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Research Article

Effects of Organic and Chemical Farming on Growth, Yield Components and Bioactive Compounds of Three Fragrant Thai Rice Varieties

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Abstract

Background and Objective: The organic and chemical cultivation of rice impacts yield and important compounds in the rice grains. This research studied how organic and chemical rice cultivation affected the growth and yield of rice as well as the bioactive compounds in fragrant rice grains. **Materials and Methods:** Experimental design was laid out in Randomized Complete Block Design (RCBD) with six treatments and three replications. This experimental research utilized two factors. The first was three varieties of fragrant rice (Hom Bai Toey, Hom Chong Sakae and KDML105), while second was two rice planting systems (organic and chemical paddy fields), using the transplanting method with a spacing of 25×25 centimeters with three repetitions. **Results:** The three fragrant rice varieties grown in organic fields had lower plant height, panicle length, number of grains per panicle, number of filled grains per panicle, seed set percentage, and grain yield compared to those grown in chemical fields. However, the organic rice fields showed higher 2-AP contents and gamma-oryzanol in brown rice grains than chemically cultivated fields for the three fragrant rice varieties. The percentage of amylose under both cultivation systems ranged from 17.98% to 21.64%, with a decrease in amylose content reflecting an increase in GABA concentration. **Conclusion:** Organic and chemical cultivation affected rice growth and grain yield. Organic cultivation resulted in higher nutrition levels and bioactive compounds such as gamma oryzanol and 2-AP than chemical cultivation but this also depended on rice variety.

Key words: Bioactive compounds, chemical cultivation, indigenous fragrant rice, organic cultivation

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Rice (*Oryza sativa* L.) is a globally cultivated crop that serves as a primary food source for more than half of the world's population. It remains a staple, particularly across Asia, with its production now extending to diverse regions worldwide[1,2]. Imbalanced fertilizer application is a primary factor behind low rice yields. The widespread reliance on chemical fertilizers not only leads to environmental and crop contamination but also poses significant health risks to both farmers and consumers[3] by increasing the risk of cancer and respiratory diseases. Cultivating rice using chemicals leads to the farmers are incurring higher costs than for organic rice cultivation[4]. Most farmers prefer inorganic fertilizers because they offer faster nutrient delivery compared to organic alternatives. Additionally, they possess a higher nutrient concentration per unit weight, requiring smaller quantities for effectiveness, and are easily accessible from industrial suppliers quire only a small amount to be effective, and are readily available from industrial sources facilities[5]. Most chemical fertilizers are salt-based; excessive application near the plant base can be detrimental and inhibit seed germination. Furthermore, heavy use of ammonium-nitrogen fertilizers tends to increase soil acidity, necessitating lime treatment for correction. Unlike chemical fertilizers, which fail to improve soil structure or aeration, organic alternatives enhance porosity, looseness, and water retention, while ensuring a slow and steady release of nutrients over time[6]. They also promote beneficial microorganisms in the soil, especially those that nourish the soil and work more effectively. Thus, organic rice cultivation can reduce chemical usage.

Organic agriculture, based on natural principles, minimizes the reliance on synthetic chemicals and promotes soil fertility and biodiversity, and reduces environmental contamination[7]. Rice produced under organic farming systems is becoming increasingly popular as consumers now pay more attention to health, opting for products that do not use chemicals. Organic rice is produced by avoiding the use of chemicals or synthetic substances such as chemical fertilizers, growth regulators, herbicides and pest control agents at all stages of development. Rice grown using organic fertilizers for an extended period leads to increased yields and improved soil fertility, unlike chemical fertilizers, which degrade the soil and increase the accumulation of toxins[8,9]. Nowadays, organic rice production is at low levels, and the cultivation of local rice is declining as farmers shift to growing rice promoted by the government, despite native rice being an important genetic resource with considerable diversity. Indigenous rice varieties are also regionally specific, being resistant to local environmental conditions or possessing unique aromatic qualities, along with having important substances and high nutritional value[10]. Rice cultivation in Thailand encompasses both chemical (conventional) and organic methods. Chemical rice cultivation has been the dominant, commercial approach for decades, while organic rice farming has emerged as a sustainable alternative, driven by environmental and health concerns[11].

Fragrant rice (*Oryza sativa* L.) is a premium variety characterized by its distinct aroma, with 2-acetyl-1-pyrroline (2-AP) serving as its primary volatile compound. Phetchaburi Province has several interesting varieties of local fragrant rice, such as Hom Chong Sakae and Hom Bai Toey. The compound responsible for the fragrant aroma is 2-acetyl-1-pyrroline, commonly found in fragrant rice[12]. In recent years, 2-Acetyl-1-Pyrroline (2-AP) has been recognized as the primary compound responsible for the distinct aroma of fragrant rice. Consequently, enhancing both grain yield and 2-AP concentration has become a central objective for breeders and growers alike[13]. Rice grains contain important bioactive compounds such as Gamma-Aminobutyric Acid (GABA) and phenolic compounds. Fragrant rice is currently popular, mirroring the trend of consuming safe food and reducing chemical use. This research studied how organic and chemical farming methods impacted the yield and changes in the content compounds of the three Thai fragrant rice.

MATERIALS AND METHODS

The field experiment was conducted at the Agricultural Productivity Learning Center, Muang District, Phetchaburi Province, Thailand, during the period from July, 2023 to November, 2023.

Plant materials: Three Thai fragrant rice varieties, namely KDML105 and two indigenous fragrant rice varieties from Phetchaburi Province, Hom Bai Toey and Hom Chong Sakae with a fragrant rice, and good cooking quality were selected.

Experimental design and treatments

Paddy field plot preparations: The experiment was laid out in a Randomized Complete Block Design (RCBD). The treatments consisted of three varieties of fragrant rice as Hom Bai Toey, Hom Chong Sakae and KDML105 was selected as a test crop. The experiment was conducted in two cultivations were 1) Chemical rice field with the application of chemical fertilizer was produced under Thai Agricultural Standard (TAS 4400-2009), which was introduced with chemical fertilizer by 16-20-0 at rate of 25 kg/rai and 46-0-0 at rate of 15 kg/rai at during the initial stage (15 days) and at the vegetative stage (35 days), respectively, and 2) Organic rice fields with the application of organic fertilizer were maintained under Organic Agricultural Standard (TAS 9000-2009), which was applied by cow manure at rate of 50 kg/rai at during the initial stage and at the vegetative stage. The soil was air-dried and sieved to pass through a 2 mm mesh sieve. The soil analysis during preplanting and postharvest periods during the pot experiment are presented in Table 1. The total land area of the experimental field was 16 m×16 m, which were divided into three replications, plots with 1 m within and between duplicates. The planting distance was 25 cm×25 cm within and between rows. The 30 day seedlings were then removed and transplanted in the field. Seedlings were transplanted into hills at a density of 1 seedling per hill. Standing water was maintained 5-10 cm in the field throughout the harvesting period.

Paddy field plot preparations: The field experiment was conducted at the Agricultural Productivity Learning Center, Muang district, Phetchaburi Province, Thailand, from July to November 2023, as a Randomized Complete Block Design (RCBD). Three varieties of fragrant rice (Hom Bai Toey, Hom Chong Sakae, and KDML105) were selected as test crops. The experiment was conducted as two cultivations, including 1) a chemical rice field using a 16-20-0 chemical fertilizer produced under Thai Agricultural Standard (TAS 4400-2009) at a rate of 25 kg/rai and 46-0-0 at a rate of 15 kg/rai during the initial stage (15 days) and at the vegetative stag (35 days), respectively and 2) an organic rice field with the application of organic fertilizer maintained under Organic Agricultural Standard (TAS 9000-2009) using cow manure at a rate of 50 kg/rai during the initial stage and at the vegetative stage. The soil analysis during preplanting and postharvest periods during the pot experiment are presented in Table 1. The total land area of the experimental field was 16 m x 16 m. The field was divided into three plots with 1 m within and between duplicates. The planting distance was 25 cm×25 cm within and between rows. Thirty-day-old seedlings were transplanted in the field in hills at a density of 1 seedling per hill. Standing water was maintained at 5-10 cm depth in the field throughout the harvesting period. Fresh grains from each plot were collected and stored at -80°C for bioactive compounds analysis at the grain-filling stage and harvest.

Data collection: At harvest, five hills were selected as samples to assess growth parameters including plant height, number of tillers per hill, panicle number per hill, and panicle length. The yield component parameters recorded included filled grain number per panicle, unfilled grain per panicle and % spikelet fertility, 100-grain weight, and yield per rai were recorded following Yoshida's method[14].

Determination of phenolic content: Total phenolic content was quantified by the Folin-Ciocalteu colorimetric method[15] with minor modifications. Extraction of the rice grain was carried out using the maceration method by dissolving 1 g of the brown rice powder in 10 mL of methanol, and the mixture was left in the dark for 24 hrs. After filtration through a 0.45 µm filter membrane, the filtrate was centrifuged at 10,000 rpm for 10 min. The extracts (150 µL) were mixed with 7.5% Sodium Carbonate (Na_2CO_3) (600 µL) and 50% Folin-Ciocalteu's reagent (750 µL), and incubated at room temperature in the dark for 30 min. The absorbance at 750 nm was measured using a spectrophotometer, and the total phenolics of the extracts were expressed as gallic acid equivalents (mg GAE/g DW). A gallic acid standard curve was prepared using 0-400 mg concentrations was employed to calculate the total phenolic content.

Determination of GABA content: The GABA content was extracted according to the method described by Park *et al.*[16]. The GABA content was determined on a GCMS-QP2010 Ultra System (Shimadzu, Japan) equipped with an auto sampler (AOC-20i, Shimadzu, Kyoto, Japan) and a DB-5 column (30 m length, 0.25 mm diameter, 1 µm thickness, Agilent Technologies, USA). Each sample was injected at a 1 µL volume and a split ratio of 10:1. The injection, ion source, and interface temperatures were 280°C, 200°C, and 280°C, respectively. Helium was used as the carrier gas (99.99%), and the column flow rate was 1.10 mL/min. Retention times (RT) and mass spectra of all samples were analyzed following comparison with the corresponding values for the standard sample and the content was expressed as mg/100g.

Determination of gamma oryzanol content (γ-Oryzanol): Total gamma oryzanol content of rice grain samples was quantified using the method detailed by Xu and Godber[17].The rice grains 3 g, were weighed and transferred to an aluminum foil-wrapped centrifuge tubes. A total of 40 mL of ethyl acetate and dichloromethane, 20 mL of each, was added and vortexed for 1 min. The content was shaken at 200 rpm at room temperature on an orbital shaker for 1 hr and centrifuged at 9,000 rpm at 20°C for 10 min. Supernatants were transferred to a rotary flask and evaporated to dryness at 40°C. The residue was redissolved in 5 mL of dichloromethane, filtered through a 0.45 µm membrane filter and transferred to the HPLC vial. After loading 1 mL of supernatant (γ-oryzanol

Table1: Soil analysis during preplanting and postharvest periods during the pot experiment soil constituent

	Fields	pH	OM (%)	N (%)	P (%)	K (%)
Preplanting	Chemical	6.43	3.20	0.240	0.009	0.011
	Organic	6.31	3.12	0.113	0.007	0.006
Postharvesting	Chemical	7.40	5.17	0.330	0.013	0.014
	Organic	5.93	4.09	0.007	0.009	0.008

pH: Soil reaction, OM: Organic matter (%), N: Total nitrogen (%), P: Available phosphorus (%), K: Available potassium (%). Values represent soil properties measured under chemical and organic treatments at preplanting and postharvesting stages

extract) and 1 mL of standard solution (γ-oryzanol, 1000 ppm), the cartridge was washed with 10 mL of dichloromethane and eluted with 1 mL of methanol. The γ-oryzanol filtrate was eluted and concentrated using N_2 gas, and then redissolved in dichloromethane-methanol (2:1, v/v) prior to analysis with by using High Performance Liquid Chromatography (HPLC) method. Finally, the γ-oryzanol contents in rice grain were calculated against the standard curve of pure γ-oryzanol[18].

Determination of grain 2-AP content: The content of 2-AP in harvest grain of fragrant rice was determined with the methods by Xie *et al.*[19]. Briefly, grain samples (10 g) were ground into powder and then extracted with dichloromethane. The 2-AP concentration was quantized using the simultaneous distillation-extraction method (SDE) and analyzed by a GCMS-QP 2010 Plus (Shimadzu Corporation, Kyoto, Japan). The grain 2-AP content was expressed as ppm (part per million).

Statistical analysis: The data were statistically computed using analysis of variance ANOVA, with treatment means compared using Duncan's Multiple Range Test (DMRT) at a 95% confidence level. The statistical analysis was implemented using the statistical package for the social sciences (SPSS) (version 22, SPSS Inc., Chicago, Illinois, USA). Pearson's correlation was used to determine the association between grain yield and the reproductive development and yield components of each crop.

RESULTS

Effects of organic farming and chemical farming practices on growth and yield components

Growth and yield performances: Growth attributes consisting of plant height, tiller number per hill, panicle number per hill, and panicle length is summarized in Table 2. Hom Chong Sakae, grown under chemical farming, was the tallest at 190.40 cm, significantly higher than the organic farming plots ($p<0.05$). Hom Bai Toey grown in the organic farming plots was the shortest at 91.90 cm and significantly different from the chemical farming plots ($p<0.05$).

In terms of tillers number per hill, Hom Chong Sakae grown under chemical agriculture had the highest tiller number at 17. 10 stems per hill, significantly higher than the organically grown plots ($p<0.05$). Hom Bai Toey grown organically, had the lowest tillering number at 9.40 stems per hill, While Hom Chong Sakae, grown under chemical agriculture, had the highest number of panicles (16.60), significantly more than the organically grown plots ($p<0.05$). In the organically grown plots, Hom Bai Toey had the lowest number of panicles (5.60). The panicle length of the three aromatic The varieties grown under chemical agriculture were significantly longer than under organic farming ($p<0.05$). Hom Chong Sakae had the longest panicles at 31.63 cm, followed by KDML105 and Hom Bai Toey with panicle lengths of 29.48 and 29.29 cm, respectively (Table 2).

The total number of grains per panicle of the three rice varieties grown under chemical agriculture was significantly higher than under organic farming ($p<0.05$). In the chemical plots, Hom Chong Sakae had the highest total grain number (287.00 grains), followed by Hom Bai Toey and KDML105 rice at 236.60 and 232.40, respectively. The three rice varieties grown under chemical agriculture had significantly higher filled grain numbers per panicle than rice grown organically ($p<0.05$). Hom Chong Sakae and KDML105 rice grown in chemical plots had a higher %spikelet fertility than rice grown in the organic plots, with values of 93.41% and 85.59% respectively. Hom Bai Toey rice grown organically had a higher %spikelet fertility compared to the chemical plots. KDML105 and Hom Bai Toey rice grown using chemical agriculture had higher numbers of unfilled grain per panicle compared to rice grown using organic agriculture. Hom Chong Sakae rice had the highest unfilled grain number per panicle at 40.60 grains in the organic cultivation plot (Table 3).

Weight of 100 grains and grain yield: From all three fragrant varieties, grown using both chemical and organic farming methods, shows that Hom Bai Toey rice grown in organic fields had the highest weight at 3.51 g, with KDML105 rice the lowest at 2.70 g. No statistical differences were recorded in the three fragrant rice varieties grown under chemical and organic farming methods (Table 4). Hom Chong Sakae cultivated

Table 2: Growth and yield components of three fragrant rice with organic rice farming and chemical rice farming

Fields	Varieties	Plant height (cm))	Tillers number per hill	Panicle number per hill	Panicle length (cm)
Chemical	KDML105	166.30±6.30[c]	13.00±1.89[b]	12.96±2.46[b]	29.48±1.06[b]
	Hom Bai toey	130.20±4.34[d]	8.20±2.97[c]	6.90±2.08[c]	29.29±1.64[b]
	Hom chong sakae	190.40±3.66[a]	17.10±2.92[a]	16.60±2.88[a]	31.63±1.54[a]
Organic	KDML105	135.70±6.57[d]	13.50±1.84[b]	13.20±1.81[b]	26.74±1.12[c]
	Hom bai toey	91.90±5.30[e]	9.40±1.71[c]	5.60±1.43[c]	22.94±1.33[d]
	Hom chong sakae	163.10±2.38[b]	13.80±1.69[b]	13.20±2.10[b]	28.33±2.41[b]
CV (%)		23.60	25.85	37.15	10.61

Means within the same column followed by the different letter are significant different at the 0.05 level by DMRT

Table 3: Yield component of three fragrant rice with organic rice farming and chemical rice farming

Fields	Varieties	Grain total number (g)	Filled grain number	Unfilled grain number	Spikelet fertility (%)
Chemical	KDML105	232.40±43.29[b]	198.90±33.44[b]	35.50±18.66[a]	85.59[b]
	Hom bai toey	236.60±37.51[b]	200.20±41.65[b]	36.40±25.14[a]	84.62[b]
	Hom chong sakae	287.00±40.60[a]	268.10±35.85[a]	18.90±7.23[b]	93.41a
Organic	KDML105	154.20±11.61[c]	124.80±14.50[c]	29.40±9.78a[b]	80.93[b]
	Hom bai toey	134.40±16.57[c]	116.10±13.96[c]	18.30±6.57[b]	86.38[b]
	Hom chong sakae	218.70±36.70[b]	178.10±34.91[b]	40.60±13.63[a]	81.44[b]
CV (%)		26.90	30.91	31.57	5.27

Means within the same column followed by the different letter are significant different at the 0.05 level by DMRT

Table 4: The 100-grain weight and grain yield of three fragrant rice varieties with organic rice farming and chemical rice farming

Fields	Varieties	100 grain weight (g)	Grain yield (Kg/rai)
Chemical	KDML105	2.84±0.07[b]	926.61±119.56[bc]
	Hom Bai Toey	3.39±0.29[a]	713.00±301.59[cd]
	Hom Chong Sakae	3.50±0.19[a]	2,069.28±507.83[a]
Organic	KDML105	2.70±0.17[b]	579.44±95.60[d]
	Hom bai Toey	3.51±0.09[a]	484.96±77.83[d]
	Hom Chong Sakae	3.42±0.24[a]	1,076.12±233.51[b]
CV (%)		11.14	59.37

Means within the same column followed by the different letter are significant different at the 0.05 level by DMRT

Table 5: Correlation between yield and yield components of three fragrant rice with organic rice farming and chemical rice farming

Parameters	PH	TPH	PN	PL	GTN	FGN	UFG	HGW	GY
PH	1								
TPH	0.828*	1							
PN	0.897*	0.969**	1						
PL	0.901*	0.556	0.678	1					
GTN	0.846*	0.482	0.554	0.952**	1				
FGN	0.826*	0.519	0.560	0.920**	0.987**	1			
UFG	0.188	-0.184	0.017	0.269	0.155	-0.007	1		
HGW	-0.089	-0.144	-0.272	-0.014	0.255	0.299	-0.267	1	
GY	0.808	0.798	0.758	0.753	0.787	0.858*	-0.369	0.235	1

PH: Plant height, TPH: Tiller per hill, PN: Panicle number, PL: Panicle length, GTN: Grain total number, FGN: Filled grain number, UFG: Unfilled grain number, HGW: Hundred grain weight, GY: Grain yield, * and **: Significant difference at the 0.05 and 0.01 probability level

using chemical agriculture produced the highest grain yield (2,069.28 kg/rai), significantly higher than the other rice varieties (p<0.05), with Hom Bai Toey grown in the organic plot yielding the least (484.96 kg/rai). The grain yield of rice grown using chemical Agriculture was higher than organic cultivation for all three fragrant rice varieties (Table 4).

Correlation coefficient: Table 5 show the analysis of pearson correlation, it was found that the plant height has a positive correlation with the parnicle length (r = 0.901, p<0.05), the panicle number (r = 0.897, p<0.05), the grain total number per parnicle (r = 0.846, p<0.05), the number of tillers per hill (r = 0.828, p<0.05), and the filled grain number per parnicle (r = 0.826, p<0.05). The number of tillers per hill had a positive correlation with the number of panicles (r = 0.969, p<0.01), while panicle length had a positive correlation with the total number of grains per panicle (r = 0.952, p<0.01) and number of filled grains per panicle (r = 0.920, p<0.01). The number of grains per panicle had a positive correlation with the number of filled grains per panicle (r = 0.987, p<0.01). The number of filled grains per panicle also had a positive correlation with grain yield (r = 0.858*, p<0.05) (Table 5).

Table 6: Bioactive compounds of three fragrant rice on chemical plot and the organic plot

Fields	Varieties	Total phenolic content (mg GAE/g DW)	GABA (mg/100 g)	Gamma oryzanol (mg/100 g)	2-Acetyl-1-pyrroline (ppm)
Chemical	KDML105	257.71± 30.04[c]	2.06[ab]	21.73[a]	0.91[a]
	Hom bai toey	299.55±14.86[ab]	2.98[a]	23.65[a]	0.94[a]
	Hom chong sakae	297.94±23.93[ab]	1.39[b]	22.63[a]	0.90[a]
Organic	KDML105	328.63±38.37[a]	1.12[b]	23.79[a]	1.04[a]
	Hom bai toey	284.17±19.28b[c]	2.53[a]	24.19[a]	1.16[a]
	Hom chong sakae	261.63±23.93b[c]	1.20[b]	24.20[a]	1.04[a]

Means within the same column followed by the different letter are significant different at the 0.05 level by DMRT

Effects of organic and chemical farming methods on the bioactive substances

Total phenolic content: According to Table 6, KDML105 grown under organic farming showed the highest total phenolic content (TPC), while the chemically farmed plots had the lowest TPC (p>0.05). Hom Bai Toey and Hom Chong Sakae, grown under organic and chemical farming, showed no statistically significant differences in TPC (p>0.05). Meanwhile, the Hom Bai Toey rice and the Hom Chong Sakae rice grown through organic and chemical farming did not show any statistically significant difference in total phenolic content (p>0.05).

GABA content: The amount of GABA in the three fragrant rice varieties grown using chemical farming was higher than in rice grown using organic farming. In the chemical agriculture plots, Hom Bai Toey had the highest amount of GABA at 2.98 mg/100 g, while KDML105 grew under organic farming had the lowest GABA at 1.12 mg/100 g (Table 6).

Gamma oryzanol content: The gamma oryzanol content in the three fragrant rice varieties grown using organic farming was higher than in rice grown using chemical farming. In the chemical agriculture plots, Hom Bai Toey rice had the highest gamma oryzanol content at 23.65 mg/100 g, while in the organic plots, Hom Chong Sakae rice had the highest gamma oryzanol content at 24.20 mg/100 g, followed by Hom Bai Toey rice at 24.19 mg/100 g (Table 6).

2-AP (2-acetyl-1-pyrroline) content: As shown in Table 6, the amount of 2-AP in the three fragrant rice varieties grown in organic plot was greater than rice grown in the chemical plots, but with no statistically significant differences (p>0.05) (Table 6). The highest amount of 2-AP was recorded in Hom Bai Toey rice (1.16 mg/100 g) grown organically (Table 6).

DISCUSSION

From the study of the growth performance of the local fragrant rice from Phetchaburi province, there were two varieties: Hom Bai Toey rice and Hom Chong Sakae rice, compared with the economic rice variety of Thailand, which is KDML105 variety, grown using both organic and chemical cultivation methods. Data were collected on growth and yield components including plant height, number of tillers, number of panicles, panicle length, grain number per panicle, filled grain number per panicle, unfilled grain number per panicle, 100-grain weight, and grain yield. The results showed that the cultivation method significantly affected the quality of rice yield components. Chemical agriculture gave better growth performance than organic agriculture, especially in Hom Chong Sakae. The chemical rice fields showed increased plant height, panicle length, filled grain number, total grain number, and grain yield for the three Thai fragrant rice varieties. These findings are partially similar to these of Mallikarjun *et al.*[20] found that rice cultivation using chemical fertilizers gave higher averages for 1,000 grain weight, number of tillers, number of panicles, filled grain number per panicle, unfilled grain number per panicle, and height of Japanese rice compared to organic compost.

This study revealed that the three rice varieties grown under chemical and organic agricultural methods had similar 100-grain weights but different filled grain number per panicle and grain yield. Rice grown in chemical plots had higher filled grain numbers per panicle, with higher grain yields than rice grown organically. Organic plots contain less organic matter than chemical plots. This serves as an indicator of soil fertility and a reservoir of nutrients such as nitrogen and phosphorus, which are released as the organic matter decomposes[21].

After harvesting, the soil in the organic farming plot was slightly acidic (pH 5.93), while soil in the chemical farming plot had an alkaline pH of 7.40, impacting the plants' ability to utilize nutrients (Table 1). In accordance with the research by Phopaijit *et al.*[22] found that rice grown with chemical fertilizer had a higher yield than with organic fertilizer, using average values of 384 and 309 kg/rai respectively. Ruan *et al.*[23] also reported that organic farming resulted in lower rice yields compared to chemical farming. Using organic fertilizers and microbial liquid fertilizers may yield lower outputs because these fertilizers release nutrients slowly, in line with soil microbial decomposition activities. When organic fertilizers are added, the soil microbes must first decompose the fertilizers to release the nutrients for plant uptake. When organic fertilizer is added to the soil, the nutrients are not released immediately and they must first go through the decomposition process by soil microorganisms. The decomposition activity of soil microorganisms is highest when the organic fertilizer is first applied. Over time, this activity gradually decreases while the amount of nutrients released from the fertilizer slowly increases. Nutrient release increases slowly over time[24]. Additionally, Abdul Khaliq *et al.*[25] reported that rice yield decreased in fields that had been continuously fertilized with chemical fertilizers for a long time. When farmers increase the use of organic fertilizers with bio-compost continuously for long periods, they can sustainably increase production[26].

While chemical fertilizers provide immediate nutrients to plants through high solubility, they can lead to environmental degradation, water pollution, and harm to living organisms[8]. Organic nutrient availability is enhanced by microbial activity and improved soil physical properties[11]. Organic manure application enhances photosynthetic efficiency and improves nutrient availability[27]. Moreover, Anisuzzaman[2] reported that the application of chemical fertilizer, whether used alone or integrated with organic manure, significantly enhanced growth and yield component traits. Furthermore, rice yields can be substantially improved through the judicious combined use of both organic and inorganic sources. Inorganic fertilizers can lead to higher yields, but they may negatively affect soil health and the environment over time. Conversely, organic fertilizers improve soil health but may not always provide sufficient nutrients for optimal yield. Rice grain characteristics result from differences in rice variety genetics and environmental effects[28]. From this study, while organic farming often leads to lower yields, it can be financially competitive due to higher market prices for organic rice. Moreover, the organic rice. farm had given better financial performance and economic viability than a conventional rice farm and organic rice farming that utilizes organic materials has been proven as a promising alternative to sustainable agriculture[29].

The total phenolic compound content in organically grown rice tends to increase compared to That has grown with chemical agriculture. This is in accordance with the research of Benzie and Strain[30], which indicates that the total phenolic content in brown rice was 70.3 mg GAE/g FW, while Indian brown rice had a phenolic content of 190.75 mg GAE/g FW. KDML105 rice grown in the organic farming plots had a higher phenolic content than rice grown in the chemical farming plots. Similarly, the report by Park *et al.*[31] compared the quality of rice using between organic and conventional rice. Their results showed that the total phenolic acid content in organic rice was 89% higher than in conventional rice. It was also found that in Rice berry rice, grown with organic fertilizers, showed increasing phenolic compound content every year[32]. The phenolic compounds in rice are highly beneficial as they play an important role as antioxidants[33,34], and it has been reported that the rice cultivation system affects the levels of phenolic compounds[35].

The amount of GABA in rice grains varies according to genetic traits and environmental conditions[36] states that rice varieties with low amylose content have a higher GABA concentration than rice with high amylose content. A study on GABA levels in the three fragrant rice varieties found that KDML105 and Hom Bai Toey rice grown in chemically treated fields had higher GABA levels than rice grown in organic fields, while Hom Chong Sakae rice grown in organic fields had a higher GABA content than rice grown in chemical fields.

A study of the gamma oryzanol content in the three varieties of fragrant rice found that rice grown in the organic farming plots had higher gamma oryzanol content than rice grown in the chemical plots. This result correlated with Kunnam's report[32], who found that rice grown organically had a higher gamma oryzanol content than rice grown using chemical fertilizers, with gamma oryzanol levels are increasing each year. However, the diverse levels of gamma oryzanol depend on the genetic characteristics of each rice type[37].

The 2-AP content in the three varieties of fragrant rice grown organically was higher than in rice grew in the chemical plots. This result aligned with Park *et al.*[31], who found that rice fertilized organically had higher amounts of 2-AP than rice fertilized chemically, and the aroma of rice treated with organic fertilizers was stronger than chemically treated rice. The 2-AP content in rice depends on environmental conditions and cultivation management. However, Jiang *et al.*[38] found that the combined application of chemical fertilizer and organic fertilizer in an optimal ratio resulted in the highest 2-AP content.

In addition, N fertilizer with less irrigation water at tillering stage not only increased head rice yield but also enhanced 2-AP content in rice grains (Li *et al.*, 2021). A study in China found that increasing nitrogen fertilizer does improve rice yield, it reduces eating quality, including aroma[39], while fragrant rice grown in low nitrogen soil had a stronger aroma than rice grown in high nitrogen soil[40].

CONCLUSION

This study provided the effects of organic and chemical rice cultivation on three varieties of fragrant rice, it was indicated that the rice grown using chemical fertilizers had greater plant height, number of panicles, number of grains per panicle, number of filled grains per panicle, and yield per rai compared to the rice grown organic plot in all three varieties. The cultivation systems of organic and chemical agriculture affects the growth and yield of all three varieties of fragrant rice. Therefore, the findings of this study could be used for further advancements in combination with organic and conventional systems.

Additionally, all of three fragrant rice that grown in organic fields had a lower growth and rice yield than chemical fields but there is more increase of important substances in rice grains than that produced by chemical fields. The findings of the study indicated that the levels of 2-AP and gamma-oryzanol in organic rice farming were higher than in conventional rice.

SIGNIFICANCE STATEMENT

This study highlights the critical trade-off between grain yield and nutritional quality in fragrant Thai rice under different cultivation systems. While chemical farming significantly enhances growth and yield performance across all studied varieties, organic cultivation proves superior in enriching the grains with essential bioactive compounds, specifically 2-acetyl-1-pyrroline (2-AP) and gamma-oryzanol. These findings are particularly significant for the development of sustainable agricultural practices in Thailand, as they demonstrate that indigenous fragrant varieties like Hom Chong Sakae and Hom Bai Toey can be optimized for high-value health markets. Ultimately, this research provides a scientific foundation for farmers and policymakers to balance economic productivity with the growing consumer demand for safe, nutrient-dense, and highly aromatic organic rice.

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