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Correlation among Quality Characteristics in Medium-Grain Rice

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Abstract

Rice (*Oryza sativa* L.) grain attributes, such as grain length and shape, milling quality, and physicochemical quality, are crucial for varietal development and subsequent farm adoption. Thus, it is crucial to comprehend the phenotypic range of these grain attributes and how they relate to one another. Therefore, this study analyzed the main grain quality traits in medium-grain rice, namely the amylose content (AC), gelatinization temperature (GT), gel consistency (GC), ratio of head rice (HR), and percentage of chalkiness (PC). Correlations among the major quality characteristics were then calculated through Pearson correlation matrix analysis. The results showed that AC was highly connected with GC, and PC and HR (GC) showed a strong correlation. The correlation between GT and GC was average. The other quality traits did not correlate significantly. The phenotypes of the grain quality traits provide a basis for improving the quality of medium-grain rice populations.

Keywords

Medium-grain rice, amylose content, chalkiness, correlation

Introduction

Medium-grain rice with good quality has become a high-value product in the market and it is forecasted that both demand from consumers and the price of this rice will remain stable or even increase (Wailes & Chavez, 2015). Rice grain quality includes physical and chemical characteristics related to grain shape, milling quality, cooking qualities, and nutritional value (Juliano, 1985; Wang *et al*., 2007; Wang *et al*., 2011; Guo *et al*., 2011; Bao, 2014). In particular, the milling (head rice and chalkiness) and physicochemical (amylose content, gelatinization temperature, gel consistency, and aroma) qualities are the two groups of characteristics that are of interest to researchers, producers, and

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consumers (Raju *et al*., 1991; Demont *et al*., 2017; Custodio *et al*., 2019; Misra *et al*., 2019).

The ratio of head rice (HR) is the first milling quality in rice. It refers to the percentage of intact grains that remain after milling (Cnossen *et al*., 2003). HR is one of the most crucial economic characteristics of rice. Lower HR ratios are linked to decreases in the market value of milled rice (Siebenmorgen *et al*., 2006; Cuevas *et al*., 2016; Demont *et al*., 2017). Many factors can affect HR, such as (i) post-harvest procedures including the drying of grains, (ii) harvest grain moisture content (Cnossen *et al*., 2003), (iii) the detrimental influence of high nighttime temperatures during the filling of seeds, and (iv) genetic components (Sreenivasulu *et al*., 2015). Another important milling quality trait is chalkiness, which is commonly defined as an opaque white discoloration in the translucent endosperm brought on by the formation of air gaps between unevenly formed starch granules (Butardo and Sreenivasulu, 2019). Grain chalkiness or the percentage of chalkiness (PC) is an undesirable trait because it is related to high levels of damage to the grain during milling, and hence, to a decrease in the recovery of head rice (Del Rosario *et al*., 1968). Chalkiness significantly affects other milling quality traits (the ratio of brown, white, and head rice) but does not significantly affect the flexibility of the rice grains (amylose content) or the taste of cooked rice (IRRI, 2006). Among the grain quality traits, HR and PC are significantly affected by the environment (Zhao & Fitzgerald, 2013).

The most significant characteristic for classifying rice varieties is amylose content (AC) (Juliano, 1985), which affects the texture and retrogradation potential of cooked rice grains (Champagne *et al*., 2004). In the rice grain, amylose content comprises about 20-30% of the total starch (Vandeputte & Delcour, 2004; Regina *et al*., 2006). However, AC alone does not explain all of the variations in the eating and cooking quality, as cultivars with similar AC values possess different eating and cooking qualities (Pang *et al*., 2016). Gelatinization temperature (GT) and gel consistency (GC) are two of the physicochemical traits in rice that are also closely related to the eating and cooking quality of rice and are correlated with AC (Hossaina *et al*., 2009; Ritika *et al*., 2010; Pang *et al*., 2016; Zhang *et al*., 2020). GT is calculated as the alkali spreading value, which is determined by how whole-milled rice grains disperse in a weak alkali solution (1.7% potassium hydroxide). Low, intermediate, and high GT rice grains disintegrate completely, partially, and non-affectedly in a diluted alkali solution, respectively (IRRI, 1996). GC is a secondary indicator to further define the quality classes of varieties within the classifications of waxy and high-AC (Custodio *et al*., 2019). GC measures the cold paste viscosity of cooked rice flour and varies from soft to hard. The connection of starch polymers in the aqueous phase determines the soft and hard gels. Rice with a soft GC is more popular with customers (Wang *et al*., 2007). Many significant studies on improving rice quality have been conducted (Qian *et al*., 2016; Lang *et al*., 2017; Ferdous *et al*., 2018). However, these results have not particularly affirmed the quality of medium-grain rice. Therefore, studying the quality characteristics and their correlations would allow breeders to comprehend and breed medium-grain rice with good quality more effectively.

This study examined the relationships among the key quality attributes in medium-grain rice varieties.

Materials and Methods

Materials

A total of 342 varieties of the rice diversity panel (RDP) were provided by the Genetic Resources Center, International Rice Research Institute (IRRI) (**Table 1**).

Methods

Experimental site and time

The experiments were conducted at the experimental station of the Institute of Food and Biotechnology, Can Tho University, Can Tho city, Vietnam from January to June 2021.

Table 1. List of rice varieties used in the study

No.	Name	Origin	Group	No.	Name	Origin	Group
1	27	Dominica	TRJ	172	Kihogo	Tanzania	TEJ
2	318	Turkey	TRJ	173	Kinastano	Philippines	TRJ
3	325	Taiwan	TRJ	174	Kitrana 508	Madagascar	ARO
4	519	Uruguay	IND	175	Kiuki No. 46	Japan	TEJ
5	583	Ecuador	TRJ	176	Kon Suito	Mongolia	TEJ
6	923	Madagascar	ADMIX	177	Koshihikari	Japan	TEJ
7	9524	India	AUS	178	KPF-16	Bangladesh	ADMIX
8	56-122-23	Thailand	TEJ	179	KU115	Thailand	ADMIX
9	68-2	France	TEJ	180	Kun-Min-Tsieh-Hunan	China	IND
10	93-11	China	IND	181	L-202	USA-CA	TRJ
11	Agostano	Italy	TEJ	182	LAC 23	Liberia	TRJ
12	Agusita	Hungary	TEJ	183	Lacrosse	USA	ADMIX
13	Ai-Chiao-Hong	China	IND	184	Lady Wright Seln	USA	TRJ
14	Aijiaonante	China	IND	185	LaGrue	USA	TRJ
15	Amposta	Puerto Rico	TEJ	186	Lambayeque 1	Peru	ARO
16	Arabi	Egypt	ADMIX	187	LD 24	Sri Lanka	IND
17	ARC 10086	India	ADMIX	188	Leah	Bulgaria	TRJ
18	ARC 10376	India	AUS	189	Lemont	USA	TRJ
19	ARC 6578	India	AUS	190	Leuang Hawn	Thailand	TEJ
20	ARC 7229	India	AUS	191	Leung Pratew	Thailand	IND
21	Arias	Indonesia	TRJ	192	Llanero 501	Venezuela	TRJ
22	ASD 1	India	TEJ	193	Lomello	Thailand	TEJ
23	Asse Y Pung	Philippines	TRJ	194	Luk Takhar	Afghanistan	TEJ
24	Aswina 330	Bangladesh	AUS	195	M. Blatec	Macedonia	ADMIX
25	Azerbaidjanica	Azerbaijan	TEJ	196	M-202	USA -CA	ADMIX
26	Azucena	Philippines	TRJ	197	Mansaku	Japan	TEJ
27	B6616A4-22-Bk-5-4	USA	TRJ	198	Manzano	Zaire	TRJ
28	Baber	India	TEJ	199	Maratelli	Italy	TEJ
29	Baghlani Nangarhar	Afghanistan	TEJ	200	Mehr	Iran	AUS
30	Bahia	Spain	TEJ	201	Melanotrix	Tajikistan	TEJ
31	Baldo	Italy	ADMIX	202	Ming Hui	China	IND
32	Basmati	Pakistan	ARO	203	Moroberekan	Guinea	TRJ
33	Basmati 217	India	TRJ	204	Mudgo	India	IND
34	Bellardone	France	TEJ	205	N12	India	ARO
35	Benllok	Peru	TEJ	206	Nipponbare	Japan	TEJ
36	Berenj	Afghanistan	ADMIX	207	Niquen	Chile	TRJ
37	Bergreis	Austria	TEJ	208	Nira	USA	IND
38	Bico Branco	Brazil	ARO	209	Norin 20	Japan	TEJ
39	Binulawan	Philippines	IND	210	Nortai	USA	ADMIX
40	Biser 1	Bulgaria	TEJ	211	Nova	USA	ADMIX

No.	Name	Origin	Group	No.	Name	Origin	Group
41	BJ 1	India	AUS	212	NPE 835	Pakistan	TEJ
42	Black Gora	India	AUS	213	Nucleoryza	Austria	TEJ
43	Blue Rose	Louisiana	ADMIX	214	Okshitmayin	Myanmar	ADMIX
44	Boa Vista	El Salvador	TRJ	215	Oro	Chile	TEJ
45	Bombilla	Spain	TEJ	216	Oryzica Llanos 5	Colombia	IND
46	Bombon	Spain	TEJ	217	OS 6 (WC 10296)	Zaire	TRJ
47	BR24	Bangladesh	IND	218	OS6	Nigeria	TRJ
48	Breviaristata	Portugal	ADMIX	219	Osogovka	Macedonia	ADMIX
49	British Honduras Creole	Belize	TRJ	220	Ostiglia	Argentina	TEJ
50	Bul Zo	South Korea	TEJ	221	Padi Kasalle	Indonesia	TRJ
51	Bulgare	France	TEJ	222	Padi Pagalong	Malaysia	TRJ
52	Byakkoku Y 5006 Seln	Australia	IND	223	Pagaiyahan	Taiwan	IND
53	C101A51	Colombia	IND	224	Pai Hok Glutinous	Hong Kong	IND
54	C1-6-5-3	Mexico	ADMIX	225	Palmyra	USA	ADMIX
55	C57-5043	USA	TRJ	226	Panda	USA	ADMIX
56	CA 902/B/2/1	Chad	AUS	227	Pao-Tou-Hung	China	IND
57	Caawa/Fortuna 6-103-15	Taiwan	TRJ	228	Pappaku	Taiwan	IND
58	Canella De Ferro	Brazil	TRJ	229	Paraiba Chines Nova	Brazil	IND
59	Carolina Gold - 1	USA	TRJ	230	Pate Blanc Mn 1	Cote D'Ivoire	TRJ
60	Carolina Gold	USA	TRJ	231	Patna	Morocco	TEJ
61	Carolina Gold Sel	USA	TRJ	232	Pato De Gallinazo	Australia	ADMIX
62	Caucasica	Russia	TEJ	233	Paung Malaung	Myanmar	AUS
63	Cenit	Argentina	TRJ	234	Peh-Kuh	Taiwan	IND
64	Chang Ch'Sang Hsu Tao	China	IND	235	Peh-Kuh-Tsao-Tu	Taiwan	IND
65	Chau	Vietnam	IND	236	Phudugey	Bhutan	AUS
66	Chibica	Mozambique	TEJ	237	PI 298967-1	Australia	ADMIX
67	Chiem Chanh	Vietnam	IND	238	Pirinae 69	Former Yugoslavia	ADMIX
68	China 1039	China	IND	239	PR 304	Puerto Rico	TRJ
69	Chinese	China	TEJ	240	Pratao	Brazil	TRJ
70	Chodongji	South Korea	TEJ	241	Priano Guaira	Brazil	TRJ
71	Chuan 4	Taiwan	AUS	242	PTB 30	India	AUS
72	CI 11011	USA	ADMIX	243	R 101	Zaire	TRJ
73	CI 11026	USA	ADMIX	244	Radin Ebos 33	Malaysia	IND
74	Coarse	Pakistan	AUS	245	Rathuwee	Sri Lanka	IND
75	Cocodrie	USA	TRJ	246	Razza 77	Italy	TEJ
76	Coppocina	Bulgaria	TRJ	247	Rikuto Kemochi	Japan	TEJ
77	Creole	Belize	TRJ	248	Rikuto Norin 21	Japan	ADMIX
78	Criollo La Fria	Venezuela	IND	249	Rinaldo Bersani	Italy	ADMIX
79	CS-M3	USA-CA	TEJ	250	Riz Local	Burkina Faso	ADMIX
80	CTG 1516	Bangladesh	AUS	251	Rojofotsy 738	Madagascar	ADMIX
81	Cuba 65	Cuba	TRJ	252	Romeo	Italy	TEJ

No.	Name	Origin	Group	No.	Name	Origin	Group
82	Cybonnet	USA	TRJ	253	Rondo (4484-1693)	China	IND
83	Dam	Thailand	ADMIX	254	Rosemont	USA	TRJ
84	Dawebyan	Myanmar	IND	255	RT 1031-69	Zaire	TRJ
85	DD 62	Bangladesh	AUS	256	RT0034	USA	IND
86	Dee Geo Woo Gen	Taiwan	IND	257	RTS14	Vietnam	IND
87	Della	USA	TRJ	258	RTS4	Vietnam	IND
88	Delrex	USA	TRJ	259	S4542A3-49B-2B12	USA	TRJ
89	Deokjeokjodo	Korea	TEJ	260	Sab Ini	Egypt	TEJ
90	Desvauxii	USSR	TEJ	261	Saber	USA	TRJ
91	Dhala Shaitta	Bangladesh	AUS	262	Sabharaj	Bangladesh	IND
92	DJ 123	Bangladesh	AUS	263	Sadri Belyi	Azerbaijan	ARO
93	DJ 24	Bangladesh	AUS	264	Sadri Tor Misri	Iran	ADMIX
94	Djimoron	Guinea	IND	265	Saku	Mongolia	ADMIX
95	DK 12	Bangladesh	AUS	266	Santhi Sufaid	Pakistan	AUS
96	DM 43	Bangladesh	AUS	267	Saraya	Fiji	AUS
97	DM 56	Bangladesh	AUS	268	Sathi	Pakistan	AUS
98	DM 59	Bangladesh	AUS	269	Saturn	USA	ADMIX
99	Doble Carolina Rinaldo Barsani	Uruguay	ADMIX	270	Seratoes Hari	Indonesia	IND
100	Dom Zard	Iran	ARO	271	Shai-Kuh	China	IND
101	Dom-sufid	Iran	ARO	272	Shangyu 394	China	TEJ
102	Dosel	Spain	TEJ	273	Shim Balte	Iraq	AUS
103	Dourado Agulha	Brazil	TRJ	274	Shinriki	Japan	TEJ
104	DV 123	Bangladesh	AUS	275	Shirkati	Afghanistan	AUS
105	DV85	Bangladesh	AUS	276	Shirogane	Japan	TEJ
106	DZ 193	Bangladesh	AUS	277	Shoemed	USA	TEJ
107	DZ78	Bangladesh	AUS	278	Short Grain	Thailand	IND
108	Early	USA	ADMIX	279	Sigadis	Indonesia	IND
109	Early Wataribune	Japan	TEJ	280	Sinaguing	Philippines	TRJ
110	ECIA76-S89-1	Cuba	IND	281	Sinampaga Selection	Philippines	TRJ
111	Edith	USA	TRJ	282	Sitpwa	Myanmar	TEJ
112	Edomen Scented	Japan	TEJ	283	SL 22-613	Sierra Leone	ADMIX
113	Eh Ia Chiu	Taiwan	TEJ	284	SLO 17	India	IND
114	EMATA A 16-34	Myanmar	IND	285	SML 242	Suriname	IND
115	Erythroceros Hokkaido	Poland	TEJ	286	Spring	USA	TRJ
116	Estrela	Colombia	ADMIX	287	Sri Malaysia Dua	Malaysia	TEJ
117	F.R. 13A	India	TEJ	288	Sufaid	Pakistan	AUS
118	Firooz	Iran	ARO	289	Sultani	Egypt	TRJ
119	Fortuna	USA	TRJ	290	Sundensis	Kazakhstan	IND
120	Francis	USA	TRJ	291	Sung Liao 2	China	TEJ
121	Gambiaka Sebela	Mali	TEJ	292	Surjamkuhi	India	AUS
122	Geumobyeo	South Korea	TEJ	293	Suweon	Korea	TEJ

No.	Name	Origin	Group	No.	Name	Origin	Group
123	Ghati Kamma Nangarhar	Afghanistan	AUS	294	Sze Guen Zim	China	IND
124	Ghorbhai	Bangladesh	AUS	295	T 1	India	AUS
125	Gogo Lempuk	Indonesia	TRJ	296	T26	India	AUS
126	Guan-Yin-Tsan	China	IND	297	Ta Mao Tsao	China	TEJ
127	H256-76-1-1-1	Argentina	TRJ	298	Taducan	Philippines	IND
128	Habiganj Boro 6	Bangladesh	ADMIX	299	Taichung Native 1	Taiwan	IND
129	Halwa Gose Red	Iraq	AUS	300	Tainan Iku 487	Taiwan	TEJ
130	Hatsunishiki	Japan	TEJ	301	Tainan-Iku No. 512	Taiwan	TEJ
131	Hiderisirazu	Japan	ADMIX	302	Taipei 309	Taiwan	TEJ
132	Hon Chim	Hong Kong	IND	303	Tam Cau 9A	Vietnam	IND
133	Honduras	Honduras	TRJ	304	Tchibanga	Gabon	IND
134	Hu Lo Tao	China	TEJ	305	TeQing	China	IND
135	Hunan Early Dwarf No. 3	China	IND	306	Tia Bura	Indonesia	TRJ
136	IAC 25	Brazil	TRJ	307	TKM6	India	IND
137	I-Geo-Tze	Taiwan	ADMIX	308	TOg 7178	Senegal	ADMIX
138	Iguape Cateto	Haiti	TRJ	309	Toploea 70/76	Romania	TEJ
139	IITA 135	Nigeria	TRJ	310	Tox 782-20-1	Nigeria	TRJ
140	IR-44595	Nepal	IND	311	Trembese	Indonesia	TRJ
141	IRAT 13	Cote D'Ivoire	TRJ	312	Triomphe Du Maroc	Morocco	TEJ
142	IRAT 177	French Guiana	TRJ	313	Tropical Rice	Ecuador	TEJ
143	IRAT 44	Burkina Faso	TRJ	314	Tsipala 421	Madagascar	ADMIX
144	IRGA 409	Brazil	IND	315	Uzbekskij 2	Uzbekistan	TEJ
145	Italica Carolina	Poland	TEJ	316	Vary Vato 462	Madagascar	ADMIX
146	Jambu	Indonesia	TRJ	317	Varyla	Madagascar	ADMIX
147	Jamir	Bangladesh	AUS	318	Vavilovi	Kazakhstan	TEJ
148	Jasmine85	Philippines	IND	319	Vialone	Italy	TEJ
149	Jaya	India	IND	320	Victoria F.A.	Argentina	ADMIX
150	JC 117	India	IND	321	WAB 501-11-5-1	Cote D'Ivoire	TRJ
151	JC149	India	IND	322	WAB 502-13-4-1	Cote D'Ivoire	TRJ
152	Jefferson	USA	TRJ	323	Wanica	Suriname	TRJ
153	Jhona 349	India	AUS	324	WC 2810	Micronesia	TRJ
154	Jing 185-7	China	IND	325	WC 3397	Jamaica	TRJ
155	Jouiku 393G	Japan	TEJ	326	WC 4419	Honduras	TRJ
156	K 65	Suriname	ADMIX	327	WC 4443	Bolivia	TRJ
157	Kachilon	Bangladesh	AUS	328	WC 521	China	ADMIX
158	Kalamkati	India	AUS	329	WC 6	China	TEJ
159	Kalubala Vee	Sri Lanka	AUS	330	Wells	USA	TRJ
160	Kamenoo	Japan	TEJ	331	WIR 3039	Tajikistan	TEJ
161	Kaniranga	Indonesia	TRJ	332	WIR 3764	Uzbekistan	TEJ
162	Karabaschak	Bulgaria	TEJ	333	Yabani Montakhab 7	Egypt	TEJ
163	Karkati 87	Bangladesh	AUS	334	Yang Dao 6	China	IND

No.	Name	Origin	Group	No.	Name	Origin	Group
164	Kasalath	India	AUS	335	Yodanya	Myanmar	IND
165	Katy	USA	TRJ	336	YRL-1	Australia	ADMIX
166	Kaukau	Mali	AUS	337	Zerawchanica Karatalski	Poland	TEJ
167	Kaukkyi Ani	Myanmar	ADMIX	338	ZHE 733	China	IND
168	Kaybonnet	USA	TRJ	339	Zhenshan 2	China	IND
169	Khao Gaew	Thailand	AUS	340	Siêu Hàm Châu	Vietnam	ADMIX
170	Khao Pahk Maw	Thailand	AUS	341	PY 2	Vietnam	ADMIX
171	Khao Tot Long 227	Thailand	AUS	342	ML202	Vietnam	ADMIX

Note: IND: Indica; TRJ: Tropical japonica; TEJ: Temperature japonica; AUS: Aus; ARO: Aromatic; ADMIX: others.

Analysis methods of grain quality characteristics (grain size, AC, GT, GC, HR, and PC) in the medium-grain rice are shown in **Figure 1**.

Identifying the medium-grain rice

Rice samples were randomly selected with 100 grains/variety, husks were removed, and brown rice grains were photographed and measured using the SmartGRAIN software (Tanabata *et al*., 2012). The grain size classification was referenced from the methods of Jenning *et al*. (1979) and IRRI (2014), who reported that medium-grain rice has a grain length from 5.51 to 6.60mm and a ratio of grain length to grain width from 2.1 to 3.0.

Analysis of amylose content

The AC of the milled rice samples was assessed using the methods of Juliano (1971) and Graham (2002). In a 50-mL glass test tube, 100 mg of milled rice flour was soaked in 1 mL of 95% ethanol and 9.0mL of 1 N NaOH, and the mixture was left undisturbed for 16 hours. Then, to bring the solution to a volume of 100mL, 90mL of distilled water was added, and 0.5mL of the solution was put into a 20-mL test tube containing 5 mL of distilled water. Following the addition of 0.1mL of 1 M CH_3COOH, 0.2mL of iodine solution (0.15% I_2 in 1.5% KI) was added and the mixture was well stirred using a vortex mixer. The solution was then diluted to 10mL using 4.2mL of distilled water. To develop the calibration curves for the determination of amylose content in a rice sample, 40mg of Avebe potato amylose (standard amylose) was put in a 50mL test tube and the procedure described above was followed. Then, 0.1, 0.2, 0.3, 0.4, and 0.5mL of the standard amylose sample solution were transferred into 20mL test tubes and the same procedure used for the test samples was followed. Construction of the calibration curve was carried out by converting the spectral reading to the percentage of amylose content according to the formula: $y = ax + b$, where y is the absorbance OD, and x is the amount of amylose in the measured sample (mg L^{-1}) (Graham, 2002).

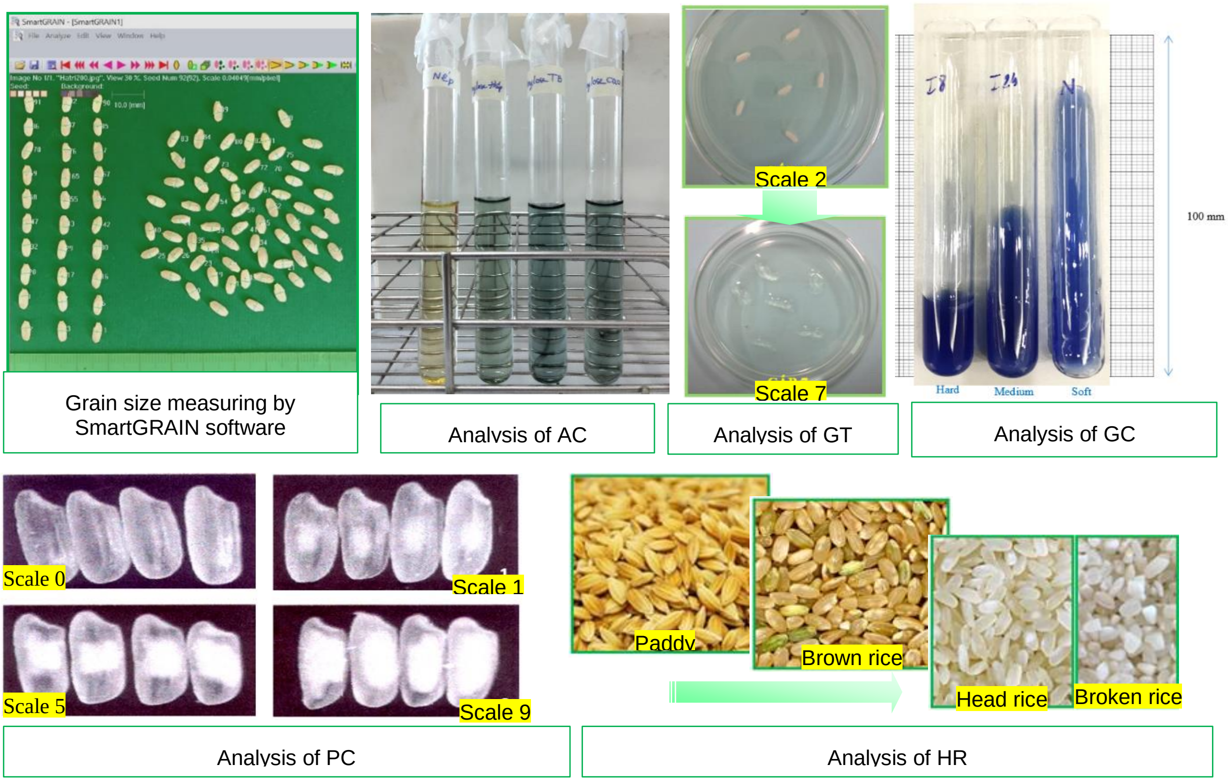
The AC in the rice was classified into high (>25%), intermediate (20-25%), low (12-20%), very low (2-12%), or waxy (0 - 2%) (IRRI, 1996; Coffman & Juliano, 1987).

Analysis of gelatinization temperature

Six whole-milled, unbroken duplicate kernels were chosen and put in a petri dish (8.0cm in diameter). Ten mL of 1.7% KOH solution was added. The samples were set up so that there was sufficient room between the kernels to permit spreading. The plates were covered and kept at 30°C for 23 hours of incubation. As part of the standard evaluation system for rice, the starchy endosperm was rated visually using a seven-point numerical spreading scale: high (1-2), high or intermediate (3), intermediate (4-5), and low (6-7) (IRRI, 2014).

Analysis of gel consistency

Analysis of gel consistency was conducted according to the methods of Tang *et al*. (1991). Milled rice flour (100mg) was put into a glass test tube (13 x 100mm). Then, 0.2mL of 95% ethanol



Note: AC: Amylose Content; GT: Gelatinization Temperature; GC: Gel Consistency; HR: the ratio of head rice; PC: Percentage of Chalkiness.

Figure 1. Analysis of grain quality characteristics in rice

containing 0.03% green thymol was placed into the test tube followed by the addition of 2mL of 0.2N KOH and the mixture was shaken thoroughly on a vortex machine. The test tube was covered and placed in a pot of boiling water (100°C) for 8min. Test tubes were cooled to room temperature for 5min and placed in an ice bath for 20min. Test tubes were removed and placed horizontally for 1h. The gel consistency was the length the gel moved as measured from the bottom of the test tube to the end of the gel. The classification of gel consistency was according to the standard evaluation system for rice of IRRI (2014): soft (61-80mm), medium (41-60mm), and hard (< 40mm).

Analysis of the ratio of head rice

Evaluation of HR was performed according to the methods of IRRI (1996). Rice samples (200g) with a moisture content of 14% were peeled and milled, and the broken grains left out. The ratio of head rice was calculated by the formula: HR (%) = (Weight of head rice grains/Weight of paddy samples) x 100.

Analysis of the percentage of chalkiness

The PC was visually assessed based on the Standards Evaluation System for Rice (SES) of IRRI. The PC in rice was classified into four scales: scale 0 (non-chalky), scale 1 (chalkiness area less than 10%), scale 5 (chalkiness area from 11 to 20%), and scale 9 (chalkiness area more than 20%) (IRRI, 1996).

For each seed sample, 100g of rice grains were milled and each grain of rice was classified for PC. The percentage of chalkiness was determined by the formula: PC (%) = (Weight of chalkiness grains in scale 9/Weight of milled rice) * 100.

Statistical analysis of quality characteristics

R-studio software version 3.2.2 (R Core Team, 2015) was used for Box-plot charting and Pearson's correlation coefficients (r) for AC, GT, GC, HR, and PC.

Results and Discussion

The medium-grain rice group

The Rice Diversity Panel (RDP) consists of long-grain, medium-grain, and short-grain rice varieties classified according to the grain size of the brown rice. Among the examined 342 RDP rice varieties, there were 122 long-grain, 106 short-grained, and 114 medium-grained types, making up 35.7%, 31.0%, and 33.3% of the total, respectively. Thus, the RDP had similar numbers of long, medium, and short grain varieties or, in other words, the medium-grain varieties accounted for about one-third. The group of medium-grain rice included many rice subpopulations, in which, the *indica* (IND) was the biggest subpopulation (accounting for 36.0%), followed by the *aus* (AUS) and *tropical japonica* (TRJ) subpopulations, accounting for 22.8% and 14.9%, respectively, and the rest were other subpopulations.

Grain quality of medium-grain rice

The characteristics of grain quality (AC, GT, GC, HR, and PC) in the medium-grain rice varieties are shown in **Table 2**.

AC had significant differences among the rice varieties, ranging from 10.83 to 30.12%. This result is similar to many previous studies on AC in rice (Manners, 1979; Juliano, 1992; Patindol *et al*., 2015). The results showed that there were no glutinous rice varieties (AC ≤ 2%), the very low amylose group accounted for 3.5%, the low amylose group accounted for 18.4%, the medium amylose group had the biggest rate of 42.1%, and the remaining 36.0% had high amylose content. The varieties having a low amylose content of less than 20% make a potential group that needs attention for breeding new rice varieties with high quality.

The experiment recorded GT values ranging from a scale of 3 to 7. The high GT (from scale 3 and lower) accounted for about 4.4%, the middle GT (from scale 4 to 5) accounted for 23.7%, and the low GT (from scale 6 to 7) made up the majority, about 71.9%. According to Juliano and Villareal (1993) and Pang *et al*. (2016), rice varieties with low or intermediate GT are preferred because these varieties require less water and cooking time than those possessing high GT. The results of this study showed that many medium-grain varieties have low GT and can be considered potential materials for breeding high-quality rice varieties.

The GC test lengths of the medium-grain rice varieties were recorded as ranging from 31 to 96mm with the average value being 57.26mm. In which, most varieties had a medium gel consistency (GC = 41-60mm), accounting for 51.8%. The group of soft GC made up 34.2% and the rest of the varieties, about 14.0%, were classified as having hard GC. Chemutai *et al*. (2016) asserted that rice with a soft GC had a higher preference among consumers. Furthermore, hard GC is closely related to high AC, identifying the varieties as hard rice, and vice versa. Similar to the AC, rice varieties with better GC (softer) are preferred (Hirano & Sano, 1998; Nguyen Ngoc De, 2008).

The PC of medium-grain rice had a large range among the varieties. Many rice varieties were non-chalky (PC = 0%), while other varieties had very high chalkiness, with the highest rate of

Table 2. Descriptive statistics of the grain quality characteristics in the medium-grain rice varieties

Characteristics	Min	Max	Mean	Range	Variance	SD	SE
AC *(%)*	10.83	30.12	22.80	19.29	20.83	4.56	0.43
GT *(scale)*	3.0	7.0	5.86	4.0	0.91	0.95	0.09
GC *(mm)*	31.0	96.0	57.26	65.0	235.13	15.33	1.44
HR (%)	42.2	66.0	53.6	23.8	38.96	6.24	0.58
PC *(%)*	0.0	86.7	15.23	86.7	444.92	21.09	1.98

Note: Statistics at 95% significance level; Min: minimum; Max: maximum; Mean: average; SD: standard deviation; SE: standard error; AC: Amylose Content; GT: Gelatinization Temperature; GC: Gel Consistency; HR: the ratio of head rice; PC: Percentage of Chalkiness.

chalkiness being 86.7%. The result of the large range of PC among the rice varieties is comparable to that of the study by Misra *et al*. (2019). Regarding the classification of the chalkiness of rice, there were 33 non-chalky varieties (scale 0) accounting for a relatively high rate of 28.9% of the total number of varieties. Rice varieties at scale 1 (≤10%), scale 5 (PC = 11-20%), and scale 9 (PC >20%) made up 35.1%, 14.0%, and 22.0%, respectively. Thus, the evaluation of chalkiness in the medium-grain rice showed a high percentage of non-chalky or low chalkiness grains, reaching about 64%. Rice varieties with less chalkiness are more popular in the market (Sreenivasulu *et al*., 2015; Misra *et al*., 2019). These varieties are potential materials for breeding rice with low chalkiness.

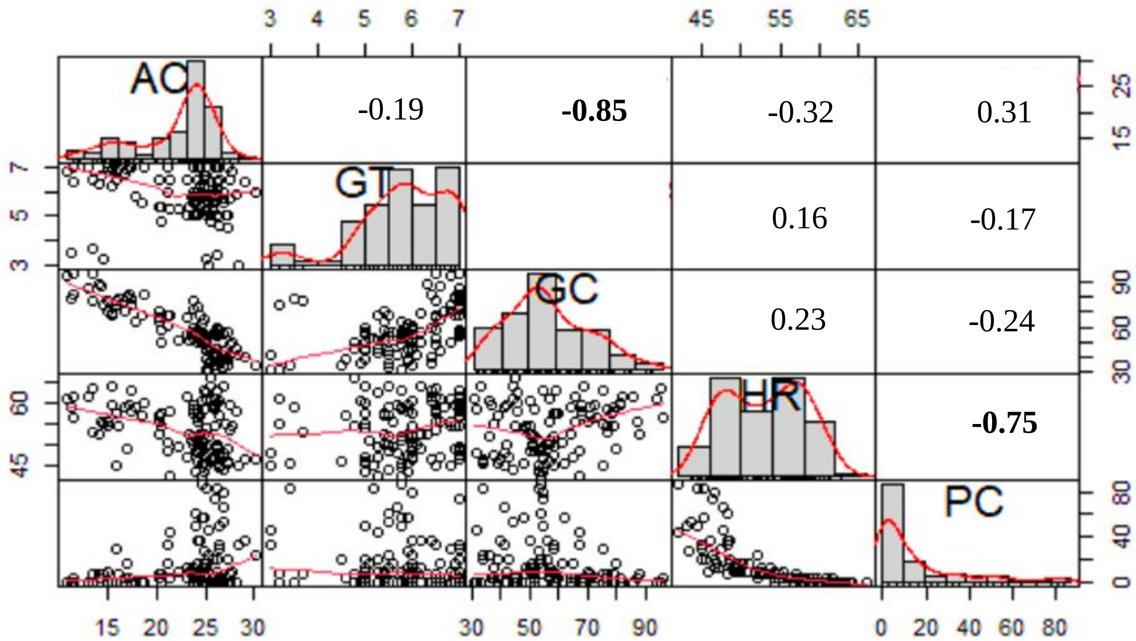
The HR of the medium-grain rice varieties ranged from 42.2% to 66.0%, showing a range of about 23.8% among the varieties. The medium-grain rice had a high percentage of head rice, with an average of 53.6%. This result is consistent with the conclusions of previous studies. IRRI (2010) stated that the average HR of Asian rice varieties was in the range of 35-50% and an optimal 55-60% HR could be reached (FAO, 1998; Nguyen Ngoc De, 2008; Lapis *et al*., 2019). Therefore, the HR values of the medium-grain rice examined in this study were good.

Correlation analysis of quality characteristics

The correlations among the quality indicators are shown in **Figure 2**.

AC was strongly associated with GC and their correlation was inversely correlated. The correlation coefficient recorded between these two indicators was -0.85. This meant that the lower the AC, the greater the GC, the more flexible the rice, and vice versa. This result was similarly recorded in previous studies (Lapitan *et al*., 2009; Ritika *et al*., 2010; Zhang *et al*., 2020). Therefore, when determining AC or GC, researchers can predict the range of the remaining indicator. Moreover, within the same AC group, the rice varieties with a softer GC are preferred (Morgante & Olivieri, 1993; Hirano *et al*., 1998; Nguyen Ngoc De, 2008).

AC was not significantly correlated with the scale of GT and their correlation tended to be



Note: Statistics at 95% significance level; AC: Amylose Content; GT: Gelatinization Temperature; GC: Gel Consistency; HR: the ratio of head rice; PC: Percentage of Chalkiness.

Figure 2. Correlations of the quality characteristics in the medium-grain rice

inverse, with a correlation coefficient of -0.19. This result is similar to the conclusions of Jennings *et al*. (1979), Hossaina *et al*. (2009), and Pang *et al*. (2016).

GT was positively correlated on average with GC, and the correlation coefficient between the two indicators was +0.46. The results showed that many varieties with a high scale of GT (low GT) corresponded with a long GC, however, there were still many exceptions. Many studies on the correlation between GT and GC have given different conclusions. Lapitan *et al*. (2009) said that the correlation between these two indicators was low but significant (+0.18), while, Yang *et al*. (2020) concluded that the correlation was average (+0.42).

PC was strongly related to HR and their correlation was inverse, with a correlation coefficient of -0.75. This meant that the higher the PC of a rice variety, the lower the HR or recovery rate. This correlation has also been recognized across many studies (Nguyen Ngoc De, 2008; Liu *et al*., 2015; Sreenivasulu *et al*., 2015; Zhou *et al*., 2015; Yue *et al*., 2020). The cause of this phenomenon can be explained by the disjointed arrangement of starch granules in the chalkiness area. Starch granules have a less tight structure and create air-filled gaps between the starch particles. As a result, this phenomenon contributes to the cracking of rice grains during milling (Nagato, 1962; Nguyen Ngoc De, 2008; Lin *et al*., 2017).

PC and AC had a low correlation, with the correlation coefficient being +0.31. This low correlation was also confirmed in the studies of Nkori Kibanda & Luzi-Kihupi (2007), Zhu *et al*. (2020), and Yue *et al*. (2020).

In addition, PC was weakly correlated with GT and GC, and HR was weakly related to AC, GT, and GC.

Conclusions

In the medium-grain rice, AC was strongly correlated with GC, and PC was significantly related to HR. GT and GC had an average correlation. The correlations of the other quality indicators were not significant. The range of quality traits and their correlations in the medium-grain rice varieties did not have remarkable differences compared to the results of the ranges and correlations of the quality traits in earlier studies. This study provides basic information on the quality indicators of medium-grain rice and can serve as a reference to help breeders comprehend medium-grain rice for breeding and selection.

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References

Bao J. (2014). Genes and QTLs for rice grain quality improvement. In: Severino V. (Ed). Rice Germplasm. Genetics and Improvement. (Oakville, ON: Delve Publishing LLC), 318p.

Champagne E. T., Bett-Garber K. L., McClung A. M. & Bergman C. J. (2004). Sensory characteristics of diverse rice cultivars as influenced by genetic and environmental factors. Cereal Chemistry. 81(2): 237-243.

Chemutai L. R., Musyoki M. A., Kioko W. F., Mwenda N. S., Muriira K. G. & Piero N. M. (2016) Physicochemical characterization of selected rice (*Oryza sativa* L.) genotypes based on gel consistency and alkali digestion. Biochemistry & Analytical Biochemistry. 5: 285.

Cnossen A. G., Jiménez M. J & Siebenmorgen T. J. (2003). Rice fissuring response to high drying and tempering temperatures. Journal of Food Engineering. 59: 61-69.

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

Custodio M. C., Cuevas R. P., Ynion J., Laborte A. G., Velasco M. L. & Demont M. (2019). Rice quality: How is it defined by consumers, industry, food scientists, and geneticists? Trends in Food Science and Technology. 92: 122-137.

Del Rosario A. R., Briones V. P., Vidal A. J. & Juliano B. O. (1968). Composition and endosperm structure of developing and mature rice kernel. Cereal Chemistry. 45: 225-235.

Demont M., Fiamohe R. & Kinkpé A. T. (2017). Comparative advantage in demand and the development of rice value chains in West Africa. World Development. 96: 578-590.

FAO (Food and Agriculture Organization). (1998). Grain losses in rice processing. Retrieved from http://www.fao.org/3/x5427e/x5427e0h.htm on April 20, 2021.

Ferdous N., Eliasb S. M., Howladerb Z. H., Biswasc S. K., Rahmand MdS., Habibae K. K. & Serajb Z. I. (2018). Profiling Bangladeshi rice diversity based on grain size and amylose content using molecular markers. Current Plant Biology. 14: 56-65.

Graham R. D. (2002). A Proposal for IRRI to Establish a Grain Quality and Nutrition Research Center. IRRI Discussion Paper Series, No. 44, International Rice Research Institute, Manila, Philippines.

Guo T., Liu X., Wan X., Weng J., Liu S., Liu X., Chen M., Li J., Su N., Wu F., Cheng Z., Guo X., Lei C., Wang J., Jiang L. & Wan J. (2011). Identification of a stable quantitative trait locus for percentage grains with white chalkiness in rice (*Oryza sativa*). Journal of Integrative Plant Biology. 53: 598-607.

Hirano H. Y. & Sano Y. (1998). Enhancement of Wx gene expression and the accumulation of amylose in response to cool temperatures during seed development in rice. Plant Cell Physiology. 39: 807-812.

Hossain M. S., Singh A.K. & Fasih-uz-Zaman. (2009). Cooking and eating characteristics of some newly identified inter sub-specific (indica/japonica) rice hybrids. Science Asia. 35: 320-325.

IRRI (International Rice Research Institute). (1996). Standard evaluation system for rice (4th ed.). IRRI, Los Banos, Philippines: 40 pages.

IRRI (International Rice Research Institute). (2006). Rice knowledge bank. Retrieved from http://www.knowledgebank.irri.org on December 20, 2021.

IRRI (International Rice Research Institute). (2014). Standard evaluation system for rice (5th ed.). IRRI, Los Banos, Philippines: 57 pages.

Jennings P. R., Coman W. R. & Kauman H. E. (1979). Rice improvement. International Rice Research Institute, Los Banos, Philippines.

Juliano B. O. (1971). A simplified assay for milled-rice amylose. Cereal Science Today. 16: 334-340.

Juliano B. O. (1985). Criteria and Tests for Rice Grain Qualities. In: Rice Chemistry and Technology, 2nd Edition, American Association of Cereal Chemists, 443-524.

Juliano B. O. (1992). Rice starch properties and grain quality. Denpun Kagaku. 39(l): 11-21.

Juliano B. & Villareal C. (1993). Grain quality evaluation of world rice. The Philippines: International Rice Research Institute.

Lang N. T., Giang P. H. T., Ha P. T. T., Toan T. B., Phuong T. A. & Buu B. C. (2017). Identifying the grain chalkiness gene using molecular marker techniques in rice (*Oryza sativa* L.). International Letters of Natural Sciences. 63: 18-26.

Lapitan V. C., Redoña E. D., Abe T. & Brar D. S. (2009). Mapping of quantitative trait loci using a doubled-haploid population from the cross of indica and japonica cultivars of rice. Crop Science. 49: 1620-1628.

Lapis J. R., Cuevas R. P. O., Sreenivasulu N. & Molina L. (2019). Measuring Head Rice Recovery in Rice. Methods in Molecular Biology. 1892: 89-98.

Lin Z., Zhang X., Wang Z., Jiang Y., Liu Z., Alexander D., Li G., Wang S. & Ding Y. (2017). Metabolomic analysis of pathways related to rice grain chalkiness by a notched-belly mutant with high occurrence of white-belly grains. BMC Plant Biology. 17(39): 1-15.

Liu Y., Wang L., Deng M., Li Z., Lu Y., Wang J., Wei Y. & Zheng Y. (2015). Genome-wide association study of phosphorus-deficiency-tolerance traits in Aegilops tauschii. Theoretical and Applied Genetics. 128: 2203-2212.

Manners D. J. (1979). The enzymic degradation of starches. In: Blanshard J. M. V. & Mitchell J. R. (Eds.). Polysaccharides in food. London: Butterworths: 75-91.

Misra G., Anacleto R., Badoni S., Butardo Jr V. M., Molina L., Graner A., Demont M., Morell M. K. & Sreenivasulu N. (2019). Dissecting the genome-wide genetic variants of milling and appearance quality traits in rice. Journal of Experimental Botany. 70(19): 5115-5130.

Morgante M. & Olivieri A.M. (1993). PCR - amplified microsatellites as markers in plant genetics. The Plant Journal. 1: 175-182.

Nagato K. (1962). On the hardness of rice endosperm (In Japanese with summary in English). Proceedings of the Crop Science Society of Japan. 31: 102.

Nkori Kibanda J. M. & Luzi-Kihupi A. (2007). Influence of genetic and genotype x environment interaction on quality of rice grain. African Crop Science Journal. 15(4): 173-182.

Nguyen Ngoc De (2008). Book of rice. National University of Vietnam, Ho Chi Minh city, 243 pages (in Vietnamese).

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.

Patindol J. A., Siebenmorgen T. J. & Wang Y. J. (2015). Impact of environmental factors on rice starch structure: A review. Starch/Starke. 67: 42-54.

Qian Q., Guo L., Smith S. M. & Li J. (2016). Breeding high-yield superior quality hybrid super rice by rational design. National Science Review. 3(3): 283-294.

R Core Team (2015). R: A Language and Environment for Statistical Computing (version 3.2.1). Vienna, Austria:

R Foundation for Statistical Computing. Retrieved from http://www.R-project.org/ on August 16, 2020.

Raju G. N., Manjunath N. & Srinivas T. (1991). Grain chalkiness in cereals. Tropical Science. 31: 407-415.

Regina A., Bird A., Topping D., Bowden S., Freeman J., Barsby T., Kosar-Hashemi B., Li Z., Rahman S. & Morell M. (2006). High-amylose wheat generated by RNA interference improves indices of large-bowel health in rats. Proceedings of the National Academy of Sciences. 103: 3546-3551.

Ritika B. Y., Khatkar B. S. & Yadav B. S. (2010). Physicochemical, morphological, thermal and pasting properties of starches isolated from rice cultivars grown in india. International Journal of Food Properties. 13(6): 1339-1354.

Siebenmorgen T. J., Bautista R. C. & Meullenet J. F. (2006). Predicting rice physicochemical properties using thickness fraction properties. Cereal Chemistry. 83(3): 275-283.

Sreenivasulu N., Butardo V. M., Misra G., Cuevas R. P., Anacleto R. & Kavi-Kishor P. B. (2015). Designing climate-resilient rice with ideal grain quality suited for high-temperature stress. Journal of Experimental Botany. 66: 1737-1748.

Tanabata T., Shibaya T., Hori K., Ebana K. & Yano M. (2012). SmartGrain: high-throughput phenotyping software for measuring seed shape through image analysis. Plant Physiology. 160(4): 1871-1880.

Tang S. X., Khush G. S. & Juliano B. O. (1991). Genetics of gel consistency in rice (*Oryza sativa* L.). Journal of Genetics. 70: 69-78.

Vandeputte G. E. & Delcour J. A. (2004). From sucrose to starch granule to starch physical behaviour: a focus on rice starch. Carbohydrate Polymers. 58: 245-266.

Wang J., Wan X., Li H., Pfeiffer W. H., Crouch J. & Wan J. (2007). Application of identified QTL-marker associations in rice quality improvement through a design-breeding approach. Theoretical and Applied Genetics. 115: 87-100.

Wang C., Chen S. & Yu S. (2011). Functional markers developed from multiple loci in gs3 for fine marker-assisted selection of grain length in rice. Theoretical and Applied Genetics. 122(5): 905-913.

Wailes E. J. & Chavez E. C. (2015). International rice outlook, baseline projections, 2014-2024 (Staff papers 199846). USA: University of Arkansas.

Yang Y., Xu X., Zhang M., Xu Q., Feng Y., Yuan X., Yu H., Wang Y. & Wei X. (2020). Genetic basis dissection for eating and cooking qualities of japonica rice in Northeast China. Agronomy. 10: 423.

Yue C., Meng-meng Z., Zheng-jin X. & Wen-fu C. (2020). The breeding of japonica rice in northern China: An 11-year study (2006-2016). Journal of Integrative Agriculture. 19(8): 1941-1946.

Zhang A., Gao Y., Li Y., Ruan B., Yang S., Liu C., Zhang B., Jiang H., Fang G., Ding S., Jahan N., Xie L., Dong G., Xu Z., Gao Z., Guo L. & Qian Q. (2020). Genetic analysis for cooking and eating quality of super rice and fine mapping of a novel locus QGC10 for gel consistency. Frontiers in Plant Science. 11: 342.

Zhao X., & Fitzgerald M. (2013). Climate change: Implications for the yield of edible rice. PLoS One. 8(6): e66218.

Zhou L., Liang S., Ponce K., Marundon S., Ye G. & Zhao X. (2015). Factors affecting head rice yield and chalkiness in indica rice. Field Crops Research. 172: 1-10.

Zhu H., Liang K., Qiu J., Wang J. & Ji Z. (2020). Variability in nutritional composition, kernel morphology and cooking quality of selected rice in Xingan Meng from Northeast China. E3S Web of Conferences. 189: 02024.