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Characterizing Rice Quality Properties and Comprehensive Taste Quality: A Case Study of Three-years of Regional Varietal Trials in the Mekong Delta

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Abstract

A data set of 140 selected rice varieties from regional registration testing in the Mekong delta with four rice registration groups was studied for quality properties and correlations between each quality parameter and comprehensive taste quality in this paper. Differences in rice quality among the four registration groups and three taste categories were identified. (1) The three maturity groups of A0, A1, and A2 could be divided into fairly good and medium taste categories only whereas the aromatic group could be divided into three taste categories. (2) In the A0, A1, and A2 groups, the amylose content values of the fairly good taste category were lower than those of the medium taste category in the three groups, by 5.91%, 4.38%, and 6.38%, respectively (P <0.05). However, the gel consistency values of the fairly good taste category were higher than those of the medium one, by 25.79mm, 16.53mm, and 26.66mm, respectively. (3) In the aromatic group, the hulling percentage and milling percentage of the good taste category were lower than that of the medium one, respectively. The grain length, length/width ratio, smell, and taste of the high-taste quality category rice were higher than those of the medium taste category rice, however, the amylose content was non-significantly different among the three taste quality categories (P <0.05). (4) The smell and tenderness were found to be highly positively correlated with the comprehensive taste quality, but the amylose content was highly negatively correlated with the comprehensive taste quality in all groups (P <0.01).

Keywords

Rice, high quality, taste, aroma, cooking quality

Introduction

Rice (*Oryza sativa* L.) is the most important crop in the Mekong delta, which produces the highest yields of *indica* long-grain rice in Vietnam with large farms and high inputs (Connor *et al*., 2020;

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Nguyen *et al*., 2020). The improvement in rice yields and production has allowed for self-sufficiency and exportation, and the Mekong delta remains the "rice bowl" of the country, producing 50% of Vietnam's paddy rice (25 million tons) and 90% of its rice exports (Demont & Rustaert, 2017; Thang, 2017). The proportion of low-quality rice and medium rice exports (**Figure 1**) shows substantial reductions, decreasing from 33.05% in 2010 to 12.45% in 2015 and 3.90% in 2017 for low-quality rice, and from 21.13% in 2010 to 18.36% in 2015 and 8.32% in 2017 for medium rice, whereas the export proportion of aromatic rice has had notable growth, increasing from 3.67% in 2010 to 22.5% in 2015 to 29.2% in 2017 and to 32% in 2019 (Doan *et al*., 2021). This data imply an increasing trend in rice exports that has shifted towards larger shares of aromatic rice and high-grade rice in recent years.

Annually, a large number of promising rice varieties are developed by research institutions, private companies, and individual breeders, are evaluated in different locations, and approved the state authorities (Khanh *et al*., 2021). Promising lines are then sent to regional testing sites before being released (Ngo *et al*., 2019). National regulations on the recognition and release of new main crop varieties are promulgated and specified in Decision No 95/2007/QD-BNN issued by the Ministry of Agriculture and Rural Development in 2007. For rice, the National Technical Regulations for Testing the Value of Cultivation and Use of new varieties is mentioned in QCVN 01-55: 2011/BNNPTNT (Ngo *et al*., 2019). In this technical regulations document, along with agronomic and pest tolerance tests, quality assessment is a must and all the testing data of VCU trials must be officially published by the Crop Production Department. This indicates that VCU data are publicly available references for rice breeding programs and allow the prediction of rice market acceptance.

There have been numerous studies evaluating the variability of various quality parameters and relationships among quality properties in rice (Matthews & Spadaro, 1976; Calingacion *et al*., 2014; Wang *et al*., 2021), however, studies focusing on the relationship between quality parameters and comprehensive taste quality have not been seen. In addition, most of these studies were published in Vietnamese journals, which are less accessible to foreign researchers. Thus, our objectives were to use published data relating to milling quality, appearance quality, physiochemical quality, and eating-cooking quality analyses of 140 promising varieties selected from four groups (A0, A1, A2, and aromatic), which passed two or more testing seasons in regional registration trials over a three year period (from 2018 to 2020) in the Mekong delta, to determine: (a) the variability of quality properties of different quality categories in different registration groups; (b) the key quality indicators that determine the quality characteristics in each taste category; and (c) if there are correlations between the quality attributes and the comprehensive taste quality.

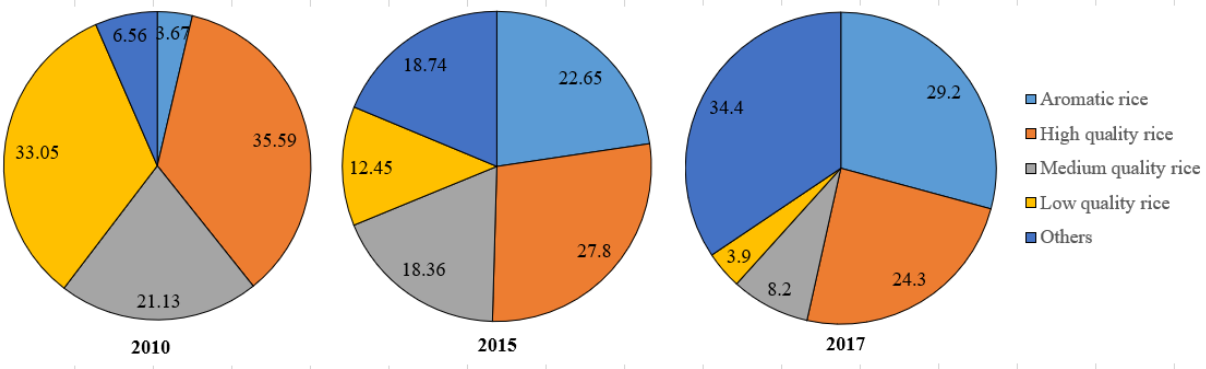

Figure 1. The structure of Vietnam's rice exports during the period of 2010-2017

Materials and Methods

Data collection and quality trait descriptions

The data relating to the quality characteristics of 140 registered varieties that passed at least two testing seasons from regional registration trials in the Mekong delta from 2018 to 2020 were collated from published reports (Supplementary data sheet 1). According to the National Technical Regulations on Testing the Value of Cultivation and Use (VCU) of rice varieties (QCVN 01-55:2011/BNNPTNT), the rice varieties in the regional registration trials were divided into four groups, namely A0 (13 varieties; growth duration after transplanting was < 90 days); A1 (78 varieties; 90-105 days); A2 (24 varieties; 106-120 days), and aromatic (25 varieties). The varieties were submitted by diverse ownership including public institutions, private companies, and individual breeders, and registration was continuously executed from 2018 to 2020 if the owners believed the varieties were promising and could be registered for commercial release. The collated data included milling quality, appearance quality, physiochemical quality, and sensory quality.

After harvesting, 1.0kg of each variety of rice was sampled in one testing location to measure milling quality (hulling quality, milling percentage, head rice recovery, and broken rice) and appearance quality (grain length, grain width, grain shape, chalkiness, and translucency) according to procedures from the International Rice Research Institute (IRRI, 1996).

The amylose content was measured by the procedure described by TCVN5716: 2008, gel consistency was estimated according to TCVN8369: 2010, and alkali digestion was determined following the protocol of TCVN 5715: 1993. For alkali digestion, a seven-point scale was used to assign different values based on kernel spreading (IRRI, 1996).

Sensory quality was determined by the protocol in TCVN 8373-2010. The sensory evaluation team was comprised of eight well-trained panelists of different sexes and ages who identified the different tastes of cooked rice of the registered products. The criteria of the sensory evaluation (5-score scale) were as listed in **Table 1**.

In this study, data were selected from testing result databases for regional registration trials (VCU) of inbred rice genotypes in the Mekong delta which were published by the Agricultural Publishing House in 2018 (pp: 130-199), 2019 (pp: 93-165), and 2020 (pp: 76-155).

Data analysis

One-way analysis of variance (ANOVA) was used before performing the least significant difference (LSD) test at the 0.05 probability level the mean value comparison of each trait between the registration groups and taste categories. The relationships between the quality parameters and

Table 1. Categorization of rice taste based on TCVN 8373-2010 in rice varietal registration

Score	Smell (score of 1-5)	Whiteness (score of 1-5)	Tenderness (score of 1-5)	Palatability (score of 1-5)	Comprehensive taste (total score)
5	Typical, high aroma	Very white	Very tender	Very delicious	Good (18.6-20.0)
4	Aroma	Milky-white	Tender	Fairly delicious	Fairly good (15.2-18.5)
3	Light aroma	Light grey	Soft	Tasty	Medium (11.2-15.1)
2	Very light aroma, not typical	Bright brown	Hard	Acceptable	Poor (7.2-11.1)
1	No smell	Brown	Very hard	Unacceptable	Very poor (<7.2)

comprehensive taste quality were evaluated by the coefficient of correlation analysis and were performed by using the "*psych*" package and "*Agricolae*" package in RStudio version 4.0.5.

Results and Discussion

Quality distribution of rice-registered varieties

According to the TCVN 8373-2010 technical regulations, the comprehensive quality values of the registered varieties of the A0, A1, A2, and aromatic groups were divided into three categories: good (score of 18.6-20.0), fairly good (score of 15.2-18.5), and medium (score of 11.2-15.1). Only the aromatic group had varieties that had comprehensive quality scores in all three categories: good (12.0%), fairly good (80.0%), and medium (8%). For the other groups, the comprehensive quality scores were only in the two categories of fairly good and medium with percentages being 15.4% and 84.6% in the A0 group, 35.9% nd 64.1% in the A1 group, and 29.2% and 80.8% in the A2 group, respectively (**Figure 2**).

Variation of milling quality

Grain milling quality consisted of the hulling percentage, milling percentage, head rice recovery, and broken rice (**Table 2**). The hulling percentages of all the registered varieties among the A0, A1, and A2 groups ranged from 78.3% to 79.26%. In the aromatic group, the hulling percentages of the good taste and fairly good categories were significantly lower than in the medium category. The milling percentages of the

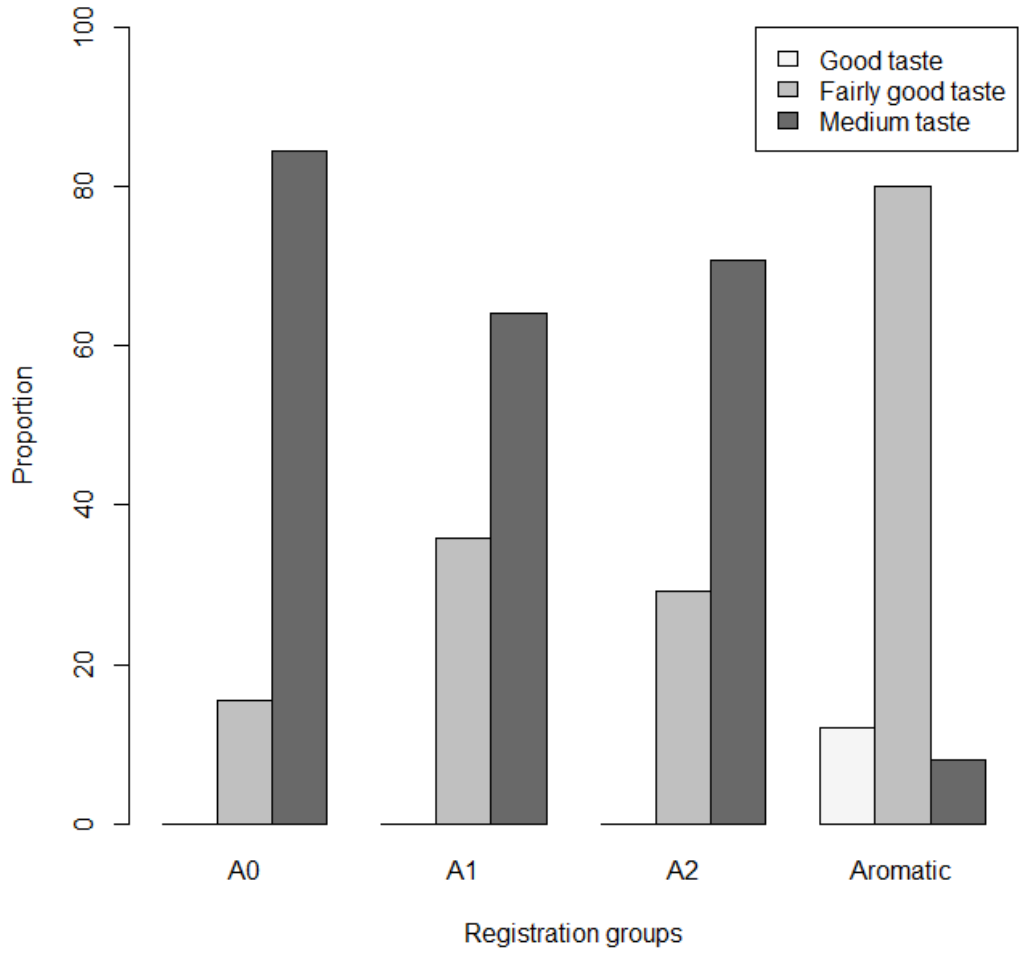

Figure 2. The proportion distribution of the different taste categories in the regional registration groups in 2018-2020

Table 2. Variation in milling quality of the different taste categories among the registration groups

Group	Taste category		Hulling percentage (%)	Milling percentage (%)	Head rice recovery (%)	Broken rice (%)
A0	Fairly good	Mean±SE	78.64^{ab}±0.44	68.62^{ab}±0.59	59.43^{a}±4.67	7.98^{abc}±2.33
		Range	(78.33-78.95)	(68.20-69.03)	(56.13-62.73)	(6.33-9.63)
		CV	0.56%	0.86%	7.86%	29.20%
	Medium	Mean±SE	79.20^{a}±0.89	68.14^{ab}±1.21	57.23^{a}±4.78	10.91^{ac}±4.50
		Range	(77.87-80.35)	(66.43-71.07)	(46.53-62.05)	(5.75-20.27)
		CV%	1.12%	1.78%	8.35%	41.25%
A1	Fairly good	Mean±SE	78.73^{a}±1.21	67.86^{ab}±1.48	55.61^{ab}±6.08	12.27^{abc}±5.55
		Range	(76.45-81.20)	(64.5-70.10)	(46.20-64.40)	(4.73-22.15)
		CV	1.60%	2.18%	10.93%	45.23%
	Medium	Mean±SE	79.06^{a}±1.04	67.47^{ab}±1.13	55.83^{ab}±4.51	11.63^{ac}±3.89
		Range	(76.90-81.03)	(64.95-69.40)	(46.20-64.60)	(5.52-7.71)
		CV%	1.32%	1.67%	8.08%	33.45%
A2	Fairly good	Mean±SE	78.30^{ab}±0.88	67.40^{ab}±1.63	52.34^{ab}±4.00	15.08^{a}±4.00
		Range	(76.75-79.15)	(65.65-69.80)	(48.07-58.20)	(7.65-19.05)
		CV	1.13%	2.42%	7.64%	26.53%
	Medium	Mean±SE	79.26^{a}±1.01	67.45^{ab}±1.26	54.99^{ab}±5.94	12.59^{abc}±5.32
		Range	(76.00-80.30)	(65.83-70.00)	(38.75-62.15)	(6.03-27.15)
		CV%	1.27%	1.87%	10.80%	42.26%
Aromatic	Good	Mean±SE	76.69^{b}±0.95	66.77^{b}±1.63	51.18^{ab}±3.73	15.59^{a}±3.24
		Range	(75.60-77.25)	(65.00-68.20)	(47.90-55.23)	(11.87-17.80)
		CV	1.24%	1.24%	7.29%	20.78%
	Fairly good	Mean±SE	77.41^{b}±1.48	66.72^{b}±1.48	52.47^{ab}±4.66	14.28^{ab}±3.53
		Range	(75.30-81.27)	(64.30-69.43)	(45.40-60.27)	(8.40-20.43)
		CV	1.91%	2.22%	8.88%	24.72%
	Medium	Mean±SE	79.34^{a}±1.36	69.24^{a}±0.90	56.35^{ab}±7.04	12.88^{abc}±6.15
		Range	(78.37-80.30)	(68.60-69.87)	(51.37-61.33)	(8.53-17.23)
		CV	1.71%	1.30%	12.49%	47.75%

Note: Letter superscripts represent significant differences at the 95% level (P <0.05).

good and fairly good taste categories in the aromatic group were the lowest (66.77% and 66.72%, respectively), but the differences among all of the registration groups and taste categories were non-significant. Similarly, the head rice recovery of all the registered groups was not different (ranged from 51.18% to 59.43%). Although the broken rice percentages in all the registration groups and taste categories were non-significantly different, the variation of the broken rice percentage within the medium taste category (41.25-47.75%) was higher than the fairly good or good taste categories (20.78-29.2%), excepting the A1 group.

Variation of grain appearance quality

The mean value of the grain length in the good taste category of the aromatic group was the highest (7.81cm) and significantly higher than that of the medium taste category, whereas no significant differences were found in this trait in the medium and fairly good taste categories in the other groups (P <0.05). Grain widths in all the medium and fairly good taste categories were

not remarkable excepting in the good taste category of the aromatic group which showed the lowest value (1.84mm) (P <0.05). Grain shape has been reported as being the first impression of the grain quality, and thus influences the choice of rice consumers (Calingacion *et al*., 2015). Although, this parameter did not vary between the fairly good and medium taste categories of the A0 and A2 groups, this trait was remarkably different in the three taste categories of the A1 and aromatic groups. The chalkiness trait in the medium and fairly good taste categories of the A0 and aromatic groups were not significantly different while the coefficient of variation of the mean value showed a great difference (13.86%-95.76%) between the taste categories in the registration groups (**Table 3**).

The translucency of the grain is known to be highly appreciated by consumers (Mestres *et al*., 2019) and it is suggestive of purity and finesse that renders higher acceptance among consumers. This trait was significantly different between the fairly good and medium taste categories but not distinguishable among the taste quality categories in the A2 and aromatic groups (P <0.05).

Variation of physiochemical quality

Many studies have stated that the amylose content of rice starch directly affects the cooking and taste of the rice (Juliano & Gonzales, 1989; Chung *et al*., 2011) because it is positively correlated with hardness and negatively correlated with stickiness (Suwannaporn, 2007). In **Table 4**, the average amylose content of the fairly good taste category varied from 16.52% to 18.45%, which was significantly lower than that of the medium taste category (22.43% to 24.21%) in the A0, A1, and A2 groups. In the aromatic group, the amylose content ranged from 17.21% to 18.63% and was not significantly different in the three taste categories (P <0.05). In conversion, the mean value of the gel consistency in the fairly good taste category (74.25-80.70mm) was higher than that of the medium taste category (52.82-57.72mm) in the A0, A1, and A2 groups while the differences in this trait were non-significant in the aromatic group. Considering alkali digestion, the mean values of this trait in the aromatic group were significantly higher than those of the other groups and were the same among the different taste categories in each of the registration groups.

Variation of cooking and eating quality

The cooking and eating quality is considered one of the most important factors for customers, and the sensory test has been shown to be a useful tool to provide a score for the overall cooking and eating quality (Hori *et al*., 2016). As the properties of cooked rice in this study were measured by well-trained panelists, the results in **Table 5** showed that the smell scores of the good and fairly good taste categories were significantly higher than the medium taste category (in the same group), and the best smell was found in the good taste category of the aromatic group (4.23 score). Similarly, the tenderness of the fairly good (or good) taste category was significantly higher than that of the medium category in all groups (P <0.05), and the highest values of this trait were determined in the good and fairly good taste categories in the aromatic group (scores of 4.71 and 4.33, respectively). The whiteness of cooked rice in the same and across groups was slightly different between the taste categories but these differences were non-significant except for the fairly good category in the aromatic group (score of 4.71). The fairly good taste category had palatability scores ranging from 3.79 to 4.25, which were significantly higher than those of the medium taste category (scores of 3.00-3.60) in each registration group (P <0.05). The good taste category in the aromatic group showed the best palatability with a score of 4.88, while the maximum score for this trait was 5.0.

Correlation analysis

With regards to the coefficient of correlation analysis between the milling, appearance, physiochemical, and cooking quality with the comprehensive quality, the results are shown in **Table 6**. In the A0 group, the gel consistency, smell, tenderness, and palatability were highly positively correlated with the comprehensive taste quality (P <0.01), but the chalkiness, translucency, and amylose content revealed

Table 3. Variation in appearance quality of the different taste categories among the registration groups

Group	Taste category		Grain length (mm)	Grain width (mm)	Length/width ratio	Chalkiness (%)	Translucency (%)
A0	Fairly good	Mean±SE	6.88^{bc}±0.19	2.24^{a}±0.07	3.08^{cd}±0.18	3.03^{b}±0.42	48.08^{cd}±2.71
		Range	(6.75-7.02)	(2.19-2.29)	(2.95-3.21)	(2.73-3.33)	(46.17-50.00)
		CV	2.76%	3.13	5.84%	13.86%	5.64%
	Medium	Mean±SE	6.74^{c}±0.61	2.25^{a}±0.16	3.02^{cd}±0.46	5.82^{ab}±3.48	51.25^{ab}±3.74
		Range	(5.75-7.81)	(2.02-2.58)	(2.30-3.89)	(1.87-11.30)	(45.75-59.37)
		CV	9.05%	7.11%	15.23%	59.79%	7.30%
A1	Fairly good	Mean±SE	6.76^{c}±0.37	2.14^{a}±0.17	3.18^{c}±0.32	5.19^{b}±4.97	48.26^{cd}±3.41
		Range	(5.69-7.29)	(1.78-2.57)	(2.26-3.71)	(0.80-26.10)	(40.93-56.00)
		CV	5.47%	7.94%	10.06%	95.76%	7.07%
	Medium	Mean±SE	6.70^{c}±0.49	2.26^{a}±0.17	3.00^{d}±0.38	8.40^{a}±4.28	52.43^{a}±3.95
		Range	(5.52-7.71)	(2.07-2.73)	(2.06-3.67)	(0.70-17.65)	(44.30-59.73)
		CV	7.31%	7.52%	12.67%	50.95%	7.53%
A2	Fairly good	Mean±SE	6.82^{bc}±0.28	2.18^{a}±0.05	3.13^{cd}±0.11	3.79^{b}±1.84	47.51^{cd}±5.84
		Range	(6.19-6.97)	(2.12-2.24)	(2.92-3.27)	(2.35-7.00)	(40.00-56.70)
		CV	4.11%	2.29%	3.51%	48.55%	12.29%
	Medium	Mean±SE	6.94^{bc}±0.50	2.21^{a}±0.12	3.15^{cd}±0.27	7.68^{a}±4.58	49.50^{bc}±4.37
		Range	(5.68-7.42)	(1.92-2.52)	(2.26-3.44)	(1.65-18.25)	(42.30-59.75)
		CV	7.20%	5.43%	8.57%	59.64%	8.83%
Aromatic	Good	Mean±SE	7.81^{a}±0.11	1.84^{b}±0.03	4.26^{a}±0.10	1.39^{b}±0.86	43.59^{d}±3.79
		Range	(7.69-7.91)	(1.81-1.87)	(4.19-4.37)	(0.45-2.13)	(39.30-46.45)
		CV	1.41%	1.63%	2.35%	61.87%	8.69%
	Fairly good	Mean±SE	7.23^{ab}±0.64	2.09^{a}±0.25	3.54^{b}±0.64	2.71^{b}±2.31	47.81^{cd}±3.55
		Range	(6.04-8.01)	(1.70-2.89)	(2.10-4.56)	(0.30-8.87)	(38.90-52.70)
		CV	8.85%	11.96%	18.08%	85.24%	7.43%
	Medium	Mean±SE	6.77^{bc}±0.33	2.30^{a}±0.14	2.96^{d}±0.33	7.13^{ab}±3.11	46.26^{cd}±3.06
		Range	(6.54-7.00)	(2.20-2.40)	(2.72-3.19)	(4.93-9.33)	(44.10-48.43)
		CV	4.87%	6.09%	11.15%	43.62%	6.61%

Note: Letter superscripts represent significant differences at the 95% level (P <0.05).

negative correlations. In the A1 group, the grain length-width ratio, gel consistency, smell, spring whiteness, and palatability also exhibited positive correlations but the hulling percentage, grain width, chalkiness, translucency, and amylose content manifested negative

Table 4. Variation in physicochemical quality of the different taste categories among the registration groups

Group	Taste category		Amylose content (%)	Gel consistency (mm)	Alkali digestion (score)
A0	Fairly good	Mean±SE	16.52^{a}±0.35	78.61^{a}±2.72	2.61^{c}±0.20
		Range	(16.28-16.77)	(76.68-80.53)	(2.47-2.75)
		CV	2.12%	3.46%	7.66%
	Medium	Mean±SE	22.43^{ab}±4.66	52.82^{c}±17.50	3.95^{bc}±1.34
		Range	(15.85-28.13)	(32.07-86.50)	(2.97-7.00)
		CV	20.78%	33.13%	33.92%
A1	Fairly good	Mean±SE	18.45^{c}±2.34	74.25^{a}±9.55	4.15^{bc}±1.77
		Range	(15.43-24.70)	(46.85-85.67)	(2.07-6.77)
		CV	12.68%	12.86%	42.65%
	Medium	Mean±SE	22.83^{a}±3.06	57.72^{bc}±12.37	3.78^{c}±1.29
		Range	(16.45-28.35)	(30.50-84.50)	(2.00-7.00)
		CV	13.40%	21.43%	34.13%
A2	Fairly good	Mean±SE	17.83^{c}±1.20	80.70^{a}±4.40	3.28^{c}±1.48
		Range	(16.25-19.05)	(73.67-86.25)	(2.20-6.50)
		CV	6.73%	5.45%	45.12%
	Medium	Mean±SE	24.21^{a}±2.47	54.04^{c}±11.29	3.42^{c}±1.14
		Range	(18.75-27.85)	(36.85-83.00)	(2.40-6.40)
		CV	10.20%	20.89%	33.33%
Aromatic	Good	Mean±SE	17.21^{c}±1.23	75.94^{a}±2.55	6.14^{a}±2.0
		Range	(16.45-18.63)	(73.00-77.50)	(6.00-6.37)
		CV	7.15%	3.36%	3.26%
	Fairly good	Mean±SE	17.81^{c}±1.65	74.68^{a}±5.42	4.84^{ab}±1.68
		Range	(16.05-23.65)	(66.67-84.40)	(1.50-6.73)
		CV	9.26%	7.26%	34.71%
	Medium	Mean±SE	18.63^{bc}±0.71	71.02^{ab}±2.85	5.98^{ab}±0.49
		Range	(18.13-19.13)	(69.00-73.03)	(5.63-6.33)
		CV	3.81%	4.01%	8.19%

Note: Letter superscripts represent significant differences at the 95% level (P <0.05).

correlations. Excepting gel consistency and translucency, the other studied traits in the aromatic group were found to either positively or negatively correlate with comprehensive taste quality (**Table 6**) from a normal correlation level (P <0.05) to a high correlation level (P <0.01). Overall, the smell, tenderness, and palatability values showed consistent trends toward being

Table 5. Differences in cooking and eating quality of the different taste categories among the registration groups

Group	Taste category		Smell (score)	Tenderness (score)	Whiteness (score)	Palatability (score)
A0	Fairly good	Mean±SE	2.62^{de}±0.02	4.29^{ab}±0.16	4.76^{b}±0.01	3.79^{cd}±0.12
		Range	(2.60-2.63)	(4.18-4.40)	(4.75-4.77)	(3.70-3.87)
		CV	0.76%	3.73%	0.21%	3.17%
	Medium	Mean±SE	2.18^{f}±0.21	3.24^{d}±0.66	4.76^{b}±0.24	3.00^{f}±0.46
		Range	(2.00-2.60)	(2.33-4.10)	(4.35-5.00)	(2.33-3.53)
		CV	9.63%	20.37%	5.04%	15.33%
A1	Fairly good	Mean±SE	2.90^{cd}±0.30	4.23^{ab}±0.31	4.86^{ab}±0.19	4.01^{c}±0.23
		Range	(2.30-3.60)	(3.45-4.77)	(4.17-5.00)	(3.63-4.47)
		CV	10.34%	7.33%	3.91%	5.74%
	Medium	Mean±SE	2.32^{ef}±0.25	3.35^{d}±0.45	4.76^{b}±0.23	3.17^{ef}±0.38
		Range	(1.93-3.00)	(2.30-4.25)	(4.20-5.00)	(2.37-4.10)
		CV	10.78%	13.43%	4.83%	11.99%
A2	Fairly good	Mean±SE	3.08^{c}±0.19	4.27^{ab}±0.15	4.72^{b}±0.28	4.04^{bc}±0.27
		Range	(2.80-3.40)	(4.05-4.50)	(4.20-5.00)	(3.55-4.30)
		CV	7.94%	10.14%	4.35%	9.97%
	Medium	Mean±SE	2.52^{e}±0.20	3.45^{cd}±0.35	4.83^{ab}±0.21	3.41^{de}±0.34
		Range	(2.15-2.87)	(2.70-4.20)	(4.20-5.00)	(2.75-4.03)
		CV	5.44%	2.12%	4.72%	0.61%
Aromatic	Good	Mean±SE	4.23^{a}±0.23^{a}	4.71^{a}±0.10	4.87^{ab}±0.23	4.88^{a}±0.03
		Range	(4.10-4.5)	(4.60-4.80)	(4.60-5.00)	(4.85-4.90)
		CV	5.44%	2.12%	4.72%	0.61%
	Fairly good	Mean±SE	3.34^{b}±0.40^{b}	4.33^{ab}±0.27	4.93^{a}±0.11	4.25^{b}±0.28
		Range	(2.60-4.15)	(3.70-4.75)	(4.60-5.00)	(3.80-4.65)
		CV	11.98%	6.24%	2.23%	6.59%
	Medium	Mean±SE	2.51^{ef}±0.02	3.92^{bc}±0.21	4.50^{b}±0.18	3.60^{cde}±0.04
		Range	(2.50-2.53)	(3.77-4.07)	(4.47-4.63)	(3.57-3.63)
		CV	0.80%	5.36%	4.00%	1.11%

Note: Letter superscripts represent significant differences at the 95% level (P <0.05).

Table 6. Correlation analysis between rice quality properties and comprehensive taste quality

Quality property	A0 group	A1 group	A2 group	Aromatic group
Hulling percentage (%)	-0.319	-0.223*	-0.317	-0.644**
Milling percentage (%)	0.105	0.960	0.092	-0.640**
Head rice recovery (%)	0.055	0.005	-0.049	-0.585**
Broken rice (%)	-0.097	0.023	0.084	0.487*
Grain length (mm)	0.513	0.112	0.149	0.651**
Grain width (mm)	-0.252	-0.325**	-0.086	-0.705**
Length/width ratio	0.397	0.263*	0.147	0.775**
Chalkiness (score)	-0.609*	-0.432**	-0.663**	-0.528**
Translucency (%)	-0.590*	-0.560**	-0.195	-0.255
Amylose content (%)	-0.890**	-0.802**	-0.846**	-0.433*
Gel consistency (mm)	0.909**	0.809**	0.674**	0.224
Alkali digestion (score)	-0.254	0.106	0.111	0.420*
Smell (score)	0.770**	0.858**	0.856**	0.929**
Tenderness (score)	0.969**	0.922**	0.856**	0.918**
Whiteness (score)	-0.523	0.233*	0.069	0.434*
Palatability (score)	0.975**	0.959**	0.885**	0.964**

*Note: * and ** represent significant correlations at the 0.05 and 0.01 levels, respectively*.

highly positively correlated with comprehensive taste quality in all the registration groups (P <0.01).

Discussion

Taste quality categories grouped by maturity: A0, A1, and A2

Rice millers prefer varieties with high milling and head rice recovery (Merca & Juliano, 1981) so these qualities are also attractive to growers because they sell the paddy to millers. Many previous research studies have reported that the milling properties of rice, such as head rice recovery, are cultivar-dependent (Siebenmorgen *et al*., 2006). The milling quality of the A0, A1, and A2 groups in this study showed non-distinguishable differences among the three categories, though somehow, the head rice recovery parameter in the A0 group was slightly higher than those of the other groups. Since three groups were determined to have different growth durations, the similarity of the milling quality in this study indicated that milling rice quality in this study did not relate to growth duration. The hulling percentage, milling yield, and head rice recovery quality in these three groups were within the same ranges as previously published research (Juliano & Gonzales, 1989; Graham, 2002; Siebenmorgen *et al*., 2006). The results of this study also showed that there was no relationship between the milling properties and comprehensive taste quality except for the hulling percentage in the A1 group.

The grain shape gives the first impression of the grain quality and thus, influences the choice of rice consumers (Calingacion *et al*., 2015). In this investigation, the grain lengths in both the fairly good and medium taste quality categories of the A0, A1, and A2 groups were classified as long grain types (>6.6mm), and the grain shape traits were classified as long slender (length/width ratio >3.0). Among the three registration groups, the length/width ratio of the fairly good taste category in the A1 group was higher than that of the medium one, and this trait was significantly correlated with the comprehensive taste quality. The chalkiness values of the fairly good taste category in the A1 and A2 groups were significantly lower than that of medium one, and this trait was found to be highly negatively correlated with the comprehensive taste quality, indicating that chalkiness played an important role in determining the two taste quality categories. Chalkiness in these groups varied widely (13.86% to 95.76%), while it has been reported that many other environmental and post-harvest factors impact this trait (Calingacion *et al*., 2014; Deng *et al*., 2021), which may explain the results of this study.

Primarily, amylose content is considered a key determinant of eating quality in rice (Juliano & Gonzales, 1989; Calingacion *et al*., 2014) because it has been linked to gel consistency, hardness, and stickiness. It is generally believed that rice with a better eating quality has a lower amylose content (Xie *et al*., 2013). Pang *et al*. (2016) also opined that amylose content is negatively correlated with gel consistency, and amylose content is a key indicator of high-quality rice. The mean value of the amylose content in the fairly good taste quality category of the three groups in this study was definitely lower than that of the medium one, but the gel consistency of the fairly good taste quality, on the contrary, was higher than that of the medium taste quality varieties. The results are in agreement with previous studies on the impacts of physiochemical traits on comprehensive taste quality, and as shown in **Table 6**, the smell, tenderness, and palatability of the fairly good taste quality category in these groups were better than that of the medium taste quality category. Because of the intermediate amylose content (>20%) and gel consistency (41-60mm), almost all of the rice varieties in the medium taste category might have a typical smell, hard tenderness, and acceptable palatability when cooked (Graham, 2002). According to Pham *et al*. (2016), every research strategy in rice breeding in the Mekong delta involves creating rice varieties with desired traits including having long grains, a low amylose content (< 20%), less chalkiness, a good aroma, and a short growth duration (90-100 days), but a particular type of high amylose rice is preferred by the food processing industry (Bergman, 2019). This can explain why rice breeders are being encouraged to develop high-yielding, climate-ready varieties with the various quality characteristics required by consumers in their local markets.

If breeders pursued breeding high-yield varieties containing high amylose contents for the Mekong region, these varieties would be preferable to consumers who are accustomed to eating grain with a high amylose content (Kasem *et al*., 2014). It is evident that varieties with a high amylose content are digested slowly like resistant starch and thus have health benefits (Wang *et al*., 2015). Even Sangpring *et al*. (2015) reported that rice noodles made from high amylose rice (>25%) showed good quality. However, some studies have reported that grain hardness, amylose content, and non-chalkiness in the rice kernels were associated with different resistance levels to stored rice insects (Astuti *et al*., 2013).

Aromatic rice

Aromatic rice is highly regarded as one of the premium rice varieties (Roy *et al*., 2020), and as such, gains a higher price in the market compared to ordinary white rice (Bairagi *et al*., 2020). With this quality parameter, consumer demand for aromatic rice has been generally increasing (Kim *et al*., 2000; Mestres *et al*., 2019) and is expected to expand more in the future (Prodhan & Shu, 2020). From quality data of the 25 aromatic varieties used in this investigation, three taste quality scales were categorized and certain variations within some of

the key physical quality traits were identified among the categories such as grain length, grain width, and the length/width ratio. The good and fairly good taste categories were identified with lower values of hulling and milling yield but higher values of grain length and length/width ratio compared with the medium taste quality category. Some scholars have stated that in a certain range, an increased length/width ratio reduces milling quality, but determines appearance quality improvement, hence, good quality is usually identified by a long slender grain shape (Li, 2001; Yang *et al*., 2021). High positive correlations of both grain length and grain shape with comprehensive taste quality in our study (0.651 and 0.775, respectively) (P <0.001) were aligned with a previous report (Zhou *et al*., 2012). Long-grain *indica* rice can enhance cooking-eating quality because its slender grain shape can eliminate the chalkiness degree, and high-quality *indica* rice usually has lower chalkiness than low-quality rice. Otherwise, low chalkiness rice can increase eating-cooking quality (Singh *et al*., 2003; Liu *et al*., 2009). The results also indicated that these traits can be used for screening high-quality lines or varieties based on their relationship with comprehensive taste quality.

Physiochemical qualities such as amylose content, gel consistency, and alkali digestion of the three taste categories in the aromatic group were non-significantly different. Since physiochemical quality traits *viz.* head rice recovery, chalkiness, and translucency had non-significant differences among the taste categories, it is difficult to use these traits for selecting high-quality lines or varieties, and this phenomenon has been seen in many reports (Park *et al*., 2019; Lu *et al*., 2021). Our study also determined that in the aromatic group, all the taste categories had low amylose content (17.21-18.63%), soft gel consistency (71.02-75.94mm), and intermediate alkali digestion, which are preferred by most consumers (Pang *et al*., 2016) and were not remarkably different.

Aroma is one of the unique and key indicators that determines the cooking and eating traits of rice grain (Sakthivel *et al*., 2009). The results from **Table 6** show that aroma was significantly different (P <0.05) in the three taste quality categories and highly positively correlated with the comprehensive taste quality in the aromatic group. Therefore, based on recent basal information about physiochemical and cooking and eating qualities, optimizing the scent or palatability indices could effectively enhance the accuracy of quality assessments of aromatic varieties.

To date, many studies have been conducted to determine the impacts of postharvest processes on rice grain quality (Cuevas *et al*., 2016). Postharvest operations, such as drying, storage, and milling, have been used to ameliorate the aging of rice grains and to achieve and maintain desirable rice grain quality, and thus, play a key role in determining the commercial quality and value of rice. Drying is a postharvest procedure that influences the rice milling output, such as head rice recovery and chalkiness, and overall quality by decreasing the moisture content of paddy grains to an acceptable level (Tong *et al*., 2019).

Breeding programs start visually selecting for grain size and shape from early generations and continue until the line develops into a variety based on these characteristics in early generations, but measurements that are more exact are made in the advanced generations. The results from this study can be valuable references for researchers and breeders to set priorities for developing better lines or varieties. Promising lines for the aromatic group should be further screened in the laboratory for traits such as long or extra-long grain and slender shape, low chalkiness, and low amylose content to enhance selection efficiency for specialty markets that have emerged in the Mekong region in recent years.

Conclusions

Rice varieties in regional registration testing, which were grouped based on maturity (A0, A1, and A2) and aromatic classifications, showed remarkable variation in terms of quality characteristics. Based on their comprehensive taste quality, the registered varieties were classified into three categories, good, fairly good,

and medium scales, to analyze 16 quality parameters. Milling, appearance, physiochemical, and sensory qualities also showed certain variations in the different taste categories. However, in the A0, A1, and A2 groups, these traits were found to be similar within the same taste category but differed significantly among different taste categories, especially in amylose content and gel consistency indices. This implied that among the three taste categories, differences in the mentioned taste quality traits in our study were related to amylose content and gel consistency, not maturity duration. The fairly good taste category can be differentiated from the medium one by a lower amylose content, longer gel consistency, and stronger smell, whereas the medium taste category showed a harder texture and less smell in cooked rice. In the aromatic group, three taste categories were also determined: varieties in the good taste category tended to have very long grains, a strong aroma, be very tender, and have a delicious taste; varieties in the fairly good taste category tended to be dominant for light aroma and tasty, while varieties in the medium taste category were determined by higher hulling and milling rates, long grains, medium grain shape, very light aroma, hardness, and an acceptable taste. However, the interaction among the quality parameters with rice genotypes in the region should be further investigated.

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References

Astuti L. P., Mudjiono G., Rasminah C. S. & Rahardjo B. T. (2013). Susceptibility of milled rice varieties to the lesser grain borer (*Rhyzopertha dominica*, F). Journal of Agricultural Sciences 5: 145-149.

Bairagi S., Demont M., Custodio M. C. & Ynion J. (2020). What drives consumer demand for rice fragrance? Evidence from South and Southeast Asia. British Food Journal. 122: 3473-3498. DOI: 10.1108/BFJ-01-2019-0025.

Bergman C. J. (2019). Rice end-use quality analysis. In Rice chemistry and Technology; Bao, J., Ed.; Elsevier, Inc.: Cambridge, MA, USA: 273-338.

Calingacion M., Laborte A., Nelson A., Resurreccion A., Concepcion J. C., Daygon V. D., Mumm R., Reinke R., Dipti S., Bassinello P. Z., Manful J., Sophany S., Lara K. C., Bao J. S., Xie L. H., Loaiza K., El-hissewy A., Gayin J., Sharma N., Rajeswari S., Manonmani S., Rani N. S., Kota S., Indrasari3 S. D., Habibi F., Hosseini M., Tavasoli F., Suzuki K., Umemoto T., Boualaphanh C. Lee H. H., Hung Y. P., Ramli A., Aung P. P., Ahmad R., Wattoo J. I., Bandonill E., Romero M., Brites C. M., Hafeel R., Lur H. S., Cheaupun K., Jongdee S., Blanco P., Bryant R., Nguyen T. L., Hal R. D. & Fitzgerald M. (2014). Diversity of global rice markets and the science required for consumer-targeted rice breeding. PloS One. 9(1): e85106. DOI: 10.1371/journal.pone.0085106 PMID: 24454799.

Calingacion M., Fang L., Quiatchon-Baeza L., Mumm R., Riedel A., Hall R. D. & Fitzgerald M. A. (2015). Delving deeper into technological innovations to understand differences in rice quality. Rice. 8(6): 1-10. DOI: 10.1186/s12284-015-0043-8.

Chung H. J., Liu Q., Lee L. & Wei D. Z. (2011). Relationship between the structure, physicochemical properties and in vitro digestibility of rice starches with different amylose contents. Food Hydrocolloids. 25: 968-975. DOI: 10.1016/j.foodhyd.2010.09.011.

Connor M., Tuan L. A., DeGuia A. H. & Wehmeyer H. (2020). Sustainable rice production in the Mekong River Delta: Factors influencing farmers' adoption of the integrated technology package "One Must Do, Five Reductions" (1M5R). Outlook on Agriculture, 003072702096016. DOI:10.1177/0030727020960165.

Cuevas R. P., Pede V. O., McKinley J., Velarde O. & Demont M. (2016). Rice grain quality and consumer preferences: A case study of two rural towns in the Philippines. PLoS One. 11: e0150345.

Decision No. 95/2007/QD-BNN (2007). Decision promulgating the Regulation on recognition of new agricultural plant varieties. Retrieved from https://www.informea.org/en/legislation/decision-no-952007qd-bnn-promulgating-regulation-recognition-new-agricultural-plant on February 2, 2020.

Demont M. & Rustaert P. (2017). Restructuring the Vietnamese rice sector: towards increasing sustainability. Sustainability 9: 325. DOI: 10.3390/su9020325.

Deng F., Li Q. P., Chen H., Zeng Y. L., Li B., Zhong X. Y., Wang L. & Ren W. J. (2021). Relationship between chalkiness and the structural and thermal properties of rice starch after shading during grain-filling stage. Carbohydrate Polymers. 252: 117212. DOI: 10.1016/j.carbpol.2020.117212.

Doan T. T. H., Pham Q. D. & Dao T. A. (2021). Market structure of rice export in Vietnam from 2010 to 2020. Taipei: FFTC Agricultural Policy Platform. Retrieved from https://ap.fftc.org.tw/article/2985 on March 23, 2022.

Graham R. (2002). A proposal for IRRI to establish a grain quality and nutrition research center. IRRI discussion paper series No. 44 (pp. 15). Los Baños: International Rice Research Institute. Retrieved from http://books.irri.org/DPS44_content.pdf on May 3, 2021.

Hori K., Suzuki K., Iijima K. & Ebana K. (2016). Variation in cooking and eating quality traits in Japanese rice germplasm accessions. Breeding Science. 66: 309-318. DOI: 10.1270/ jsbbs.66.309.

Juliano B. O. & Gonzales L. A. (1989). Physiochemical and economic aspect of rice grain quality. Progress in Irrigated Rice Research. International Rice Research Institute (IRRI): 1-16.

Kasem S., Waters D. L. E., Ward R. M., Rice N. F. & Henry R. J. (2014). Wild *Oryza* grain physico-chemical properties. Tropical Plant Biology. 7(1):13-18. DOI: 10.1007/s12042-013-9133-1.

Kim S. S., Lee S. E., Kim O. W. & Kim D. C. (2000). Physicochemical characteristics of chalky kernels and their effects on sensory quality of cooked rice. Cereal Chemistry. 77: 376-379. DOI: 10.1094/CCHEM.2000.77.3.376.

Khanh T. D., Duong V. X., Nguyen P. C., Xuan T. D., Trung N. T., Trung K. H., Gioi D. H., Hoang N. H., Tran H.-D., Trung D. M., Huong B. T. T. (2021). Rice Breeding in Vietnam: Retrospects, Challenges and Prospects. Agriculture. 11(5): 397. DOI: 10.3390/agriculture11050397.

Li C. G. (2001). A chalkiness indica CMS lines Yuefeng A developed in Guangdong. Hybrid Rice. 1: 57 (in Chinese).

Liu Q. H., Zhou X. B., Yang L. Q. & Tian L. (2009). Effects of chalkiness on cooking, eating and nutritional qualities of rice in two indica varieties. Rice Science. 16(2): 161-164. DOI: 10.1016/S1672-6308(08)60074-8.

Lu H., Yuan Y. J., Zhang S. Q., Shen H., Chen D., Zhong X. Y., Li B., Deng F., Chen Y., Li G. Y. & Ren W. H. (2021). Evaluation of rice eating quality and optimization of varieties of Southwest indica hybrid rice based on three taste evaluation methods. Scientia Agricultura Sinica. 54(6): 1243-1257 (in Chinese).

Matthews J. & Spadaro J. J. (1976). Breakage of long grain rice in relation to kernel thickness. Cereal Chemistry. 53: 13-19.

Merca F. E. & Juliano B. O. (1981). Physico-chemical properties of starch of intermediate amylase and starch. Satarke. 33: 253-260. DOI: 10.1002/star.19810330802.

Mestres C., Briffaz A. & Valentin D. (2019). Rice cooking and sensory quality. In J. Bao (Ed.), Rice (4th ed.). Sawston, UK: AACC International Press. DOI: 10.1016/B978-0-12- 811508-4.00012-5: 385-426.

Ngo D. D., Baruah S. & Mohanty S. (2019). Value chain analysis of rice seed and potato tuber seed in Vietnam: Case study in four provinces from North, Central and South. Hanoi, Vietnam: CGIAR Research Program on Climate Change, Agriculture and Food Security Southeast Asia (CCAFS).

Nguyen V. K., Nguyen H. H. & Cramb R. (2020). Trends in rice-based farming systems in the Mekong delta. In: Cramb R. (Ed.). White Gold: The Commercialization of Rice Farming in Lower Mekong Basin. Singapore: Palgrave Macmillan: 347-373.

Park S. G., Park H. S., Baek M. K., Jeong J. M., Cho Y. C., Lee G. M., Lee C. M., Suh J. P., Kim C. S. & Kim S. M. (2019). Improving the glossiness of cooked rice, an important component of visual rice grain quality. Rice: 12: 87. DOI: 10.1186/s12284-019-0348-0.

Pang Y., Ali J., Wang X., Franje N. J., Revilleza J. E., Xu J. & Li Z. (2016). Relationship of rice grain amylose, gelatinization temperature and pasting properties for breeding better eating and cooking quality of rice varieties. PLoS One. 11(12): e0168483. DOI: 10.1371/journal.pone.0168483.

Pham T. T. H., Do T. K., Phung T. T., Truong N. M., Tran D. X., Nguyen T. L. & Bui C. B. (2016). Study on physical-chemical characters and heritability for yield components in rice (*Oryza sativa* L.). International Letters of Natural Sciences. 57: 67-78.

Prodhan Z. H. & Shu Q. (2020). Rice aroma: A natural gift comes with price and the way forward. Rice Science. 27: 86-100. DOI: 10.1016/j.rsci.2020.01.001.

Roy S., Banerjee A., Basak N., Kumar J. & Mandal N. P. (2020). Aromatic rice. In: Costa de Oliveira A., Pegoraro C. & Ebeling Viana V. (Eds.): The future of rice demand: Quality beyond productivity. Cham: Springer.

Sakthivel K., Sundaram R. M., Rani N. S., Balachandran S. M. & Neeraja, C. N. (2009) Genetic and molecular basis of fragrance in rice. Biotechnology Advances. 27(4): 468-473. DOI: 10.1016/j.biotechadv.2009.04.001.

Sangpring Y., Fukuoka M. & Ratanasumawong S. (2015). The effect of sodium chloride on microstructure, water migration, and texture of rice noodle. LWT-Food Science and Technology. 64: 1107-1113.

Siebenmorgen T. J., Matsler A. L. & Earp C. F. (2006). Milling characteristics of rice cultivars and hybrids. Cereal Chemistry. 83: 169-172. DOI: 10.1094/CC-83-0169.

Singh N., Sodhi N. S., Kaur M. & Saxena S. K. (2003). Physio-chemical, morphological, thermal cooking and texture properties of chalky and translucent rice kernels. Food Chemistry. 82(3): 433-439. DOI: 10.1016/S0308-8146(03)00007-4.

Suwannaporn A., Pitiphunpong S. & Champangern S. (2007). Classification of rice amylose content by

discriminant analysis of physicochemical properties. Starch/Stärke. 59: 171-177. DOI: 10.1002/star.200600565.

Thang T. (2017). Current Status of Vietnam Rice Export Quality. Taipei: FFTC Agricultural Policy Platform. Retrieved from https://ap.fftc.org.tw/article/ 1204 on April 30, 2022.

Tong C., Gao H., Luo S., Liu L. & Bao J. (2019). Impact of postharvest operations on rice grain quality: a review. Comprehensive Reviews in Food Science and Food Safety. 18: 626-640. DOI: 10.1111/1541-4337.12439.

Wang K., Wambugu P. W., Zhang B., Wu A. C., Henry R. J. & Gilbert R. G. (2015). The biosynthesis, structure and gelatinization properties of starches from wild and cultivated African rice species (*Oryza barthii* and *Oryza glaberrima*). Carbohydrate Polymers. 129:92-100. DOI: 10.1016/j. carbpol.2015.04.035.

Wang Z. D., Zhou S. C., Wang C. R., Chen Y. B., Li H., Huang D. Q., Zhou D. G., Gong R., Zhao L., Wu Y. K., Pan Y. Y. & Yang Y. Q. (2021). Relationship between eating quality and other quality traits of indica rice with different amylose content. Chinese Rice. 27(1): 38-44 (in Chinese).

Yang F., Hu W. B., Zhou Z., Liu Y. & Zhao Z. H. (2021). Comparison of eating quality between indica hybrid rice and conventional indica rice. Hybrid rice. 36(3): 71-78 (in Chinese).