 2020; 8: 2675-78. https://doi.org/10.22271/chemi.2020.v8.i5ak.10721

33. Chauhan, Sahil, Jay NP, Mohd SA. Effect of integrated nutrient management on nutrient content and their uptake by Mung Bean Crop (*Vigna radiata* L.) under mid hill conditions of Himachal Pradesh. Journal of Scientific Research and Reports. 2024; 30: 611-21. https://doi.org/10.9734/jsrr/2024/v30i72174

34. Gupta R, Patel JN, Alam MS. Effect of integrated nutrient management on nutrient content and their uptake by Soybean Crop (*Glycine max* L.). Journal of Scientific Research and Reports. 2024; 30: 1021-032. https://doi.org/10.9734/jsrr/2024/v30i72212

35. Dhaliwal SS, Sharma V, Shukla AK, Verma V, et al. Interactive effects of foliar application of zinc, iron and nitrogen on productivity and nutritional quality of Indian mustard (*Brassica juncea* L.). Agronomy. 2021; 11: 2333. https://doi.org/10.3390/agronomy11112333

36. Singh P, Saini SP. Micronutrient's availability in soil-plant system as influenced by long-term integrated nutrient management under rice-wheat cropping. Journal of Plant Nutrition. 2022; 45: 457-70. https://doi.org/10.1080/01904167.2021.1943680

37. Mohapatra S, Vivek A, Ujjwal T, Gurjar J, Mishra T, et al. Influence of micronutrient application on nutrient content, uptake and residual soil nutrient status in rice (*Oryza sativa* L.) in Western Uttar Pradesh Condition. Int J Plant and Soil Sci. 2023; 35: 253-59. https://doi.org/10.9734/ijpss/2023/v35i203805

38. Rath B. Effect of INM on growth and yield of rice in south and coastal plain of Odisha. Pharm J. 2021; 2287-890.

39. Mangaraj S, Paikaray RK, Maitra S, Pradhan SR, et al. Integrated nutrient management improves the growth and yield of rice and greengram in a rice-greengram cropping system under the coastal plain agro-climatic condition. Plants. 2022; 11: 142. https://doi.org/10.3390/plants11010142

40. Neti S, Sidar RS, Singh VK, Yadav D. Effect of integrated nutrient management on rice (*Oryza sativa* L.) yield under Surguja district. J Pharm Innov. 2022; 11: 3473-476.

41. Chandrika S, Prathibha Sree S, Jaffar Basha S, Madhu Vani P. Yield and economics of black rice as influenced by integrated nutrient management practices. Biological forum - An International Journal. 2024; 16: 106-09.

42. Yadav S, Lal M, Naresh RK, Yadav RB, Yadav AK, et al. Effect of organic and inorganic nutrient sources on productivity, grain quality of rice and soil health in north-west IGP: A Review. Int J Curr Microbiol Appl Sci. 2019; 8: 2488-514. https://doi.org/10.20546/ijcmas.2019.812.293

43. Dambale AS, Goswami J, Sharma KK, Kurmi K, Das KN, Das R. Qualitative assessment of black rice under an organic ecosystem of Northeast India. 2024. https://doi.org/10.33545/2618060X.2024.v7.i3i.499

44. Fongfon S, Prom-u-thai C, Pusadee T, Jamjod S. Responses of purple rice genotypes to nitrogen and zinc fertilizer application on grain yield, Nitrogen, Zinc and Anthocyanin Concentration. Plants. 2021; 10: 1717. https://doi.org/10.3390/plants10081717

45. Utasee S, Jamjod S, Lordkaew S, Prom-U-Thai C. Improve anthocyanin and zinc concentration in purple rice by nitrogen and zinc fertilizer application. Rice Sci. 2022; 29: 435-50. https://doi.org/10.1016/j.rsci.2022.07.004
46. Ajaykumar R, Sivasabari, K. Eco-Friendly management practices on quality characteristics of transplanted rice (*Oryza sativa* L.) as influenced by organic manures. International Journal of Environment and Climate Change. 2020; 10: 193-01. https://doi.org/10.9734/ijecc/2020/v10i1230296
47. Banotra M, Sharma BC, Kumar R. Influence of using inorganic fertilizers, FYM and vermicompost on basmati rice (*Oryza sativa*). Int J Agric Sci. 2022; 18: 542-46. https://doi.org/10.15740/HAS/IJAS/18.1/542-546
48. Rao IJ, Rao CS, Prasad PRK, Rao CP, Jayalalitha K. Effect of manures and phosphorus on yield and quality under rice-blackgram cropping sequence. International Journal of Plant and Soil Science. 2023; 35: 1024-034. https://doi.org/10.9734/ijpss/2023/v35i193639
49. Krishnaprabu N, Myrtle Grace T, Balakrishnan K, Vijayalakshmi R. Influence of integrated and organic nutrient management on yield and biochemical properties in traditional red rice landraces (*Oryza sativa* L.). J Pharmacogn Phytochem. 2017; 6: 2413-417
50. Bhuriya KP, Nagar VL, Bamaniya VP, Parg KL. Effect of integrated nutrients management on nutrients content and uptake of forage sorghum. Int J Plant & Soil Sci. 2022; 34: 1457-461.https://doi.org/10.9734/ijpss/2022/v34i232563
51. Mangaraj S, Paikaray RK, Garnayak M, Rpradhan S, Behera SD. Integrated nutrient management module to improve productivity and economics of short grain aromatic rice (*Oryza sativa*)-greengram (*Vigna radiata*) sequence. Indian J Agric Sci. 2023; 93: 1002-006. https://doi.org/10.56093/ijas.v93i9.111116
52. Lahari S, Hussain SA, Parameswari YS, Sharma SH. Grain yield and nutrient uptake of rice as influenced by the nano forms of nitrogen and zinc. Int. J. Environ. Clim. Change. 2021; 11: 1-6. https://doi.org/10.9734/ijecc/2021/v11i730434
53. Mohan G, Gohain T, Tzudir L, Singh AP, Nongmaithem D. Study on yield, nutrient content and nutrient uptake of rice-based intercropping system as influenced by integrated nutrient management. Biological Forum - An International Journal. 2023; 15: 141-146.
54. Vineela K, Subramanyam D, Karuna Sagar G, Naga Madhuri KV, et al. Nutrient uptake and yield of rice as influenced by different systems of rice cultivation and organic nutrient management practices. J Res ANGRAU. 2024; 52: 30-38. https://doi.org/10.58537/jorangrau.2024.52.1.04