Morphologies, chemical compositions, bioactive compounds and heavy metal contamination in Paka-umpuel local rice in Surin province, Thailand

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Abstract

Nutritional profiles and food safety are being concerned with consumers in recent years because they are directly involved with human health. Researches into favorable nutritional profiles and heavy metal contamination of rice are a foundation for future food security. In this study, we studied and compared morphologies, chemical compositions, bioactive compounds, and heavy metal contamination of Paka-umpuel local rice (PLR) variety from Surin province, Thailand, which nine PLR samples were divided into two groups based on different cultivation processes: four samples for organic rice (OR) and five samples for non-organic rice (NR). The results showed that the two rice groups differed significantly in morphological parameters, except the L/W of the OR and NR kernels. The PLR exhibited the average contents of ash (1.34%), moisture (10.62%), protein (9.01%), fat (3.36%), and carbohydrate (75.37%). Besides, the OR group showed the highest total phenolic contents and antioxidant activities (344.06 mg GAE/100 g DW and 158.09 mg VCE/100 g DW, respectively). Interestingly, none of the PLR samples were contaminated with toxic heavy metals. This study provides a better understanding of rice cultivars

that should be selected for consumers, and serves as an interesting breeding site in Thailand for supporting the one health approach.

***Keywords**:* Antioxidant, Healthy food, One health approach, Rice kernel, Thai rice

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1. Introduction

Rice (*Oryza sativa* L.) is a staple food of Asia-Pacific people and is an important economic crop that creates revenue for many countries including Thailand. Rice is also considerable for economic stability, particularly in most Asian countries [1–5]. Rice production represents an essential portion of Thai economy and local labor force. Jasmine rice is one of the most widely grown rice varieties in Thailand. Especially, farmers in northeastern Thailand mostly grow rice varieties, i.e. Jasmine rice KDML 105, Jasmine rice RD 15 and glutinous rice RD 6, and there are many varieties locally grown throughout Thailand [6]. Currently, rice variety development is focused on enhancing market productivity rather than nutritional value [7]. The Thai government plans to develop a contemporary rice agriculture promotion system that emphasizes on rice monoculture with only a few key rice varieties. Hence, many local rice varieties have become extinct while having higher nutritional value than common rice varieties [3, 8, 9].

Nowadays, many basic chemical and molecular research data on healthy food in Thailand are not sufficient to be investigated and are still in the early stages, especially in natural products for medicinal purposes. Those data would support a healthy food consumption along with regular meals for health benefits including boosting immunity. Furthermore, local rice varieties not only provide sources of energy and fibers but also bestow high bioactive metabolites such as phenolic acids, flavonoids, anthocyanins, proanthocyanins, and tocotrienols [4, 10]. Several studies have found that local rice varieties are healthy foods and relieve diabetes [3, 8]. Local rice varieties contain nutrients that help nourish epidermis, neurological system, and blood cells [10]. Additionally, local rice varieties generally contain copper, zinc, beta-carotene, vitamin E, and antioxidants [9, 10], which will prevent the occurrences of cancer, cardiovascular disease, Alzheimer's disease, and rheumatoid arthritis [11]. Furthermore, germs in local rice verities are high in dietary, which aid the excretory system in preventing colon cancer [8, 12]. However, toxic heavy metals such as lead, cadmium, and arsenic, probably found in local rice varieties, can cause a substantial morbidity and an increased death at critical concentrations [3, 13]. Heavy metals are probably found in local rice varieties and cultivating soil because they can contaminate, circulate, transmit, and then accumulate in the environmental compartments (air-water-soil-biota) after being polluted from anthropogenic activities [14].

Local rice varieties are traditionally cultivated in varying geographic regions [9]. The principle of choosing the right variety of rice to cultivate in an area is mainly from the local wisdom of farmers. Paka-umpuel local rice (PLR) is a unique local rice of Surin province, especially mainly cultivated in Prasat district, northeastern Thailand. This species was discovered along the Thai-Cambodian border and has been cultivated in Surin province, Thailand, and Oddar Meanchey province, Cambodia [15, 16]. This rice is distinguished by its drought tolerance and resistance to insects, providing an ideal for growth in limited water areas. Nowadays, PLR is a high-quality organic rice that is popular but rare for both domestic and international consumers. We are then of utmost concerns for this local rice representing high-quality and tolerance to harsh cultivating conditions, which might be extinct because most farmers nowadays prefer to cultivate jasmine rice owing to strong market demand.

The preliminary survey of PLR information in the study area, we found that there are two groups of farmers in the cultivation process of PLR. There are groups of members of organic farming cooperatives who grow organic rice (OR) and groups of farmers who are not members of cooperatives who grow non-organic rice (NR). The first group farms following natural principles and avoiding chemical contamination in all forms. This group grows OR without using chemicals or synthetic substances such as chemical fertilizers, herbicides, and insecticides at any stage of production, even during storage to maintain soil fertility. Organic farming is intended for export and commercial distribution. The second group's rice cultivation practices differ from those of the first group, which cultivates rice with chemicals, insecticides, and growth regulators, among other things. This form of farming is projected to not only create non-organic yields, but also to have a severe impact on the ecosystem and consumer health.

Therefore, this pilot study aimed to compare and analyze their morphologies, chemical compositions, bioactive compounds, and heavy metal contamination in PLR variety of OR and NR groups in Surin province, Thailand. This study would encourage farmers to concern about food safety and promote the one health approach for integrating and unifying approaches to sustainably balance and optimize the health of humans, plants, animals, and shared environments. Furthermore, our study was an urgently discovered matter that should be addressed in order to preserve PLR.

2. Materials and methods

2.1 Study area and sample collection

Two groups of PLR samples, OR and NR, were collected from Prasat district, Surin province (14°49′60″N/103°45′0″E), northeastern Thailand (Fig. 1) because of being the main cultivating area of this rice variety [17]. Southern part of Surin province is a plateau with complex mountains and dense forests along the border of Thailand and Cambodia. The soil in the study area has a relatively high level of dissolved salt owning to the geography and the environment. The weather is dry and humid with intermittent rain. In an event of rainy season, there is flash flood because the soil does not hold water. Then, this area is suitable for growing PLR, indigenous aromatic rice, which relies mainly on rainwater. This rice variety can only be sown once a year and harvested when the weather is cold and dry from November to January [17]. Distinctively, PLR provides a distinct flavor with high-quality as a result of favorable climatic conditions.

The PLR samples were collected during January to April 2022 covering the study area of Prasat district, Surin province from two farmer groups who have been cultivating this rice variety for more than 10 years. The first group was four farmers who produce OR using an organic farming process using compost or green manure instead of chemical fertilizers and without the use of any type of pesticides. The latter group was made up of five farmers who grow NR in a non-organic farming procedure. This group cultivates rice utilizing insecticides, herbicides, and growth regulators both during production and throughout storage. This is done to simplify and shorten the stages involved in rice production. Then, there were 9 PLR samples divided into two groups: four samples for OR and five samples for NR.

2.2 Morphological characterization

A colorimeter was used to measure the L*, a*, and b* color values of the PLR samples; where, L* indicates the degree of lightness or darkness (L* = 0 indicates the most perfect black, and L* = 100 indicates the most perfect white); a* indicates the degree of redness (+) and greenness (-); whereas, b* indicates the degree of yellowness (+) and blueness (-). The weight of 1000 kernels in each sample was determined. The length (L) and width (W) were measured with vernier calipers and the L/W ratio was then calculated [8].

2.3 Chemical composition analysis

Proximate chemical compositions of the PLR samples were analyzed, i.e. ash, moisture, protein, fat and carbohydrate contents according to the standard method of the Association of Official Analytical Chemists [18]. Moisture content was analyzed using the Gravimetric method. Protein content was determined by the Kjeldahl method. Fat content was determined by the petroleum ether extraction method. Ash content was analyzed using the Gravimetric method. And, an amount of carbohydrate content (as % Carbohydrate) was calculated according to the following formula.

$$\% \text{ Carbohydrate} = 100 - (\% \text{ Protein content} + \% \text{ Moisture content} + \% \text{ Ash content} + \% \text{ Fat content})$$

2.4 Preparation and extraction of rice

Nine PLR samples were collected from Prasat district, Surin province, Thailand. They were divided into two groups: four samples of OR and five samples of NR. Rice grains were dried and dehusked manually. Brown rice kernels were ground using a mortar and pestle before filtering through a 0.5 mm mesh. The resultant powder was then sealed in an airtight container and stored in a desiccator for further analysis. The powder samples were extracted with 90% ethanol (1:10 w/v) at room temperature for 24 h. After filtering with filter paper, the filtrates were evaporated to remove the solvent with a rotary vacuum evaporator. The extracts were stored in order to determine of total phenolic contents (TPC) and antioxidant activity. All experiments were performed in triplicate.

2.5 Total phenolic content determination

TPC of the local rice extracts were determined with slight modifications by the Folin–Ciocalteu (FC) method with appropriate concentrations of gallic acid according to the standard [19]. For analysis, 20 μL of samples were made up to 2.5 mL with distilled water, mixed thoroughly with 100 μL of FC reagent before being added to 200 mL of Na_2CO_3 for 10 min. The mixtures were then vortexed and incubated at 40 ^oC for 60 min. The absorbance of the mixtures was determined at 765 nm in a UV–Vis spectrophotometer (PerkinElmer Lambda 365, Japan). TPC in the extracts were expressed in mg gallic acid equivalent (GAE)/100 g dry weight (DW).

2.6. Study of DPPH radical scavenging activities

Free radical scavenging activities of the local rice extracts were determined using a stable 1-diphenyl-2-picrylhydrazyl (DPPH) radical [10]. The extract solution (0.3 mL) was well mixed with 2.5 mL of ethanol and 1.0 mL of DPPH solution. The mixture was vigorously agitated and allowed to stand for 30 min at room temperature in a dark room. The absorbance was measured at 517 nm with a spectrophotometer. Ethanol was used as a control. Then, DPPH was calculated according to the following formula.

DPPH scavenging effect (%) = (Absorbance of the control – Absorbance of the test sample)/Absorbance of the control) x 100

The actual decrease in absorption induced by the test was compared with the positive controls. The IC_{50} value is the 50% inhibition concentration calculated from the linear range dose inhibition curve by plotting the local rice extract concentrations against the corresponding scavenging effects.

2.7 Heavy metal content detection

Heavy metal contents were detected using an atomic absorption spectrophotometer (PerkinElmer, AAnalyst 400) following the standard protocols. PLR samples were kept in a desiccator for further experiments. First, 1.0 g of ground rice samples was digested in 10 mL of concentrated nitric acid and 1 mL of perchloric acid, and left at room temperature for 24 h. Next, they were decomposed at 180 °C for 1 h to complete digestion. The solution was then filtered and volume-adjusted with 2% nitric acid for comparison with the sample solution. Finally, a flame and graphic furnace atomic absorption spectrometer was used to examine the digested solution for Pb, Cd, and As concentrations. Soil samples were collected by the AOAC standard methods and analyzed for heavy metal contamination at Surin Land Development Station, Land Development Department, Thailand. Heavy metal contamination by functional group vibration was examined by FT-IR spectrometer (Shimudsu FT-IR-8900).

3. Results and discussion

3.1 Morphologies of PLR grains

Quantitative and qualitative morphological characteristics of rice grains and brown rice kernels in two PLR groups (OR and NR samples) were studied using a colorimeter. The results showed that the colors and brightness of rice grains in both groups were considerably different as shown in Table 1. However, the color and brightness values of both groups were quite low, as seen by the dark rice grain color [8, 20]. While most non-organic brown rice kernel has relatively high L*, a* and b* color values, its color is slightly darker than the organic brown rice kernel because of the pigmented exterior layers of the kernel. This indicates a tendency to find relatively high levels of nutritional and bioactive compounds. The morphologies and color characteristics of both rice groups are shown in Fig. 2.

The results for the physical properties of PLR are given in Table 1. Higher weights in the PLR samples are related to their larger kernel sizes. The results showed that all the parameters of rice grains and brown rice kernels in the OR samples were higher than those of all the NR samples. The OR group was heavier than the NR group [8, 20]. Rice grains and brown rice kernels had a L/W ratio larger than level 3 [21]. However, the L/W ratio indicated that there was no significant difference between the OR and NR kernels. As a result, all brown rice samples are extended in shape, as illustrated in Fig. 2. When compared, the weights of both OR grain and OR kernel samples were higher than those of NR grain and

NR kernel samples. This suggests that cultivation procedures and cultivating environments are critical determinants of rice grain and kernel weight.

3.2 Proximate chemical compositions

The approximate chemical compositions obtained from the four OR samples and the five NR samples are presented in Table 2. There was no significant difference among all components of the PLR samples from both groups. The results showed that the contents of ash, moisture, protein, and fat were in the ranges of 1.24-1.42%, 10.19-11.12%, 8.85-9.38%, 3.14-3.55% and 74.84-76.41%, respectively. However, only the carbohydrate content of both groups was significantly different.

3.2.1 Ash content

The ash content of rice can be used as an indicator of its quality and mineral content [22]. This is due to the fact that ash content is the inorganic components that remains after the organic components have been burned. It can be considered as a representative of the levels of various minerals contained in food. Normally, the ash content of brown rice is generally reported in the range of 1.0-1.5% [4], while the average ash content of PLR samples is 1.34 ± 0.10%. This is comparable with the means of ash content in the rice samples reported by other researchers [20, 22, 23]. However, the high ash content may be a component that improves the sensory quality of rice, especially the color and taste. The difference in ash content between rice varieties may be due to differently environmental conditions, particularly minerals, soil, and water employed in the cultivation process [24].

3.2.2 Moisture content

The moisture content of rice grains influences their quality, storage period, and palatability [4]. In addition, moisture might indicate the shelf life of rice. Rice with a moisture content of 12% is considered safe for storage and can be stored for up to 6 months. However, the moisture content of PLR samples was in the range of 10.62 ± 0.21%, which is slightly below the acceptable limit. It is possible that the PLR sampling interval for analysis until a new rice harvest is too long. This may cause the moisture content of all samples to be slightly lower. Rice moisture content is affected by cultivating and harvesting circumstances. However, the moisture content found in this study was consistent with the previous studies of Thai local rice varieties from Nakhon Ratchasima province (11.41 ± 03%) [25], Yala province (12.53 ± 0.09 13.33 ± 0.16%) [26], Kanchanaburi province (10.30-12.29%) [27], and Phatthalung province (9.56-13.68%) [28]. In addition, the moisture content in this study was lower than the previous studies of Indonesian rice (11.07 ± 0.16-12.22 ±0.24%) [29], Ghanian rice (14 ± 0.88%) [22], Bangladesh rice (11.25-15.13%) [23], Indian rice (13.7±0.12%) [20], Chinese and Sri Lankan rice (9.85-12.94%) [7], and Nigerian rice (3.67-18.0%) [30].

3.2.3 Protein content

Protein is regarded as the second most important chemical content in rice after studying carbohydrate content. The average protein content of PLR samples in this study was 9.01 ± 0.25%, while the optimum protein content in rice was in the range of 7.1-8.3% [4]. However, the protein content was comparable to Thai local rice [7, 25–28]. Previous studies reported that protein content greater than 10% was classified as high [31]. Protein content was comparable to other local rice varieties in this study [20, 22, 23, 29]. The amount of protein in each rice variety varies based on the production environment, which is an essential condition in rice protein content. Protein is generated in various sections of the seed, with the seed coat and outside seed being more abundant than the center. Therefore, improving the protein content by enhancing rice types is very appealing, particularly in countries where rice is included in every meal like Thailand. This is of great interest for food goods and people who are protein-deficient.

3.2.4 Fat content

Most rice fats are triglycerides, phospholipids, glycolipids, and terpenoids. High-quality fats contain unsaturated fatty acids, linoleic acid, and oleic acid, as well as gamma oryzanol which helps control cholesterol levels in the blood vessels. The average fat content of all the PLR samples was found to be 3.36 ± 0.27% (Table 2). PLR kernels are manually dehusked, causing the seed coat to slip off in little portions. As a result, rice retains a high concentration of beneficially unsaturated free fats. However, the fat content in this study was compared with Thai traditional rice varieties indicating that the protein content was consistent implying similar nutritional qualities [25–28]. In addition, the fat content in this study was comparable to Asian local rice varieties assuming that they were at the same level [7, 20, 22, 23, 29]. Rice has a healthy fat content ranging from 0.2-4.0% depending on the type and growing conditions. However, the differences in fat content between rice cultivars could be explained by differences in extraction methods. This is due to the fact that the majority of the fat in rice kernels is the unsaturated fat, which is easily oxidized by atmospheric oxygen [4].

3.2.5 Carbohydrate content

The carbohydrate content of both rice groups was thoroughly examined and discussed. The results found that the carbohydrate contents in the OR group (75.77-76.41%) are slightly higher than those in the NR group (74.84-75.71%) (Table 2). This could be due to the organic PLR production process or the absence of herbicides and pesticides, which can benefit carbohydrate levels. All the PLR samples had a total carbohydrate content greater than 67%, indicating that all rice varieties were good sources of carbohydrate [1]. Kernels of all rice varieties generally have the starch composition, which is a carbohydrate biomolecule providing energy. In this study, the carbohydrate contents found was consistent with those found in local rice in Yala province ranging from 76.28-77.37% [26], Kanchanaburi province ranging from 75.45-83.77% [27], Pathum Thani province ranging from 75.05-80.64% [28], and Nakhon Ratchasima province ranging from 75.28-78.21% [25]. Moreover, black glutinous rice was previously reported to provide the most energy. Red and black rice in Thailand, China, and Sri Lanka provide carbohydrate contents in the ranges of 73.73-79.67% [7]. Besides, the carbohydrate contents were detected in Indian rice ranging from 75.87-81.41% [4, 20], Indonesian rice ranging from 84.76-89.06% [29], Ghanian rice ranging from 67.11-83.27% [22], and Nigerian rice ranging from 76.92-86.03% [30]. Rice is an excellent dietary source of carbohydrate for a variety of health and nutrition reasons. In contrast, the chemical composition of each rice variety was compared. The amount of chemical ingredients identified varied based on species, cultivating environment, short growing distance, topography, and climate of cultivation areas.

3.3 Total phenolic content

TPC was determined by the modified Folin–Ciocalteu reagent method. The results showed a significant difference between the OR samples with a higher TPC content (342.74-359.96 mg GAE/100 g DW) and the NR samples (335.47-343.51 mg GAE/100 g DW) as shown in Fig. 3. Therefore, the overall TPC could have been influenced by herbicides and pesticides used in the cultivation process. However, the TPC of rice bran extract have previously been reported in the range of 251-359 mg GAE/100 g [32]. In this study, only brown rice kernels were extracted, resulting in a low TPC. This is because the concentration of TPC is higher in the rice bran layer than other parts.

Additionally, TPC obtained in this study compared to other rice cultivars was found to be close to those reports in Thai rice cultivars as shown in Table 3. TPC of PLR samples were found to be close to those studies in Thai rice varieties [7, 25, 27, 28], except rice samples from Sakon Nakhon and Surin provinces which had slightly higher values [6, 33]. Furthermore, the level of TPC in this study was comparable to those reported in local rice in Indonesian rice (47-70 mg GAE/g) [29], Indian rice (15.32-900.9 mg GAE/g) [9, 10, 20], Chinese and Sri Lankan rice (79.18-691.37 mg GAE/g) [7]. Additionally, TPC of PLR samples showed higher values than those found in rice varieties from other countries as shown in Table 3. This clear finding implies that the pigmented rice varieties had a higher phenolic content than the non-pigmented rice varieties [24]. Furthermore, these findings may differ due to variances in cultivar, rice extraction technique, plant origin, cultivation conditions, genetics, preprocessing and storage period [34].

3.4 Antioxidant activities

The antioxidant activities in the ethanol extract of PLR samples were determined using the DPPH free radical assay with the percentage inhibitory activity in the range of 65.47-92.93%. The slope curve was constructed using the percentage inhibition to calculate the quantity of antioxidants that made the residual DPPH concentration 50% (IC_{50}). A substance with a low IC_{50} has a high level of antioxidant activity. The results showed that the concentrations of all nine PLR extracts had the ability to inhibit DPPH free radicals at doses ranging from 132.58-185.37 mg VCE/g DW (Fig. 4). The antioxidant activities of the OR group were slightly higher than those of the NR group. The findings showed that the antioxidant activities of PLR ethanol extracts were effective as a reducing agent that stabilized reactive free radicals through the electron donor [35]. The IC_{50} values were calculated and compared to those of other rice varieties. The PLR extract was found to have a reduced inhibitory ability but was comparable to the findings of the extracts from the other rice cultivars as shown in Tables 3 and 4.

Moreover, the findings support previous reports showing the antioxidant activities of rice with a colorless husk, which were lower than those of red and black rice, respectively [9, 10]. For this reason, the color of the seed coat affects its antioxidant capabilities. It was also found that antioxidant capabilities differed among rice varieties of the same color. Furthermore, previous reports on phenolic compounds found a high correlation with DPPH scavenging capacity [8–10]. The phenolic and flavonoid content of DPPH is related to its antioxidant capabilities. The key elements that impacted antioxidant capabilities in local rice were found to have phenolic and flavonoid contents. However, the lengthy process of boiling rice at high temperatures may result in a reduction in antioxidant concentration.

3.5 Comparisons with local rice and commercial rice

The TPC and antioxidant activity of PLR, local rice and commercial rice from nearby locations are compared in Table 4. The TPC and antioxidant activity of PLR were found to be in the range of 335.51-359.96 mg GAE/100 g DW and 132.58-185.37 mg VCE/100 g DW, respectively. In the previous report, red and black rice showed higher TPC and antioxidant activity than colorless local rice [7]. Rice berry has the greatest TPC and IC_{50} (260.25 ±10.01 mg GAE/g FW and 0.02 ±9.10 mg/mL, respectively). While, the brown rice with the lowest TPC and IC_{50} is Traditional jasmine rice (18.86 ±0.09 mg GAE/g FW and 6.19 ±0.05 mg VCE/100 g DW, respectively). However, the TPC and antioxidant activity of local rice were related to the color of the rice coat. Rice with red and black seed coats has a higher TPC and antioxidant activity than colorless rice [37]. This is because colorless brown rice mostly contains phenolic compounds such as phenolic acids, especially ferulic acid and coumaric acids. While red and black brown rice contain anthocyanins, cyanidin-3-O-β-D-glucoside and peonidin-3-O-β-D-glucoside [37]. Therefore, the color of the seed coat affects its antioxidant properties. Even rice of the same hue has varying antioxidant properties [25]. Each rice type has a unique phenolic content and antioxidant activity. This might be due to the species, cultivation site, culture circumstances, storage length, and phenolic extraction technique [28, 34].

3.6 FT-IR spectra of rice

The representative FT-IR spectra of the two PLR groups are presented in Fig. 5. However, the spectra of both groups are very similar indicating that both representative rice samples have similar physical and chemical compositions. Both spectra show broad and intense peaks at wave numbers of 3309-3591 cm^{-1}, corresponding to free or hydrogen-bonded O–H groups of water. The peak observed at 2890-3017 cm^{-1} is attributed to the stretching vibration of the $C–H_2$ asymmetric and $C–H_3$ symmetric bonds. The peak observed at 1691-1738 cm^{-1} is due to the stretching vibration of the C=O functional group of amide and ester bonds. Finally, the peak at 1058-1151 cm^{-1} is attributed to the stretching vibration of C–O and bending C–OH of the O-glycosidic bond [2, 10, 38]. Although the two rice groups had different cultivation procedures, those conditions did not affect the types of chemical compositions, nutritional compositions, and functional groups as bioactive molecules including heavy metal contamination. Therefore, the evidence from the FT-IR spectra indicated that the PLR samples were free from toxic heavy metal contamination and were appropriate for consumption.

3.7 Heavy metal concentrations in rice and cultivated soil

The heavy metal concentrations in PLR samples and the cultivated soils are shown in Table 5. The results showed that none of the PLR samples contained heavy metal concentrations, which the permissible limits of the Codex Alimentarius Commission [39] for Pb, Cd and As in rice grains are coordinate at 0.2 mg/kg [40]. Our findings clearly demonstrate that the quality of this local rice is cultivated in an area that is safe from heavy metal contamination in soil. Therefore, it is very suitable for the safe consumption of this type of rice. Generally, living organisms are extremely sensitive to toxic metals, especially, Pb, Cd and As. Cd and Pb are toxic elements that can cause severe kidney disease and have a harmful effect on the nervous and cardiovascular systems, eventually leading to cancer [37].

Frequent ingestion of As, a toxic metal, can cause many health risks such as cardiovascular disease, nervous disorders and even cancer [24]. However, these toxic concentrations in PLR samples were below the permissible limits indicating that they were safe for consumption.

Additionally, the Pb concentrations in this study were much lower than the 5.67 mg/kg of average levels in the Indian rice samples [41], while Cd found in rice samples on the east coast of India was closer to the average concentrations ranging of 0.001-0.05 mg/kg [42]. As concentrations detected in this experiment were significantly higher than those reported in rice from the northern regions of India (0.04-0.45 mg/kg) [43]. Heavy metal levels in rice samples imported from India, Pakistan, and Iran ranging from 0.048-0.314 mg/kg for As, 0.085-0.385 mg/kg for Cd, and 0.223-1.961 mg/kg for Pb [40]. This is due to the suitable environment and focus on the cultivation process of organic rice, resulting in the production of high-quality organic rice. As shown in Table 4, the heavy metal contamination in the different cultivation soils was also investigated. The results found that Pb (1.049 mg/Kg) and Cd (0.007 mg/Kg) concentrations had slightly increased in both organically cultivated soil (OS) and non-organically cultivated soil (NS), while As was not found in both cultivated soils. Surprisingly, the small quantities of heavy metals in this soil showed no indication of transmission to and accumulation in the rice samples. However, the heavy metals found in the studied soil were below the maximum allowable concentration of CODEX and the Land Development Department of Thailand. Therefore, the soil in this study area is appropriate for the general cultivation of vegetables and orchards without causing damage to local rice or the environment.

Furthermore, this study is worth to support the one health approach that is inextricably linked among the optimal health of humans, plants, animals and shared environments. This approach can be applied to food safety, sustainable food production and environmental stewardship [44]. This study is related to the food safety because all the PLR samples were free of toxic heavy metal contamination that is safe for human consumers and provided great qualities in all the measured parameters; to the sustainable food production because this area is proper to cultivate PLR without applying chemical fertilizers, herbicides and insecticides for the OR group and with small amount of those chemicals for the NR group; and the environmental stewardship because this local rice variety was discovered and has been being cultivated in this area for a long time with drought tolerance, insect resistance and water-limited growth, then chemicals are less used in the NR group when compared to other rice varieties, and farmers normally use cow's and buffalo's manures for fertilizers, which are beneficial to the environmental compartments (air-water-soil-biota).

4. Conclusions

This pilot study revealed the insight results of morphologies, chemical compositions, and bioactive compounds in Paka-umpuel local rice (PLR) variety of organic rice (OR) and non-organic rice (NR) groups in, Surin province (principally cultivated in Prasat district), northeastern Thailand. The results demonstrated that both OR and NR groups provided marvelous qualities in all the parameters. The rice grains and brown rice kernels of OR were heavier than those of NR. These morphological features indicate crucial elements influencing the agricultural process and environmental circumstances. Interestingly, the OR group contained high nutritional elements and antioxidant activities higher than those in the NR group. PLR had the ash content of 1.24-1.42%, the moisture content of 10.19-11.12%, the protein content of 8.85-9.38%, the fat content of 3.14-3.55% and the carbohydrate content of 74.84-76.41%. Additionally, phenolic compounds and antioxidants were in the ranges of 335.51-359.96 mg GAE/100 g DW and 132.58-185.37 mg VCE/100g DW, respectively. Moreover, all the PLR samples were not contained any toxic heavy metals.

Therefore, the relatively high levels of nutrients and bioactive compounds of these OR in this research information can be used for further agricultural management, utilization, and selection of high nutrient varieties for rice breeding, as well as to encourage farmers to recognize and jointly conserve local rice varieties in these proper and very low chemical areas. Furthermore, it can be concluded that PLR from Surin, Thailand, is a rice variety with an excellent promise to be used as a nutritious food and a raw material in producing healthy and nutritional supplements and food product components for encouraging the one health approach to attain the optimal health of humans, plants, animals, and shared environments.

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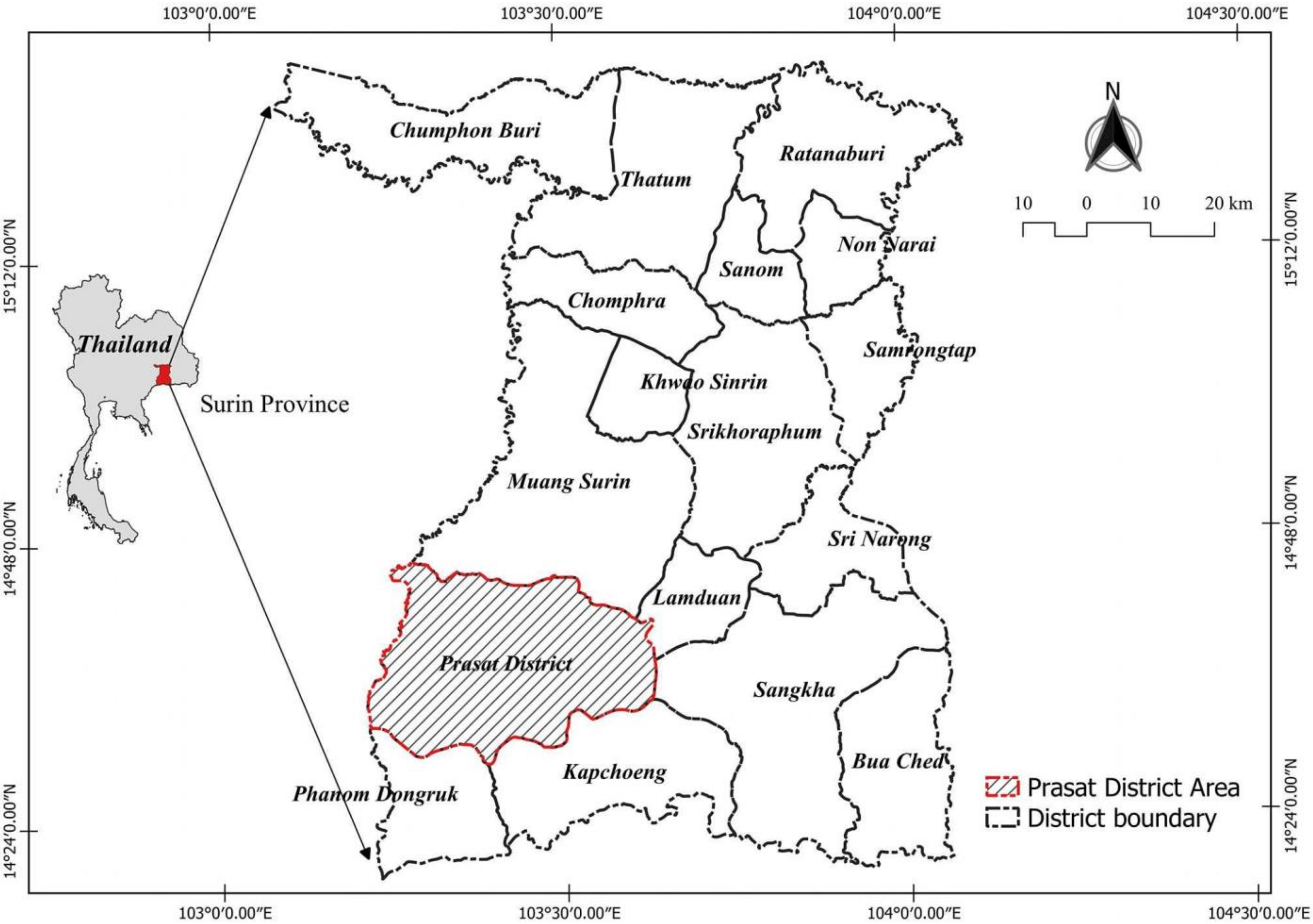

Fig. 2. Morphologies of representative rice grains and kernels

a) Organic rice grains

b) Non-organic rice grains

c) Organic brown rice kernels

d) Non-organic brown rice kernels

Fig. 3. Total phenolic contents of nine PLR samples

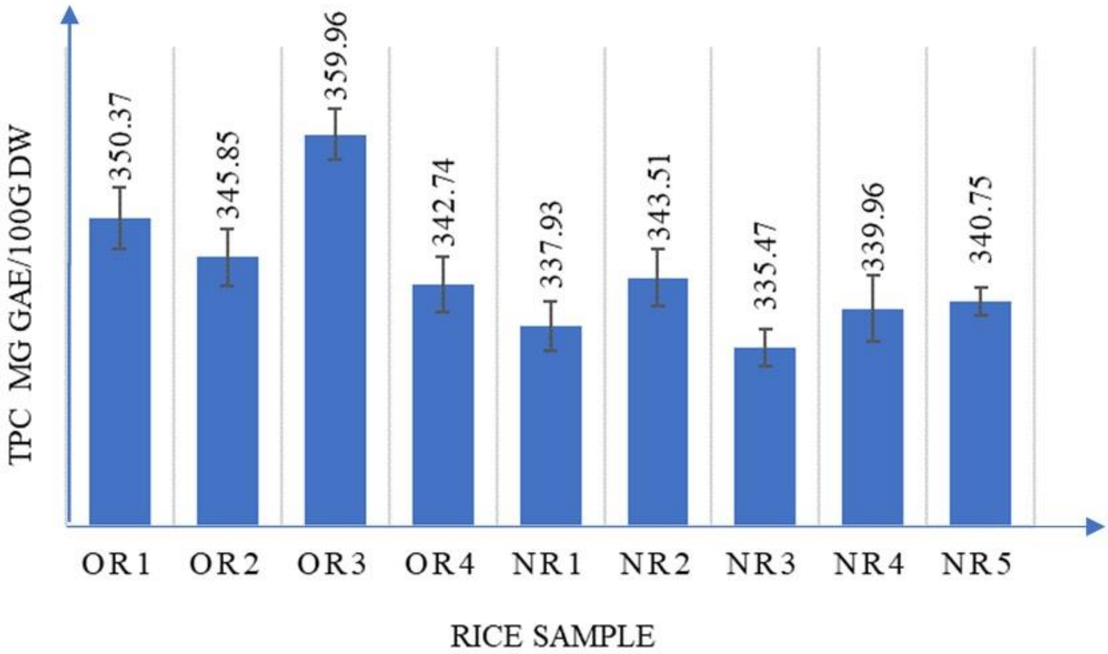

Fig. 4. DPPH radical scavenging activities of the nine PLR samples

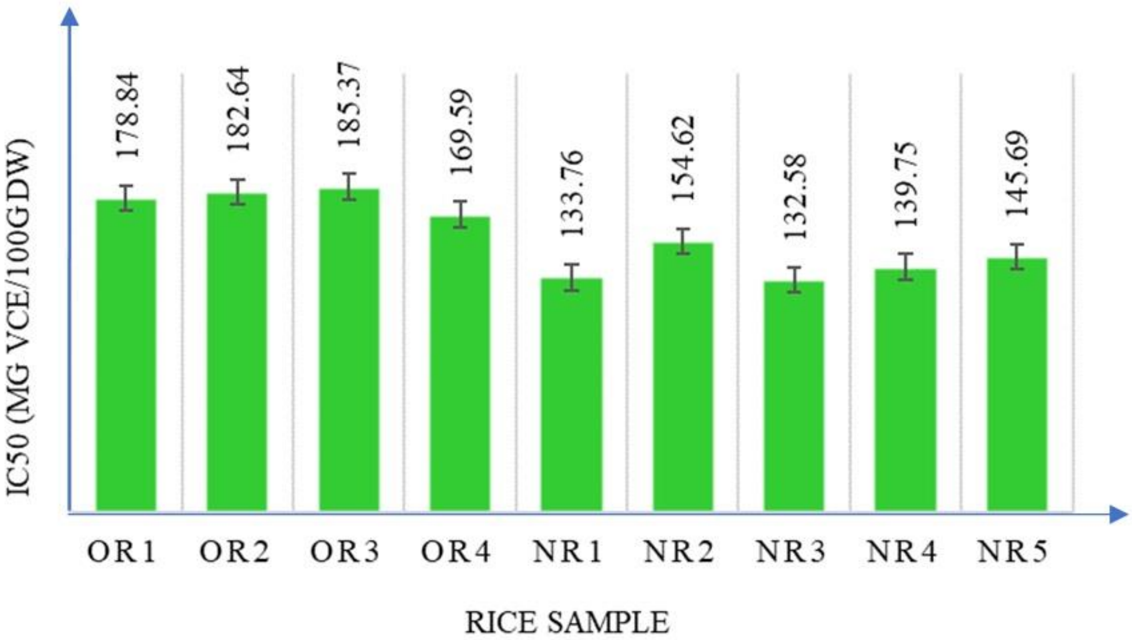

Fig. 5. Representative FT-IR spectra of two groups of PLR samples

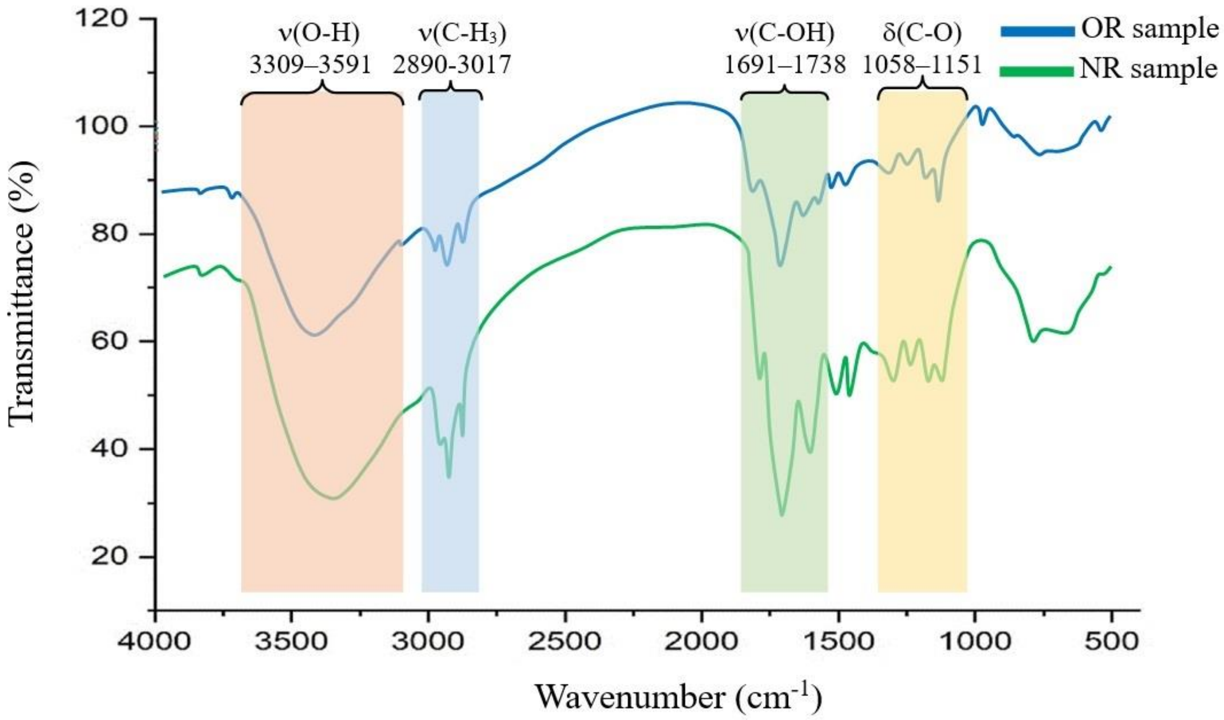

Table 1 Means of morphological parameters of representative rice grains and brown rice kernels

Rice samples	Means of morphological parameters						
	L*	a*	b*	L (mm)	W (mm)	L/W ratio	Weight (g)
Organic rice (OR)							
Grain	19.47 ±2.89	7.21 ±0.48	29.56 ±1.69	11.18 ±0.43	2.84 ±0.26	3.94 ±0.26	24.16 ±0.30
Brown rice kernel	42.62 ±1.49	39.20 ±0.43	20.49 ±0.48	8.56 ±0.16	2.81 ±0.17	3.04 ±0.26	20.64 ±0.39
Non-organic rice (NR)							
Grain	17.66 ±0.44	13.56 ±1.19	30.71 ±0.68	10.55 ±0.35	2.75 ±0.24	3.83 ±0.38	22.94 ±0.41
Brown rice kernel	39.41 ±0.43	35.59 ±1.56	21.40 ±1.12	8.32 ±0.53	2.76 ±0.15	3.01 ±0.34	20.10 ±0.29

Means within a row indicate significant differences ($p \leq 0.05$).

Table 2 Proximate chemical compositions of the PLR samples

Rice sample	Proximate chemical composition (%)				
	Ash	Moisture	Protein	Fat	Carbohydrates
Organic rice (OR)					
OR1	1.27 ± 0.11	10.19 ± 0.19	8.93 ± 0.26	3.43 ± 0.14	76.18 ± 0.47
OR2	1.32 ± 0.08	10.31 ± 0.14	9.06 ± 0.34	3.55 ± 0.28	75.77 ± 0.34
OR3	1.24 ± 0.04	10.25 ± 0.26	8.85 ± 0.29	3.25 ± 0.25	76.41 ± 0.48
OR4	1.35 ± 0.10	10.27 ± 0.15	8.91 ± 0.15	3.36 ± 0.24	76.11 ± 0.56
Non-organic rice (NR)					
NR1	1.34 ± 0.14	10.86 ± 0.11	9.38 ± 0.27	3.55 ± 0.29	74.87 ± 0.63
NR2	1.39 ± 0.09	11.01 ± 0.14	9.33 ± 0.24	3.43 ± 0.38	74.84 ± 0.49
NR3	1.37 ± 0.19	10.69 ± 0.25	8.91 ± 0.19	3.34 ± 0.31	75.69 ± 0.64
NR4	1.33 ± 0.11	11.12 ± 0.39	8.89 ± 0.36	3.22 ± 0.36	75.44 ± 0.61
NR5	1.42 ± 0.08	10.91 ± 0.18	8.82 ± 0.23	3.14 ± 0.23	75.71 ± 0.72
Mean	1.34 ± 0.10	10.62± 0.21	9.01 ± 0.25	3.36 ± 0.27	75.67 ± 0.54

** Means within a row indicate significant differences ($p \leq 0.05$).*

Table 3 Total phenolic contents and DPPH radical scavenging activities of different rice sources

Country	Phenolic content (mg GAE/100 g DW)	Antioxidant activity (mg/mL)	References
Thailand	335.51-359.96	132.58-185.37[e]	This study
Thailand	79.18-691.37	13.51-62.76	[7]
Thailand	92.66-437.16[a]	-	[33]
Thailand.	80.35-295.43[b]	0.02-0.08	[28]
Thailand	110.61- 251.99	8.35- 15.23	[6]
Thailand	39.35-219.35[c]	0.03-.0.06	[27]
Thailand	22.41-211	0.38-3.42	[25]
India	1968.67	-	[19]
India	94.8 - 900.90	2.92-86.74[f]	[10]
India	39-579.00	0.56-5.45[f]	[20]
India	15.32-276.80	33.32-176.4[f]	[9]
India	0.20-0.85[a]	-	[24]
China	325.08	3.70-34.6	[12]
China	149.82-1160.17[d]	-	[36]
China	36.50 ± 3.80	5.80-14.20[g]	[8]
Indonesian	47-70	28–47	[29]
Malaysia	2.70-54.10	-	[1]
Bangladesh	268.67-474	-	[23]
Nigeria	1.05-1.95[a]	1.01-1.70[g]	[11]

a= mg GAE/g, b= mg GAE/g FW, c= µg GAE/g, d= mg/L, e= mg VCE/100g DW, f= mg QE/g DW, g= mmol TE/kg

Table 4 TPC and antioxidant activity in extracts from commercial and local rice varieties

Rice varieties	Phenolic content (mg GAE/g FW)	Antioxidant activity (mg/mL)	References
White rice			
Paka-umpuel local rice	335.51-359.96[a]	132.58-185.37[b]	This study
Traditional jasmine rice	18.86±0.09[a]	6.19±0.05[b]	[25]
Red jasmine rice 1	88.75±0.2[a]	98.09±0.1[b]	[25]
Red jasmine rice 2	108.45±0.58[a]	101.84±0.90[b]	[25]
Jasmine rice 105	101.09±9.58	0.08±8.03	[28]
Cheek Choei Sao Hai Rice	70.45±12.02	0.07±9.29	[28]
Thung Kula jasmine rice	123.98±9.57	0.08±10.2	[28]
Pathum Thani fragrant rice 1	154.23±8.03	0.06±9.10	[28]
Red rice			
Bahng Gawk	691.37 ± 28.06[a]	12.99 ± 0.31[c]	[7]
Haek Yah	340.38 ± 6.70[a]	15.04 ± 0.48[c]	[7]
Sung Yod Phatthalung	341.70 ± 10.83[a]	14.56 ± 0.07[c]	[7]
Sang Yod Phatthalung rice	251.98±10.00	0.04±10.23	[28]
Chumphae Ruby rice	231.34±11.34	0.05±10.21	[28]
Black rice			
Rice berry	260.25±10.01	0.02±9.10	[28]
Black brown rice	245.47±10.45	0.03±10.11	[28]

a= mg GAE/100 g DW, b= mg VCE/100 g DW, c= DPPH in % remaining DPPH

Table 5 Toxic heavy metal concentrations in rice and cultivated soil samples

Rice sample	Heavy metal concentration in rice (mg/Kg)			Soil sample	Heavy metal concentration in cultivated soil (mg/Kg)		
	Lead	Cadmium	Arsenic		Lead	Cadmium	Arsenic
OR1	ND	ND	ND	*Organically cultivated soil (OS)*			
OR2	ND	ND	ND	OS1	1.070	0.005	ND
OR3	ND	ND	ND	OS2	1.010	0.006	ND
OR4	ND	ND	ND	OS3	1.008	0.005	ND
NR1	ND	ND	ND	*Non-organically cultivated soil (NS)*			
NR2	ND	ND	ND	NS1	1.108	0.010	ND
NR3	ND	ND	ND	NS2	1.009	0.009	ND
NR4	ND	ND	ND	NS3	1.091	0.009	ND
NR5	ND	ND	ND	Mean	1.049	0.007	-
STD[a]	0.2	0.2	0.2	STD[b]	45	1.7	30

ND = Not detected, a= WHO/FAO. (2011), b = The Land Development Department of Thailand (2015)