Comparison of Nutritional and Physicochemical Quality of Rice Under Organic and Standard Production Systems

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ABSTRACT

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Growing interest in sustainable agriculture has prompted this study aiming to evaluate nutritional content of rice grain produced from an organic production system. Here, we grew nine quality rice cultivars under organic methods in the wet and dry seasons, and the nutritional values, grain quality, and physiological parameters were compared with respective cultivars grown under the standard cultivation method (SCM). Obtained results revealed that the yield and plant height were lower, but tillering capacity was higher, in the organic field compared with the standard one. The organic crop showed significantly lower contents of protein and phytate compared with reference values under the SCM. Antioxidative capacity and its responsible phytochemicals such as phenolics, flavonoids, and γ-oryzanol were also significantly higher under organic cultivation than under the SCM. Among physicochemical characteristics, apparent amylose content, gel consistency, and area and perimeter of grain were also higher in the organic crops, but hulling quality, milling quality, head rice recovery, and all other cooking qualities were at par. Higher crude oil and lower total protein content of rice bran were observed in the organic crop, but ash, fiber, and moisture contents did not vary significantly in these two cultivation systems.

Rice is the staple food for more than half of the world's population. Yield and productivity of rice have significantly increased over the last 60 years owing to improved cultivars for almost all agroclimatic zones, advanced agronomic practices, and the use of agrochemicals (synthetic fertilizers, pesticides, herbicides, etc.). According to a Department of Agriculture and Cooperation, Government of India, 2013–2014 report (DAC 2014), the average yield of rice is 2.42 t/ha. However, injudicious application of agrochemicals can pose a threat to human health and environment (Yang and Hwa 2008). Organically grown rice, which excludes use of any agrochemicals, has started to gain popularity with consumers as the safer and healthier alternative, especially in developed countries. Hence, organic rice fetches a higher value in the international market than its conventionally grown counterpart. Increased demand and higher profit have generated considerable enthusiasm about organic rice farming. Interestingly, organic and nonorganic produce differed in quality parameters. For example, keeping the variety constant, higher grain protein content was obtained in the case of rice grown under standard conditions (Magkos et al. 2003), whereas total phenolics, phytic acid (PA) content, minerals content, and antioxidative activity were higher in organically generated rice (Park et al. 2010). Nutrient sources also influenced the physicochemical properties of the produce. Lower doses of organic manures resulted in better hulling quality, whereas the best head rice recovery (HRR) (i.e., unbroken rice kernels obtained after 10% polishing of dehulled grain) was obtained by using kudzu compost, but different sources and levels of nutrients had no significant influence on kernel elongation (Saha et al. 2007). Milling recovery was significantly correlated with hulling, and kernel length after cooking with the elongation ratio. HRR and the length-to-breadth ratio were also reported to increase in organic treatments (van Quyen and Sharma 2003). Overall, a critical review of available literature suggests that in terms of physicochemical properties and cooking qualities, an organic production system (OPS) can yield better quality rice than a standard cultivation method (SCM) generally adopted by the farmers. This study was conducted to investigate comprehensively the yield and processing, physicochemical, nutritional, and antioxidative quality of rice grain and rice bran under the OPS and SCM.

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MATERIALS AND METHODS

Experimental Sites and Agronomic Practices. This study was undertaken during the wet and dry seasons of 2013–2014 in the experimental farm of the ICAR–Central Rice Research Institute, Cuttack (20°25′N, 85°55′E; 24 m above mean sea level), situated in the eastern part of India. The mean annual precipitation was around 1,500 mm. The soil is an Aeric Endoaquept with sandy clay loam texture (25.9% clay, 21.6% silt, and 52.5% sand); bulk density, 1.40 Mg/m^3; percolation rate, <10 mm/day; pH (H_2O) 6.16, cation exchange capacity, 15 cmol (p+)/kg; and electrical conductivity, 0.5 dS/m. This site has been growing rice crops organically for about 9 years (since 2007). Nine cultivars, namely Annapurna, Geetanjali, Ketakijoha, Heera, Satabdi, ARC10075, Padmini, Sharbati, and CR Sugandha Dhan 907 (CRSD907), were laid out in a randomized complete block design with three replications in both the dry and wet seasons and were grown purely under an OPS. On the other hand, conventional puddling followed by transplanting of rice seedlings was practiced in the case of SCM, along with the recommended dose of fertilizer (N/P/K 80/60/40 kg/ha). An isolation distance (40 m) was maintained around its peripheral boundary, and some deep-rooted rice cultivars were grown in this area, which acted as a buffer zone. The organic plots were divided by bunds (walls) made of soil. Seedlings were raised in a nursery under a similar organic environment. Tender sunn hemp (*Crotalaria juncea* L.) was incorporated at the time of puddling as green manure, and farmyard manure equivalent to 60 kg of nitrogen per hectare was also applied at the time of tillage operation. The doses of organic manures were adjusted according to the need for nitrogen and phosphorus of rice (because potassium is not generally deficient in Indian soils). For the wet and dry seasons, 25-day seedlings were transplanted in each plot (72.1 m^2) with 30 × 30 cm spacing. Plot preparation and transplanting of seedlings were done during the last week of July and last week of October for the two wet season corps for every year depending upon prior crop duration, and for the dry season it was the first week of February and the last week of May. All the field plots were kept flooded throughout the entire period of crop growth to a water depth of 7 ± 2 cm and were drained out 10 days before harvesting. Rice grains produced by the SCM were collected from the other agronomic field, which was about 800 m apart from the organic plot. These fields were prepared by conventional puddling, and crops were managed accordingly. Because the field was puddled thoroughly and inundated during the growth period of rice, the weed incidence was negligible. There was no application of pesticides (synthetic or organic) in the organic field, whereas synthetic pesticides were applied in the SCM field. It was noticed that the pest and disease incidence of the OPS plot was under the economic threshold level.

Materials. The dried grains were stored at 20°C in a closed room for one month prior to analysis of physicochemical properties. The moisture content of grain was measured with a digital moisture meter (Osaw, India) and 12–13% moisture content was maintained throughout the experiment. Another set of grain samples (100 g) was stored at 4°C for estimation of antioxidants and other compounds. For analysis of antioxidants and all other chemical compounds, brown rice flour was used. For microbiological and enzymatic analysis, root zone soil from the organic plots was collected. The physiological and yield data were collected from the fields. Because this field had been maintained organically since 2007, only the mean value of two seasons, that is, wet season of 2013 (July–October) and dry season of 2014 (December–March) data are presented here. For all the parameters estimated, three field replications (from both organic and standard plots) were made for each cultivar from three random sites of the same experimental plots.

Chemicals. 2,2-Diphenyl-1-picrylhydrazyl (DPPH) and 2,2′-azino-bis 3-ethylbenzthiazoline-6-sulfonic acid (ABTS) were purchased from Sigma-Aldrich, whereas Folin–Ciocalteu reagent, potassium ferricyanide, catechol, catechin, isopropanol, potassium persulfate, phytate, and others were purchased from Merck and MP Biomedicals.

Physicochemical Properties. The rough rice was dehulled to obtain brown rice, which was further polished (or milled) for 60 s. Hulling percentage was calculated by weighing the whole brown rice after hulling and expressed as percentage basis, whereas milled rice outturn was expressed as percent of milled rice (broken plus unbroken grain). After broken rice separation with a manual separator, HRR was calculated as percentage of whole unbroken polished rice obtained from the rough rice sample. This polished rice was ground with a Glen mini grinder to get rice flour. A digital image analyzer (Annadarpan, India) was used for measurement of grain length, breadth, length-to-breadth ratio, area, and perimeter. Volumes of cooked and milled rice were measured by the water displacement method. Briefly, 5 g of milled rice was added to a graduated cylinder containing 50 mL of water, and the change in volume was noted. To measure the volume of cooked rice, 5 g of milled rice was cooked and then added to the same cylinder to note the change in volume. Optimum cooking time, gel consistency, alkali spreading value, and amylose content were measured according to the methods of Juliano (2003).

Near-Infrared (NIR) Spectroscopic Analysis of Rice Bran. Nearly 10 g of bran sample was taken in a small cup for obtaining the proximate data. The NIR spectrometer was calibrated with three software programs associated with NIR spectroscopy (FOSS-NIRSDS 2500, FOSS Analytical, Sweden). The software programs ISI Nova scan, Mosaic solo, and WinISI III Project Manager version 1.50e (Windows Infra Soft International, U.S.A.) were used for scanning, configuration, and calibration of samples, respectively. A small cup (size: inner diameter 66 mm and height 25 mm) was used for scanning of the samples with a full spectrum (400–2,500 nm). The prediction model was developed through “1,4,4,1 regression equation” with standard normal variate plus deviation under modified partial least squares (Bagchi et al. 2016).

Total Antioxidant Capacity by DPPH Scavenging Assay. The determination of total antioxidant capacity was based on the method of Zhu et al. (2011). Briefly, 1 g of fine defatted brown rice flour and 10 mL of ethyl alcohol were mixed and shaken for 24 h at 50 rpm in a tube shaker. After centrifugation at 10,000 × *g* for 20 min, the supernatant was collected, and the volume was made up to 10 mL with ethanol. With 1 mL of the extracts, 2 mL of ethyl alcohol and 1 mL of DPPH (100 μM) solution were added. After 30 min, the absorbance was measured at 517 nm against the blank. The percentage of radical scavenging ability was calculated by using the following formula:

$$\text{DPPH activity (\%)} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100 \qquad (1)$$

where A is absorbance.

Reducing Power of Rice by Ferricyanide (FRAP) Test. FRAP was estimated according to the method of Jeng et al. (2010), taking ethanol/water (70:30) as the extractant and phosphate buffer solution (0.2M, pH 6.6), potassium ferricyanide, ferric chloride, and trichloroacetic acid as reagents. Increased absorbance indicates increase of reducing power.

ABTS Radical Scavenging Assay. The total antioxidant capacity of ground brown rice fractions was measured with a method adapted from Serpen et al. (2008) without any prior extraction step. In this methodology, both the soluble and insoluble fractions of antioxidant compounds come into contact with the ABTS radical. The $ABTS^+$ reagent was prepared by reacting a 7 mM aqueous solution of ABTS with 2.45 mM potassium persulfate and further dissolving the mixture in ethanol/water (50:50, v/v) so that a 1:5:28 (v/v) ratio of ABTS, potassium persulfate, and ethanol/water was maintained, and final absorbance at 734 nm was 0.70 ± 0.02 arbitrary units. $ABTS^+$ reagent (6 mL) was added to 10 mg of brown rice flour, and the mixture was vortexed for 1.5 min to perform the surface reaction. Following centrifugation at 9,200 × *g* for 2 min, the absorbance of the optically clear supernatant was measured at 734 nm exactly 30 and 60 min after sample mixing with the ABTS reagent. The antioxidant capacity was expressed as percent reduction of absorbance.

Total Phenolic Content. The total phenolic content was determined according to the Folin–Ciocalteu procedure with a few modifications of the method described by Žilic et al. (2011). Briefly, 0.3 g of brown rice flour sample and 10 mL of 70% acetone were mixed thoroughly in a centrifuge tube at room temperature. After centrifugation for 20 min at 15,000 × *g*, aliquots (0.2 mL) of aqueous acetone extracts were transferred into test tubes and their volumes made up to 0.5 mL with distilled water. After addition of the Folin–Ciocalteu reagent (0.25 mL) and 20% aqueous sodium carbonate solution (1.25 mL), tubes were vortexed. After 40 min, the absorbance was recorded at 725 nm against a reagent blank. The total phenolic content of each sample was determined by means of a calibration curve prepared by using catechol and expressed as milligrams of catechol equivalents (CE) per gram of brown rice flour.

Total Flavonoids Content. Total flavonoids content was determined spectrophotometrically at 510 nm according to the method of Eberhardt et al. (2000) with ethanolic extract. For the detection of flavonoids, 1 g of brown rice flour was extracted in 10 mL of 40% (v/v) ethanol for 30 min at room temperature by shaking (120 rpm). The supernatant, after centrifugation for 20 min at 15,000 × *g*, was used in this experiment. Briefly, 0.075 mL of 5% $NaNO_2$ was mixed with 0.5 mL of the sample (ethanolic extract diluted with 1 mL of water). After 6 min, 0.15 mL of a 10% $AlCl_3$ solution was added, and the mixture was allowed to stand for another 5 min. Then, 0.5 mL of 1M NaOH was added, and the volume was made up to 2.5 mL with distilled water. The absorbance was measured at 510 nm immediately after mixing, against the blank containing the extraction solvent instead of a sample. The result was expressed as milligrams of catechin equivalents (CEt) per gram of sample.

γ-Oryzanol Content. Determination of γ-oryzanol content was based on the modified protocol of Bucci et al. (2003). It is available in the market as a mixture of four derivatives, namely, cycloartenyl ferulate, 24-methylenecycloartanyl ferulate, campesteryl ferulate, and sitosteryl ferulate. It was extracted using 200 mg of brown rice flour through vortexing with isopropanol, and after extraction twice, the final volume of the supernatant was 10 mL, and the absorbance was measured at 324 nm against the blank. Concentration of γ-oryzanol in the sample was measured through comparison with a standard curve prepared by taking different concentrations of γ-oryzanol (obtained from Oryza Oil and Fat Chemical Co., Japan).

PA Content. PA content of brown rice was estimated according to the method of Gao et al. (2007) with some modifications. Extraction of PA was done by taking 1 g of brown rice flour sample in 10 mL of 2.4% HCl in a 100 mL conical flask, and the flasks containing the samples were shaken at 220 rpm for 16 h in an incubator shaker at 50°C (Rivotek, India) and centrifuged at 10,062 × *g* in a tabletop centrifuge (Remi, India) at 25°C for 20 min. The supernatant was then collected, and after adding 1 g of NaCl, it was shaken for 20 min at 350 rpm. After keeping for 20 min at –20°C, these tubes were again centrifuged at 3,000 × *g* for 20 min. After 25 times dilution of supernatant with double-distilled water, 3 mL of sample and 1 mL of Wade reagent (0.03% $FeCl_3$, $6H_2O$ + 0.3% sulfosalicylic acid) were mixed thoroughly by vortexing. After 1 h, absorbance was measured at 500 nm. A standard curve was prepared by sodium phytate so that the blank absorbance was 0.453 ± 0.002. PA concentration was determined through the following formula:

$$\text{PA\%} = \frac{(0.463 - A) \times 25 \times V}{22.05 \times M} \quad (2)$$

where A is absorbance, V is the final volume (mL), and M is the weight of sample (g).

Total Protein Content. The total protein content was determined by taking 10 brown rice flour samples in three replications and, as described in the AOAC methodology (Kjeldahl digestion) (AOAC 1990), using the formula N × 5.95. Accordingly, per grain protein content was calculated.

Statistical Analysis. The complete data set consisted of a matrix of 22 × 9 × 3, where the rows represented the physiological and biochemical parameters (i.e., values for variables of nine cultivars with three replications in respect of two systems of cultivation) and columns represented number of cultivars (nine). Two-way ANOVA was performed to obtain significant differences between cultivars as well as two systems of cultivation by using PROC GLM of SAS software. The raw data used for final statistical analysis were actually the mean of two seasons (wet and dry). When differences were statistically significant, Tukey's honestly significant difference was used to compare the means. The 5% level of significance was used for interpretation of the results. All analysis was performed with SAS 9.2 and Microsoft Excel.

RESULTS AND DISCUSSION

Yield and Physiological Parameters. The yield and physiological parameters are shown in Table I. We observed that the yield of the OPS crop was significantly ($P < 0.001$) lower (mean deficit 23.19%) than the SCM crop. Plant height was also found to be reduced significantly ($P < 0.001$) for the OPS compared with SCM. Interestingly, tiller number was a little higher in the OPS than in the SCM; however, the difference was statistically insignificant ($P = 0.096$). The observed yield advantage of SCM over OPS was constant with an earlier report in which standard practice yielded 15–20% more in both wet and dry seasons over organic in four consecutive years (Surekha et al. 2013). However, in the same study both standard and organic yielded at par (4.0–4.2 t/ha) in the long run (after five years), which is indicative of diminishing yield under standard compared with yield sustainability under organic systems (Surekha et al. 2013). Urkurkar et al. (2010) also found that the growth and yield of rice increased under long-term organic cultivation. Therefore, in the long run, organic cultivation might be more beneficial compared with conventional, because it has the potential to deliver a sustainable economic yield with low cost inputs over the years.

Physicochemical and Cooking Properties of the Grain. Variations in the physicochemical parameters of the rice grain in response to cultivation methods were significant (Table II). The hulling percent was highest in organic Ketakijoha (78.73%) and ARC10075 (77.17%), whereas the lowest (73.37%) was observed from Satabdi grown under SCM, but this difference was statistically insignificant ($P = 0.5176$) (Table II). The highest milling percentage was also recorded from organic Ketakijoha (68.23%), but again the difference in milling percentage was insignificant ($P = 0.8497$) between the two different cultivation methods. Significant difference ($P = 0.0052$) was observed in the case of HRR (Table II). The highest HRRs were found in the case of standard Ketakijoha and CRSD907 (63.92 and 64%, respectively) (Fig. 1A). Interestingly, HRR of Annapurna under OPS was drastically reduced (24.17%) compared with SCM (50.33%). In general, it was observed that HRR of rice containing red pericarp was lower than the rice containing white pericarp. For example, HRR of Annapurna, a red-pericarp-containing rice, was visibly lower than the others. The reason for this phenomenon is unknown as yet. Because length, breadth, and length-to-breadth ratio of the grain are genetically controlled, the differences in these parameters were insignificant between the same cultivars whether these were derived from the OPS or SCM (Fig. 1B). For instance, in the case of organic farming, the highest grain length-to-breadth ratio among all cultivars was recorded from Satabdi (3.60) followed by Geetanjali and CRSD907 (3.28 for both). Among environmental factors, supply of nutrient

TABLE I
Comparison of a Few Physiological Components and Yield of Nine Cultivars Grown Under Organic (OPS) and Standard (SCM) Cultivation Methods[z]

Cultivars	Plant Height (cm)		Number of Tillers per Hill		Crop Duration (days)		Yield (t/ha)	
	OPS	SCM	OPS	SCM	OPS	SCM	OPS	SCM
Annapurna	78.33d	84.33c	7.00c	8.67	119.00b	119.00b	2.57b	3.10bc
Sharbati	97.33ab	100.00ab	9.00abc	8.00	137.67a	137.67a	2.53b	4.70a
ARC10075	98.67a	106.00a	11.00a	8.33	134.33a	134.33a	3.37a	3.87ab
Ketakijoha	98.00a	104.00ab	9.67ab	9.00	137.67a	137.67a	2.50b	3.53bc
Geetanjali	100.00a	102.67ab	9.67ab	8.67	132.67a	132.67a	2.50b	3.37bc
Heera	67.67e	77.67c	8.00bc	8.67	115.67b	115.67b	2.50b	2.77c
Satabdi	93.67abc	101.00ab	8.00bc	8.00	115.00b	115.00b	3.73a	4.73a
Padmini	88.33bc	96.00b	11.00a	8.33	117.00b	117.00b	3.80a	4.77a
CRSD907	85.33cd	96.67b	8.33bc	9.00	115.67b	115.67b	3.30a	4.10ab
Tukey's HSD at 5%	9.4	8.5	2.43	NS	6.15	6.15	0.71	1.04
Mean	89.7	96.5	9.07	8.52	124.96	124.96	2.98	3.88
P value (5%)	<0.001		0.0960		NS		<0.001	

[z] HSD = honestly significant difference; NS = nonsignificant.

sources during the life cycle of the crop contributes to the physicochemical quality of the grain (Miller et al. 1980). Therefore, we found some variations of physicochemical properties of grain under both the production systems in this study. Cooking quality is an important parameter with respect to consumers' acceptance, and it varied significantly among the cultivars (Table II, Fig. 1C). The highest kernel length after cooking was found from organic Geetanjali (11.60 mm), but there was insignificant difference between the OPS and SCM. Other parameters such as elongation ratio and optimum cooking time did not vary significantly between the two types of cultivation practices. The highest volume expansion ratio was observed from both organic and standard Ketakijoha (4.00). The highest water uptake was recorded from organic Sharbati (206.67 mL/100 g of sample), but again the variations were statistically insignificant (P = 0.657) between the two production systems. Figure 1D depicts chemical quality of grains obtained from different cultivars under these two systems of cultivation. It was observed that gel consistency was slightly higher (significant at 1%) in a few organic cultivars. In general, amylose content was found to be higher in organic rice (ranging from 18.35 to 26.14%) compared with conventional rice (16.65–24.65%). This contradicts to the earlier report of Keawpeng and Meenune (2012), in which amylose content was found to be higher in standard than organic Sungyod rice. Any particular trend was not observed in the case of alkali spreading values under both types of cultivation methods (significant at 1%) with respect to these nine cultivars.

TABLE II
Two-Way ANOVA Test for Various Physicochemical Qualities of Rice Grains, Produced Under Both Organic and Standard Cultivation Methods[z]

Parameters	Effects	*P* Value	*F* Ratio	Significance
Hulling	MC	0.5176	0.6	NS
	C	<0.0001	62.4	**
	MC × C	<0.0001	14.7	**
Milling	MC	0.8497	0.0	NS
	C	<0.0001	61.5	**
	MC × C	<0.0001	9.8	**
HRR	MC	0.0052	191.5	**
	C	<0.0001	243.2	**
	MC × C	<0.0001	70.4	**
Area	MC	0.0246	39.1	*
	C	<0.0001	43.1	**
	MC × C	0.0024	3.9	**
Perimeter	MC	0.0195	49.9	*
	C	<0.0001	42.3	**
	MC × C	<0.0001	6.9	**
Length (L)	MC	0.0857	10.2	NS
	C	<0.0001	40.3	**
	MC × C	0.0004	5.1	**
Breadth (B)	MC	0.0203	47.8	*
	C	<0.0001	100.1	**
	MC × C	0.0265	2.6	*
L/B ratio	MC	0.6246	0.3	NS
	C	<0.0001	261.2	**
	MC × C	<0.0001	13.7	**
WU	MC	0.657	0.3	NS
	C	<0.0001	25.2	**
	MC × C	0.0004	5.1	**
OCT	MC	0.0695	12.9	NS
	C	<0.0001	31.6	**
	MC × C	0.0587	2.2	NS
ER	MC	0.1265	6.4	NS
	C	<0.0001	33.6	**
	MC × C	0.0215	2.7	*
VER	MC	0.0003	3,844.0	**
	C	<0.0001	33.0	**
	MC × C	0.0003	5.2	**
KLAC	MC	0.178	4.2	NS
	C	<0.0001	348.1	**
	MC × C	<0.0001	12.8	**
ASV	MC	0.0123	80.1	*
	C	<0.0001	544.9	**
	MC × C	<0.0001	70.5	**
AC	MC	0.0033	301.5	**
	C	<0.0001	575.5	**
	MC × C	<0.0001	23.1	**
GC	MC	0.0243	39.6	*
	C	<0.0001	242.3	**
	MC × C	<0.0001	11.1	**

[z] ** and * signify variability at the 1 and 5% level of significance, respectively; NS = nonsignificant. MC = method of cultivation; C = cultivars; MC × C = interaction between MC and C; HRR = head rice recovery; L/B = grain length-to-breadth ratio; WU = water uptake (mL/100 g of rice); OCT = optimum cooking time (min); ER = grain elongation ratio after cooking; VER = volume expansion ratio; KLAC = kernel length after cooking (mm); ASV = alkali spreading value; AC = apparent amylose content (%); and GC = gel consistency (mm).

Proximate Analysis of Bran by NIR Spectroscopy. NIR spectroscopy methods have been extensively used for rapid and nondestructive estimation of grain quality, especially in the case of cereals, pulses, and oilseeds. In our experiment, fresh rice bran samples obtained from nine cultivars were used for analysis of moisture, protein, crude oil, crude fiber, and ash contents, because bran is the most nutritional component of grain and some essential nutrients have been found in this layer. The rice bran obtained from the SCM was found to contain more protein than OPS (Fig. 2), following a similar trend as brown rice samples (Table III). But in the case of crude oil content, it was the reverse. Total fiber, moisture, and ash contents of bran varied significantly (P = 0.0175, 0.0025, and 0.0091, respectively) between organic and standard rice (Fig. 2). Among all cultivars, rice bran of organic Annapurna showed the lowest ash content (3.65%), whereas the highest was obtained from standard ARC10075 (6.29%). Components of bran samples were predicted using a NIR spectrum (with standard deviation) under 1,4,4,1 chemometric equation (Fig. 3). Five maximum absorption peaks (overtones) were observed between 400 and 2,499 nm of the spectrum. NIR spectroscopy is a spectroscopic method based on molecular overtones and combination vibrations of C-H, O-H, and N-H. Hooke's law can be used to calculate the fundamental vibrations for diatomic molecules in infrared. Transition from the ground state to the first excited state absorbs light strongly in the infrared region and gives rise to intense bands called the fundamental bands. Transition from the ground state to the second excited state with the absorption of NIR gives rise to weak bands called the first overtone in NIR spectroscopy. Transition from the ground state to the third excited state with the absorption of NIR gives rise to weak bands called the second overtone in NIR spectroscopy. Likewise, the third and fourth overtone bands will occur simultaneously (Aenugu et al. 2011). The green (or light gray, in print) line in Figure 3 represents the mean value of the absorbance. Sirikul et al. (2009) reported that there was no significant difference (at $P < 0.05$) of crude protein and crude oil between organic and conventional rice bran, whereas the contents of fiber and ash of organic rice bran were significantly higher ($P < 0.05$) than those of conventional rice bran.

Antioxidant Activity. In our study, organic brown rice flour showed higher antioxidant activity compared with their conventional counterparts in all nine rice cultivars (Table III). In the case of the ABTS assay, it ranged from 40.2 to 98.9% for organically managed rice and from 33.7 to 98.5% for standard rice. The variations were statistically significant when compared between organic and standard rice. A similar trend was observed in the FRAP assay with respect to all the cultivars. The FRAP antioxidant activity values ranged from 0.35 to 1.75% for organic and from 0.29 to 1.10% for standard rice, respectively. But in the case of the DPPH assay, the five cultivars showed slightly higher antioxidant activity in organic than standard rice except for Sharbati, Geetanjali, Heera, and Padmini. However, again the difference between OPS and SCM was statistically insignificant (P = 0.0591). The highest antioxidant capacity was observed in Annapurna (red rice) and the lowest in Geetanjali, Heera, and CRSD907 in organic rice samples (Table III). Previous studies demonstrated that organically grown spinach contained 120% higher antioxidant activity, whereas Welsh onion,

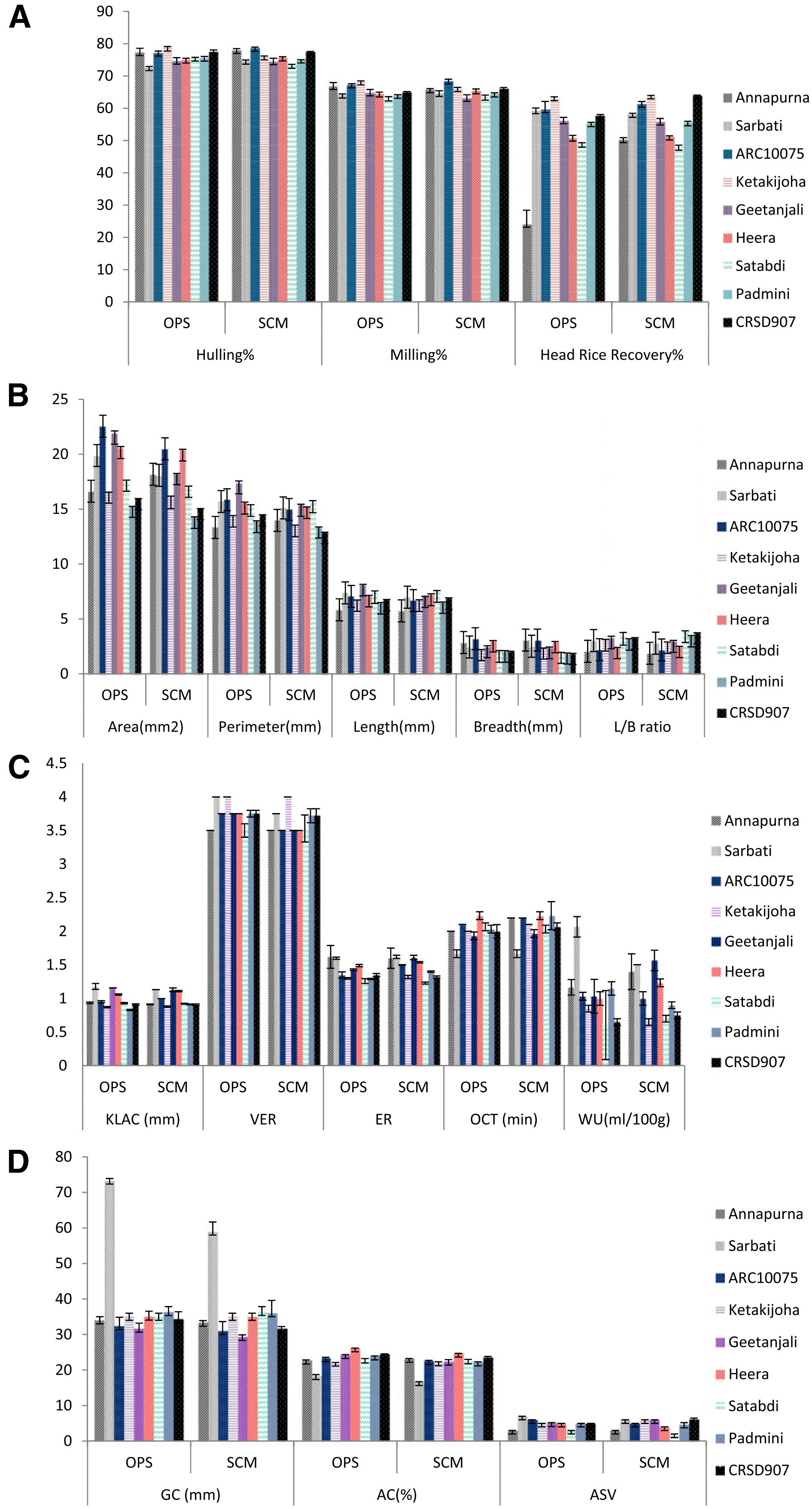

Fig. 1. Bar diagram (with standard deviations) of various physicochemical qualities of rice grains, produced under organic (OPS) and standard (SCM) cultivation methods: **A,** milling quality; **B,** physical quality; **C,** cooking quality; and **D,** chemical quality of rice. L/B = length to breadth; KLAC = kernel length after cooking; VER = volume expansion ratio; ER = grain elongation ratio after cooking; OCT = optimum cooking time; WU = water uptake; GC = gel consistency; AC = apparent amylose content; and ASV = alkali spreading value. In C, the actual data of KLAC and OCT have to be read as 10 times more, and for WU 100 times more, than the data shown in this bar diagram.

Chinese cabbage, and qing-gen-cai (a Chinese leafy vegetable) contained 20–50% higher antioxidant activity compared with their inorganically grown counterparts (Ren et al. 2001; Chen and McClung 2015). Crops such as oranges (Tarozzi et al. 2006), grapes, onions, and potatoes (Faller and Fialho 2010) were found to contain higher antioxidant activity when grown organically. The antioxidant activity was associated with some plant secondary metabolites capable of protecting a biological system against the reactive oxygen (and nitrogen) species, which cause damage to cell organelles. We have purposefully chosen three different assays for antioxidants in this study. $ABTS^{+}$ is soluble in aqueous as well as in organic media. Hence, antioxidant activity derived as resultant of both hydrophilic and lipophilic compounds in samples can be measured by this assay. In contrast, DPPH can only be dissolved in aqueous media, not in organic media, which limits its use in interpreting the role of hydrophilic antioxidants (Kim et al. 2002). We also used FRAP as well to measure the reducing power of the antioxidant compounds present in our samples under study. Unlike the conventionally used inorganic fertilizers, organic fertilizers do not provide nitrogen in a form that is readily accessible to plants. The accessibility of nitrogen has the potential to negatively influence the synthesis of phenolic antioxidants. Several studies demonstrated decreased concentration of phenolic antioxidants in plants with increasing nutrient availability (Sander and Heitefuss 1998). Reports are also available for consistent higher production of total phenolics in organic strawberries, marionberries, and sweet corn (Asami et al. 2003) when grown organically. The results of our study are consistent with these earlier findings.

Total Phenolics, Flavonoids, and γ-Oryzanol. The phenolics, flavonoids, and γ-oryzanol contents were higher in organic rice than in conventional rice in all nine cultivars (Table IV). The highest amount of both phenolics and flavonoids was found in red rice Annapurna under OPS, whereas the lowest was obtained in Geetanjali (1.24 mg of CE/g of phenolics) and Padmini (0.51 mg of

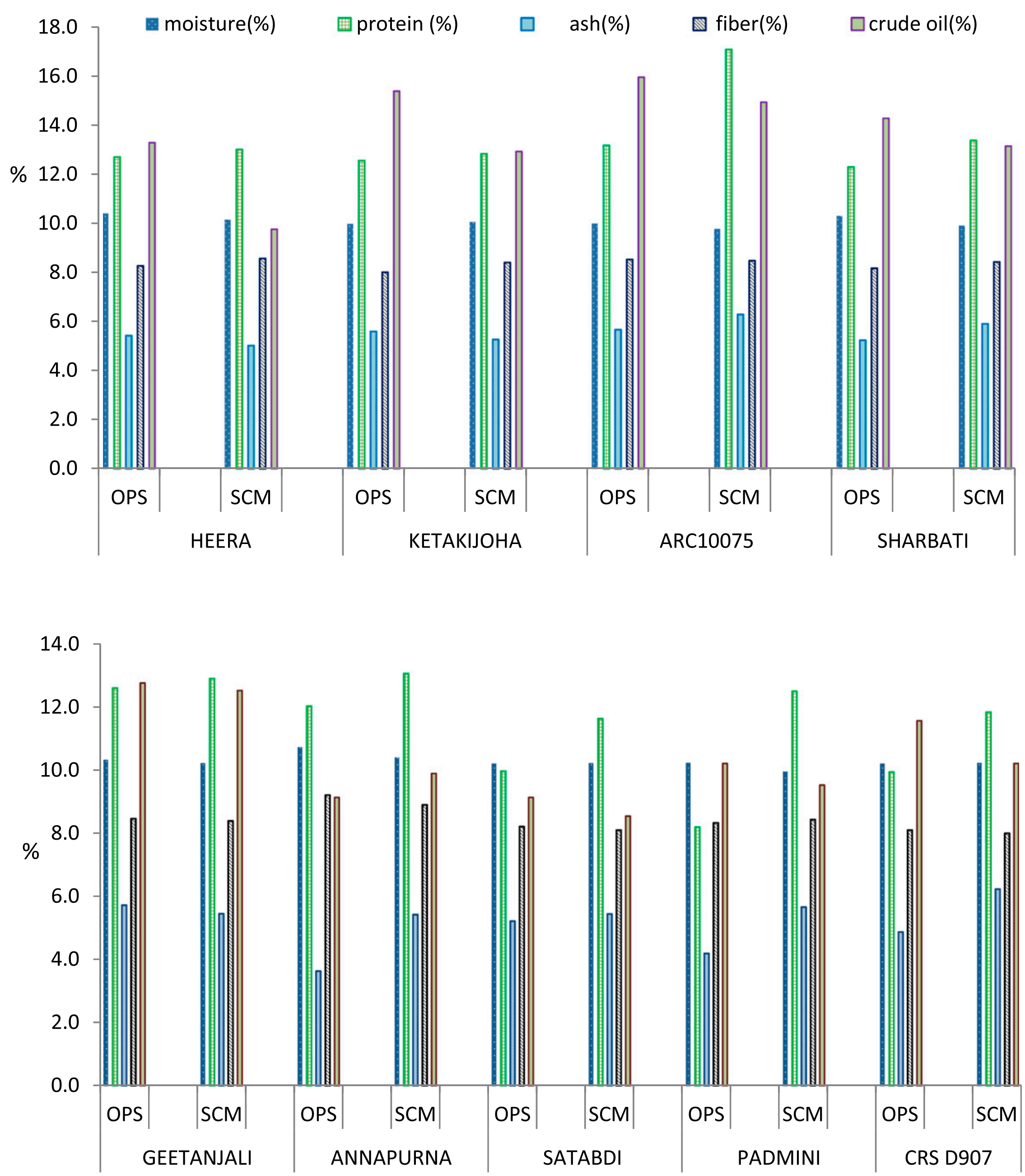

Fig. 2. Column diagram of NIR analysis of proximate compositions of rice bran sample collected from the organic (OPS) and standard (SCM) cultivation methods.

CEt/g of flavonoids) grown under SCM. Previously, it was reported that organically grown fruits of peaches and pears had increased concentrations of total polyphenols (10–36% higher; $P < 0.05$) compared with their conventionally grown counterparts, demonstrating improved antioxidative defense of the organically cultivated plants (Carbonaro et al. 2002). Flavonoids are secondary plant metabolites found in the vacuoles of plant cells, and they play crucial roles as antioxidants. There are several classes of flavonoids (flavonols, flavones, flavanones, isoflavones, etc.), which are grossly classified based on the oxidation state of their pyran ring (Benbrook 2005). These also encompass a large and widespread array of water-soluble phenolic derivatives, some of which are colored and contribute to the bright color of petals in flowers, which serve to attract insect pollinators. In the case of cereals, these are mostly present in the outer bran layer of the seed grain. In this study, all organic rice exhibited a higher amount of flavonoids compared with their standard counterparts (Table IV). Limited nutrient accessibility and higher pest and disease occurrence in organics than in standards may increase the biosynthesis of secondary metabolites including flavonoids (Wu et al. 2008; Park et al. 2015). Several experiments indicated that flavonoids can accumulate in plant leaves in response to different mineral (nitrogen, phosphorus, and potassium) nutrition deficiencies (McClure 1975) and by pathogenic pressure. Hence, we hypothesize that slow release of available nitrogen in organic rice farming led to up-regulation of phenylalanine ammonia lyase activity, which ultimately led to the increase in flavonoid concentration. This could be a typical example of dynamic reprogramming of metabolism in which a considerable amount of cellular energy has been diverted to activate secondary metabolism to adapt to an environment in which defense is the priority over growth (Meyer et al. 2006). This also explains the reason for obtaining a lower amount of total protein in brown rice cultivated under OPS than under SCM. γ-Oryzanol, composed of mainly the esters of *trans*-ferulic acid, is mostly found in the bran layer of rice. γ-Oryzanol is known for its antioxidative, antitumor, and anti-inflammatory properties. The results of our study showed that brown rice of all nine cultivars had higher γ-oryzanol content when grown under OPS compared with SCM (Table IV), which is consistent with the earlier findings of Cho et al. (2012).

PA Content of Brown Rice Grain. PA is one of the main inhibitors influencing the availability of divalent cations such as Fe^{2+}, Ca^{2+}, Mg^{2+}, and Zn^{2+}. The phosphate groups of PA (*myo*-inositol

TABLE III
Comparison of Antioxidative Capacity and Protein Content of Nine Cultivars Grown Under Organic (OPS) and Standard (SCM) Cultivation Methods[z]

	DPPH (% Inhibition)		ABTS (% Inhibition)		FRAP (% Increase in Absorbance)		Protein Content (%)	
Cultivars	**OPS**	**SCM**	**OPS**	**SCM**	**OPS**	**SCM**	**OPS**	**SCM**
Annapurna	81.2a	80.7a	98.9a	98.5a	1.75a	1.10a	6.75b	9.90b
Sharbati	63.7e	64.3g	43.6e	34.1f	0.39d	0.37b	4.95f	8.10c
ARC10075	72.2bc	69.2c	43.2e	40.0e	0.37d	0.37bc	6.75b	9.90b
Ketakijoha	67.6d	66.3f	57.4b	54.7b	0.35d	0.29f	4.95f	6.30d
Geetanjali	60.1f	68.9cd	40.2f	33.7f	0.37d	0.32e	6.30c	6.75d
Heera	61.0f	70.6b	40.2f	27.4g	0.37d	0.36d	8.10a	10.35a
Satabdi	73.3b	67.6ef	55.1c	54.8b	0.60b	0.36cd	4.95ef	5.40f
Padmini	60.9f	62.6h	49.0d	47.3d	0.49c	0.36d	5.40d	5.85ef
CRSD907	70.9c	67.8de	57.3b	49.1c	0.32d	0.31e	5.40de	5.85e
Mean	67.89	68.68	53.9	48.9	0.60	0.43	5.95	7.60
Tukey's HSD at 5%	1.3	1.2	1.1	0.8	0.07	0.01	0.01	0.005
P value of MC (1%)	0.0591(NS)		0.0002**		<0.0001**		0.011**	

[z] Tukey's honestly significant difference (HSD) at 5% depicts significant or nonsignificant variability among cultivars, and *P* value of method of cultivation (MC) refers to significance between both methods of cultivation. ** signifies variability at the 5% level of significance; NS = not significant. All the parameters were calculated on the basis of brown rice flour. DPPH = 2,2-diphenyl-1-picrylhydrazyl; ABTS = 2,2′-azino-bis 3-ethylbenzthiazoline-6-sulfonic acid; and FRAP = reducing power of rice by ferricyanide.

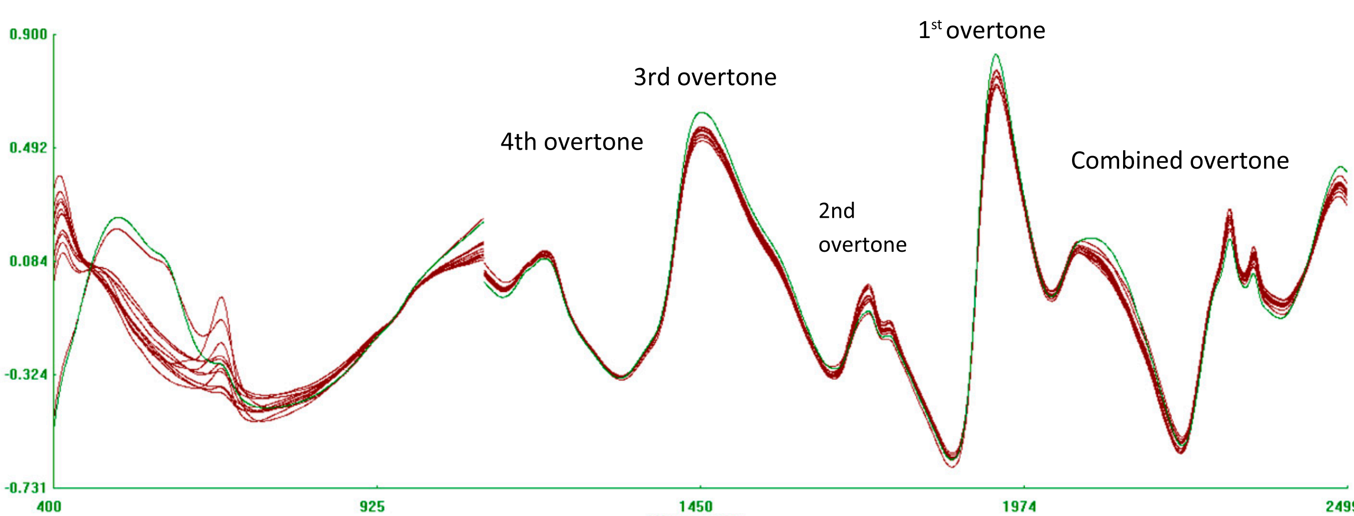

Fig. 3. NIR spectrum of bran samples (predicted) with standard deviation in the best (1,4,4,1) chemometrics treatment. Here, five constituents (crude fiber, moisture, protein, ash, and oil) of rice bran were predicted with four overtones and one combined overtone for nine cultivars (nine red lines [dark gray in print]). Log 1/*R* is based on reflectance and transmittance of waves from the molecules.

TABLE IV
Comparison of Some Beneficial Phytochemicals and Antinutritional Components (Phytic Acid) of Nine Cultivars Grown Under Organic (OPS) and Standard (SCM) Cultivation Methods[z]

Cultivars	Phenolics (mg of CE/g)		Flavonoids (mg of CEt/g)		γ-Oryzanol (mg/g)		Phytic Acid (%)	
	OPS	SCM	OPS	SCM	OPS	SCM	OPS	SCM
Annapurna	10.47a	10.40a	4.53a	3.00a	0.81	0.71de	0.58c	0.75bc
Sharbati	1.63d	1.26bc	1.36c	0.83bc	0.81	0.98ab	0.63c	0.73bcd
ARC10075	1.79cd	1.30bc	2.25b	0.82bc	0.76	0.72de	0.65bc	0.70cde
Ketakijoha	2.45b	1.32bc	1.25c	0.98b	0.97	0.90bc	0.49d	0.67e
Geetanjali	1.64d	1.24c	1.33c	0.67cd	0.81	0.76cd	0.64ab	0.68de
Heera	1.69d	1.28bc	1.95b	0.86bc	0.74	0.67e	0.72a	0.74bc
Satabdi	1.80cd	1.44b	1.16c	0.83bc	0.92	0.60e	0.22f	0.81a
Padmini	1.82cd	1.34bc	1.16c	0.51d	0.75	0.45f	0.32e	0.76ab
CRSD907	2.22bc	1.41bc	1.36c	0.87b	0.77	0.67e	0.71b	0.74bc
Mean	2.83	2.33	1.82	1.04	0.82	0.72	0.55	0.73
Tukey's HSD at 5%	0.515	0.19	0.34	0.186	NS	0.133	0.062	0.0573
P value of MC (1%)	0.0052**		0.0002**		0.0367**		0.0032**	

[z] Tukey's honestly significant difference (HSD) at 5% depicts significant or nonsignificant variability among cultivars, and *P* value of method of cultivation (MC) refers to significance between both methods of cultivation. ** signifies variability at the 5% level of significance. All the parameters were calculated on the basis of brown rice flour. CE = catechol equivalents, and CEt = catechin equivalents.

hexaphosphoric acid) form stable complexes with these cations, thus preventing their bioavailability (Liang et al. 2008). PA content in brown rice under OPS was found to be lower than under SCM (Table IV), which may indicate greater bioavailability of micronutrients in the case of organic rice. In this study, the lowest PA content was found in organic Satabdi (0.22%) and the highest in its standard counterpart (0.81%). Therefore, as far as PA accumulation in grains is concerned, Satabdi cultivar was found to be highly responsive to the method of cultivation. The site and pathway of PA biosynthesis are not well understood, but it is mainly stored with protein bodies inside the Golgi bodies. Glucose-1-phosphate is the precursor of PA, which is in turn synthesized from the pool of available glucose in the cell. This glucose pool is commonly shared by other biosynthetic pathways such as those of starch, phenolics, and so on, which also use glucose as their precursor. At nitrogen-limiting conditions when plant growth is impaired, which is often the case under organic cultivation, the metabolism shifts toward carbon-rich compounds such starch, phenolics, and so on. As a result, synthesis of total soluble sugars, glucose, and fructose is reduced, as was found in the case of organic potato (Lombardo et al. 2012). Most probably, limiting soluble sugars and glucose concentration in organic crops leads to reduced PA biosynthesis.

Total Protein Content. We have determined the protein content (%), because it is the most reliable estimation of protein in rice grain. Table III depicts that organic rice has a lower protein content than rice grown under the standard method. The highest protein content was found in standard Heera (2.3 mg) followed by ARC10075 (2.2 mg), whereas the lowest protein content was found in the cultivars Sharbati, Ketakijoha, and Satabdi produced under OPS. Differences in protein content within the same variety were found to be statistically significant when compared between the grains obtained from the organic and standard cultivation practices. Increased nitrogen fertilization leads to a higher protein content, most of which is accumulated as storage proteins such as glutelin and prolamin and less as albumin and globulin (Cagampang et al. 1966). Because readily available nitrogen to the plants is lower under OPS compared with SCM, the synthesis of free amino acids is expected to decrease, which ultimately limits protein biosynthesis in the grain.

CONCLUSIONS

This study elucidates that, over SCM using inorganic agrochemicals, organic farming has the potential to enhance the nutritive value of rice grain in terms of antioxidative capacity and essential phytochemicals such as phenolics, flavonoids, and γ-oryzanol, but with a compromise in protein content. In addition, the concentration of an antinutritional factor (PA) was found to be consistently lower in rice grain produced under OPS compared with SCM. Furthermore, average physicochemical and cooking characteristics of the produced grains appeared to be more or less similar, irrespective of the method of cultivation. We have noted some exceptions with the existing literature in a few parameters regarding physicochemical and cooking properties of grain under these two cultivation methods in some cultivars. NIR data showed a higher crude oil content and a lower total protein content in organic rice bran compared with conventional rice bran. However, ash, fiber, and moisture content of bran did not differ significantly between these two methods of cultivation practices. The yield and plant height were substantially reduced in the OPS compared with SCM, but the existing body of literature suggests that the former might be more sustainable and economical in the longer run. Therefore, organic cultivation may be a viable option to achieve sustainable agriculture.

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