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**RESEARCH ARTICLE**

# The index traits for palatability of rice under high temperatures during the ripening period in Japan

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## Abstract

To clarify the index traits for evaluating the eating quality of rice produced under high-temperatures, during the ripening period in Japan, the relationship between palatability and appearance quality, grain size, grain weight, and physicochemical properties of rice produced over a wide range of areas were analyzed and its factors were investigated. Palatability was positively correlated with the percentage of perfect rice grain (as an indicator of appearance quality) and grain thickness of brown rice; palatability deteriorated when the percentage of perfect rice grain was < 60%. On the other hand, there was no significant relationship between palatability and grain length, width, protein content of brown rice, and amylose content of milled rice. Palatability was negatively correlated with the hardness/adhesion (H/-H) ratio in texture characteristics of cooked rice (an effective indicator of palatability). A quadratic curve relationship between palatability and moisture content of brown rice (MR) was observed. It was concluded that MR was neither too high nor too low for palatability and that the suitable moisture content from the viewpoint of palatability is 14.0-15.0%. The differences in palatability due to differences in MR were larger than those due to differences in the production area, suggesting that moisture content was a primary factor in the differences in palatability among districts. These results indicate that, as indicator traits for evaluating the eating quality of rice produced under high-temperatures during the ripening period, the percentage of perfect grain and thickness of brown rice grain is effective for grain traits, and the H/-H ratio of cooked rice and MR are effective for physicochemical properties. The findings of this study can be used to select highly palatable rice cultivars with heat temperature tolerance and for index traits for highly palatable rice production.

**Keywords:** palatability; moisture content; H/-H ratio; physicochemical properties; during the ripening period; rice.

## 1. Introduction

Rice (*Oryza sativa* L.) is one of the world's most important food crops and is a staple food in Japan, where yield, appearance quality, and palatability are the main objectives of rice breeding and cultivation. Palatability is the most important trait in situations in which there is severe competition between producing regions (Ono 2008; Aoyagi *et al*., 2010). Palatability, as described here, refers to the overall eating-quality as evaluated using a sensory test. Currently, deterioration of appearance quality (Terashima *et al*., 2001; Wakamatsu *et al*., 2007; Morita *et al*., 2016) and palatability (Oh-e *et al*., 2007; Matsue, 2012) due to abnormally high temperatures during the

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ripening period have become serious problems for rice farmers in Japan (MAFF, 2006). Therefore, it is urgent to establish highly palatable rice production technology to avoid or overcome damage from high-temperature ripening.

Appearance quality due to high-temperature ripening damage results in a decrease in the percentage of perfect grain (Wakamats *et. al*., 2007; Tashiro and Wardlaw, 1991) and grain weight (Tashiro and Wardlaw, 1989; Nagato and Ebata, 1960) due to high occurrence of chalky and translucent rice. Grain size (length, width, thickness) will also be smaller (Nagato and Ebata, 1965; Tashiro and Wardlaw, 1991). In addition, the appearance quality is greatly influenced by physicochemical properties (Matsue and Ogata, 1997). Regarding palatability, the overall eating-quality of cooked rice is inferior due to poor appearance (decreased whiteness and gloss), decreased stickiness, and increased hardness (Oh-e *et al*., 2007; Matsue 2012). On the other hand, it has been reported that the maximum viscosity and breakdown of amylographic characteristics and amylose content (Matsue, 2012), which were recognized as index traits for eating quality, cannot be valid index traits under high-temperature ripening conditions.

Although there have been many studies on the relationship between palatability and physicochemical properties of rice, little is known about the relationship between the palatability and percentage of perfect grain, grain size, grain weight, and physicochemical properties of rice produced and their factors under the high-temperature ripening conditions that have become a problem in recent years. To develop highly palatable rice production technology for high-temperature ripening, it is important to clarify the index traits for eating quality evaluation based on the relationship between the palatability of rice produced over a wide area and the degree of grain development and physicochemical properties. Therefore, to clarify the index traits for evaluating eating quality under high-temperature ripening conditions, this study analyzed the relationship between the eating quality of rice and the percentage of perfect grain, grain size, 1,000-grains weight and physicochemical properties of rice, and also investigated the factors that contribute to the eating quality of rice. The indicator traits for rice eating quality elucidated in this study can be used for the selection of heat-tolerant and highly palatable rice cultivars and for target traits for highly palatable rice production technology. Furthermore, it can be used as effective knowledge on how to dry paddy rice and sort of brown rice grain thickness to produce highly palatable rice.

## 2. Materials and Methods

### *2.1. Production district*

Rice from the growing regions used in this study were produced in 2014 and 2015 at four of Japan’s leading large-scale rice farms (agricultural production corporations). As shown in Table 1, four large-scale rice farms utilized in this study were Yokotanojo Co. Ltd. (35°54′N, 140°14′E) in Ryugasaki city, Ibaraki Prefecture, Buttanosan Co. Ltd. (36°51′N, 136°60′E) in Nono city, Ishikawa Prefecture, Fukuhara farm Co. Ltd. (35°27′N, 136°25′E ) in Hikone city, Shiga Prefecture, and AGL Co. Ltd. (32°58′N, 131°03′E) in Aso city, Kumamoto Prefecture. The paddy rice cultivation areas were 125 ha in Yokotanojo, 28 ha in Buttanosan, 165 ha in Fukuhara farm, and 21.2 ha in AGL.

### *2.2. Plant materials and treatments*

The highly palatable *japonica* cultivar of rice (*Oryza sativa* L.), Koshihikari was used in this study. The planting area of Koshihikari has been the largest in Japan since 1979. Cultivation management followed the conventional cultivation standards in each region. The number of paddy fields for Koshihikari used for each production area is shown in Table 1. The paddy collected from four production areas was turned into brown rice by a small hulling machine FC2K (Otake Co., Ltd., Aichi, Japan). Brown rice grains were used for determining the percentage of a perfect rice grain, grain size**,** 1,000-grain weight, physicochemical properties, for conducting the sensory test, and had a thickness of > 1.85 mm.

### *2.3. Grain size, 1,000-grain weight, percentage of perfect rice grain, and physicochemical properties*

Length, width, and thickness of brown rice grain were measured using a grain shape tester (Kett Electric Laboratory, Tokyo, Japan) for 30 grains and expressed as a mean value. The 1,000-grain weight of brown rice was calculated by converting 20g of brown rice into the number of grains and expressed as an average of three measurements. The percentage of perfect rice grain, an indicator of appearance quality (MAFF, 2020) was measured with a Grain Quality Inspector RGQI 20A (Satake Co., Ltd., Hiroshima, Japan). The protein content of brown rice was measured with an Infratec1241 Grain Analyser (Foss Japan Co., Ltd., Tokyo, Japan) and values were adjusted to a moisture content of 15%. The amylose content of milled rice was measured with an Auto Analyzer type-II (Bran+Luebbe Co. Ltd., Germany). Milling was done prior to the test to the extent of a 91% milling rate. The texture characteristics and hardness/adhesion ratio (H/-H ratio) of cooked rice (an effective indicator of palatability) were measured with a Tensipresser My Boy2 (Taketomo Electric Inc., Tokyo, Japan). The moisture content of brown rice (MR) was measured with Rice Moisture Tester f2 (Kett Electric Laboratory, Tokyo, Japan).

### *2.4. Sensory test*

The palatability evaluation of cooked rice was evaluated by the Matsue method (Matsue 1992), which is a modified version of the Food Agency method (Ministry of Agriculture and Forestry, Food Agency 1968). The check cultivar for the sensory tests was Hinohikari produced in Fukuoka Prefecture. The evaluation panel consisted of 20 university faculty members at Kyushu University. The following five sensory attributes were evaluated by the 20 panel members: overall eating-quality, appearance, stickiness, taste, and hardness. Five sensory attributes were classified into seven stages compared with a check cultivar; −3 (considerably poor), −2 (poor), −1 (slightly poor), 0 (no difference), +1 (good), +2 (very good), and +3 (excellent) for overall eating-quality, appearance and taste; −3 (considerably weak) ~+3 (considerably strong) for stickiness; and −3 (considerably soft) ~+3 (considerably hard) for hardness.

### *2.5. The average temperature during the ripening period*

The average temperature during the ripening period was calculated from the AMeDAS meteorological data of the Japan Meteorological Agency in each region. The average temperature during the ripening period is the average daily mean temperature during 20 days after heading.

### *2.6. Statistical analysis*

Correlation coefficients were determined by Pearson’s correlation coefficient test. An ANOVA was used in conjunction with Tukey–Kramer to test for significant differences. All statistical analysis was performed with the software statistical analysis system (Statcel-the Useful Addin Forms on Excel-3rd ed., 2012, OMS Publishing Ltd., Tokyo, Japan).

## 3. Results

### *3.1. The average temperature during the ripening period*

The average temperature during the ripening period in each production district is shown in Table 1. Except for AGL in Kyushu district, the average temperatures during ripening period in the three regions were extremely, above 26 ℃ in both 2014 and 2015. The average temperature during the ripening period in the three production areas was higher than 26 °C, which is the temperature that adversely affects the appearance quality (Terashima *et al.*, 2001; Wakamatsu *et al.*, 2007; Morita *et al.*, 2016) and palatability (Matsue, 2012).

**Table 1.** Number of test paddy fields of Koshihikari and average temperature during ripening period per production district.

| Production year | Production district | Agricultural production corporations (L) | Number of test paddy fields of Koshihikari | Average temperature during ripening period* (℃) |
|---|---|---|---|---|
| 2014 | Kanto | Yokotanojo | 9 | 26.7 |
| | Hokuriku | Buttanousan | 9 | 27.3 |
| | Kansai | Fukuhara farm | 14 | 27.2 |
| | Kyushu | AGL | 5 | 23.8 |
| 2015 | Kanto | Yokotanojo | 28 | 27.2 |
| | Hokuriku | Buttanousan | 24 | 27.2 |
| | Kansai | Fukuhara farm | 18 | 28.4 |

**: Average daily mean temperature during 20 days after*

### *3.2. Relationship between palatability, percentage of perfect rice grains, and grain size, 1,000-grains weight of brown rice*

A significant positive correlation was observed between palatability and the percentage of perfect rice grains, as an indicator of appearance quality, and a deterioration in palatability was observed when the percentage of perfect rice grains was <60%. (Figure. 1). Regarding the relationship between palatability and grain size of brown rice, there was no significant relationship between length (Figure. 2) and width (Figure. 3) of brown rice and palatability. There was a significant positive correlation between palatability and grain thickness of brown rice in both 2014 and 2015, and palatability tended to be inferior when brown rice grain thickness was < 2.04 mm (Figure. 4). No significant correlation was found between the 1,000-grain weight of brown rice and palatability in both years (Figure.5).

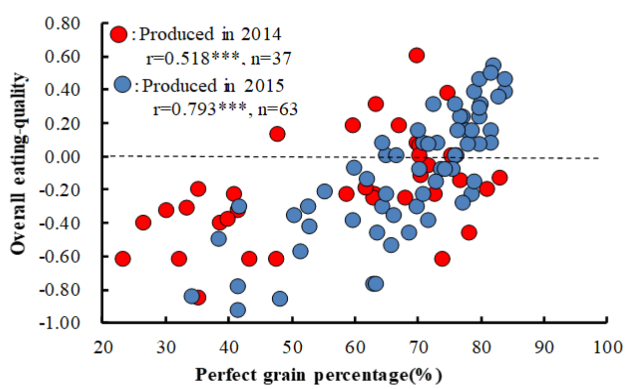


**Figure 1.** Relationship between overall eating-quality and perfect grain percentage

The check cultivar (0.00) for the sensory test was Hinohikari

***: Significant at P<0.001

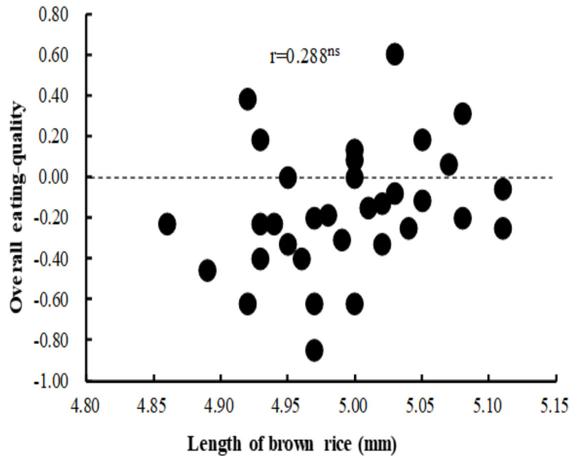


**Figure.2** Relationship between overall eating-quality and length of brown rice produced in 2014

The check cultivar (0.00) for the sensory test was Hinohikari
ns: Not significant

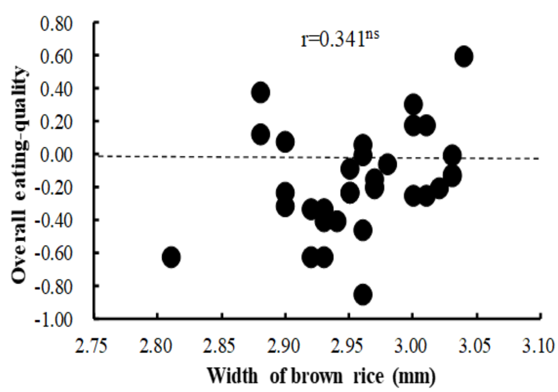


**Figure. 3** Relationship between overall eating-quality and width of brown rice produced in 2014.

The check cultivar (0.00) for the sensory test was Hinohikari.

ns: Not significant.

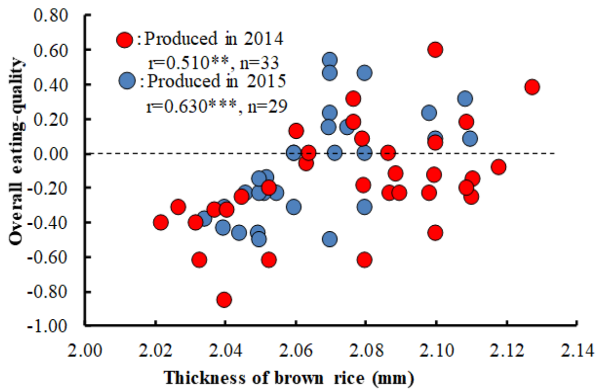


**Figure.4** Relationship between overall eating-quality and thickness of brown rice.

The check cultivar (0.00) for the sensory test was Hinohikari.

***, **: Significant at P<0.001 and 0.01, respectively.

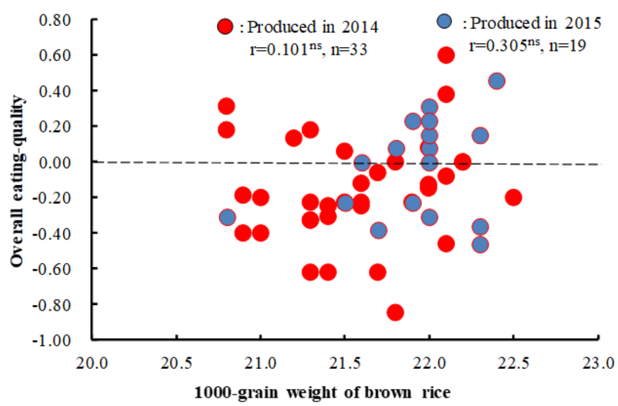


**Figure.5** Relationship between overall eating-quality and 1000-grain weight of brown rice.

The check cultivar (0.00) for the sensory test was Hinohikari.

ns: Not significant.

### *3.3. Relationship between palatability and physicochemical properties*

There was no significant correlation between palatability and protein content in both 2014 and 2015 (Figure 6). There was also no significant correlation between amylose content and palatability (Figure 7). The H /-H ratio, as an indicator of the food texture of cooked rice, had a significant negative correlation with palatability, i.e., palatability tended to be improved with a smaller H/-H ratio (Figure 8). Fig.9 shows the relationship between the moisture content of brown rice (MR) after harvesting and drying and palatability. In the case of the same cultivar, a quadratic curve relationship between palatability and MR was observed, and the area from 14.7%

and 14.6% of MR reached the peak of palatability for two years. In addition, the palatability level got poorer as the MR level became greater than 15% or smaller than 13.5%. In particular, when MR was < 13.0%, the palatability of the cooked rice was inferior due to its remarkably weakened stickiness and too-soft hardness. Furthermore, to compare the effect of differences in agricultural production corporations on palatability and the difference in palatability due to the difference in MR, Table 3 result shows that analysis of variance of palatability at three agricultural production corporations based on two MR levels (< 13.5% and > 13.6%) (Table 3). The mean squares value was higher for MR than agricultural production corporations in both years. A significant negative correlation was found between MR and the H/-H ratio throughout the two years (Figure 10).

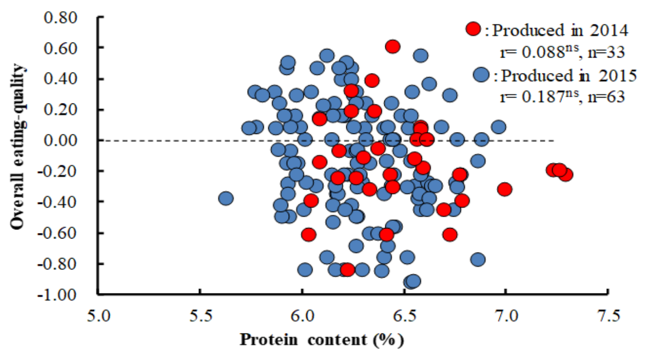


**Figure.6** Relationship between overall eating-quality and protein content of brown rice.

The check cultivar (0.00) for the sensory test was Hinohikari.
ns: Not significant.

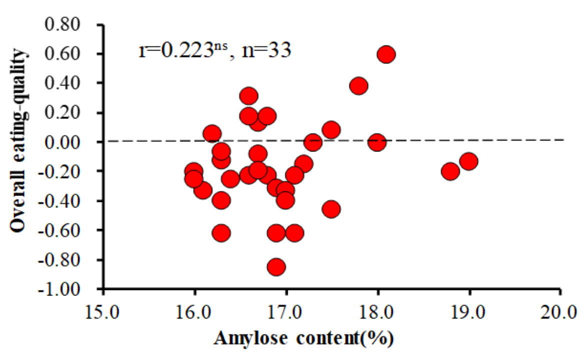


**Figure.7** Relationship between overall eating-quality and amylose content of the milled rice produced in 2014.

The check cultivar (0.00) for the sensory test was Hinohikari.
ns: Not significant.

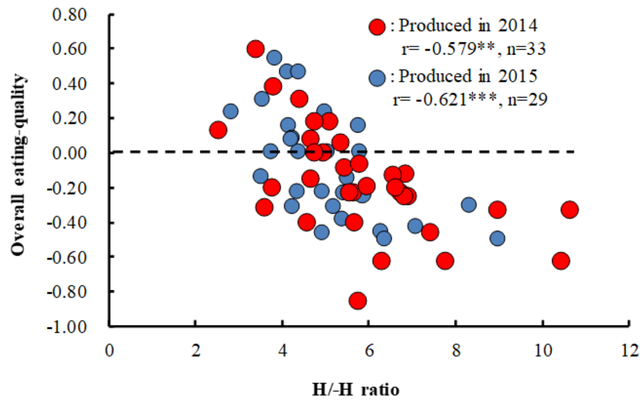


**Figure.8** Relationship between overall eating-quality and H/-H ratio of cooked rice.

The check cultivar (0.00) for the sensory test was Hinohikari.

*: Significant at P<0.05.

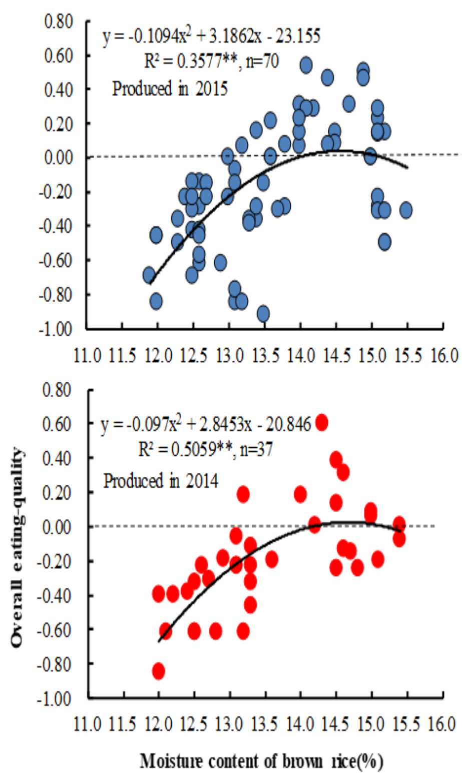


**Figure.9** Relationship between overall eating-quality and moisture content of brown rice.

The check cultivar (0.00) for the sensory test was Hinohikari.

***, **: Significant at P<0.001 and 0.01, respectively.

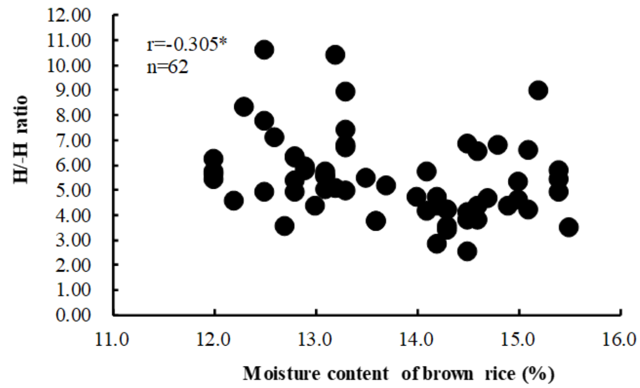


**Figure. 10** Relationship between moisture content of brown rice and H/-H ratio of cooked rice produced in 2019 and 2020.

*: Significant at P<0.005.

**Table 2.** Analysis of variance for the palatability and component of variance between agricultural production corporations and moisture content of the brown rice.

| Production year | Source of variance | df | Mean squares | F |
|---|---|---|---|---|
| 2014 | Total | 29 | | |
| | Agricultural production corporations (L) | 2 | 0.378 | 6.85** |
| | Moisture content of the brown rice (G) | 1 | 0.531 | 9.63** |
| | L×G | 2 | 0.125 | $2.27^{ns}$ |
| | Error | 24 | 0.055 | |
| 2015 | Total | 28 | | |
| | Agricultural production corporations (L) | 2 | 0.126 | $2.16^{ns}$ |
| | Moisture content of the brown rice (G) | 1 | 0.608 | 10.46** |
| | L×G | 2 | 0.204 | 3.50* |
| | Error | 23 | 0.058 | |

**, **: Significant atP<0.05 and P<0.01, respectively. ns: Not significant.*

### *3.4. Multiple linear regression analysis of palatability for physicochemical properties*

A multiple regression analysis was performed using the four physicochemical properties related to palatability as explanatory variables and palatability as the objective variable. Table 3 shows the standard partial regression coefficient for protein content, amylose content the MR, and H/-H ratio against the overall eating-quality of cooked rice. The standard partial regression coefficients against palatability were high values for the H/-H ratio (-0.435, -0.471) and MR (0.469, 0.304) in both 2014 and 2015. On the other hand, the standard partial regression coefficients against palatability were low values for protein content (-0.035, -0.172) and amylose content (0.027). The contributions of the H/-H ratio and MR estimated from the ratio of standard partial regression coefficients were 45%, 50%, and 49%, 32%, respectively, with the H/-H ratio and MR making the largest contribution to overall eating-quality. The contributions of protein and amylose content were 4%, 18%, and 3%, respectively, protein and amylose content making the smallest contribution to overall eating-quality.

**Table 3.** Standard partial regression coefficient for percentage of perfect rice grain, thickness and moisture content of brown rice and physicochemical properties against the overall eating-quality.

| Production year | Protein content | Amylose content | H/-H ratio | Moisture content of brown rice |
|---|---|---|---|---|
| 2014 R=0.740***, n=33 | -0.035$^{ns}$ (3.6$^{\#}$) | 0.027$^{ns}$ (2.6) | -0.435** (45.1) | 0.469** (48.7) |
| 2015 R=0.709***, n=29 | -0.172$^{ns}$ (18.1) | - - | -0.471** (49.8) | 0.304* (32.1) |

*R: Multiple correlation coefficient.*

****,**, *, : Significant at P< 0.001, 0.01 and 0.0 5, respectively.*

*ns: Not significant.*

*#: Contribution estimated from the ratio of standard partial regression coefficients*

## 4. Discussion

Deterioration of appearance quality and palatability due to abnormally high temperatures during the ripening period have become serious problems for rice farmers in Japan (MAFF, 2006). Therefore, it is urgent to establish highly palatable rice production technology to avoid or overcome damage from high-temperature ripening. In this study, to clarify the index traits for evaluating eating quality under high-temperature ripening conditions, this study analyzed the relationship between the eating quality of rice collected from many fields over a wide area in Japan and the percentage of perfect grain, grain size, 1,000-grain weight. In addition, the relationship between physicochemical properties was analyzed and the factors contributing to the eating quality of rice were also examined.

### *4.1. Relationship between palatability, percentage of perfect rice grains, and grain shape of brown rice*

In Japan, appearance quality is determined by inspection grade. The inspection grade consists of three grades: first grade (percentage of perfect rice grains of 70% or more), second grade (percentage of perfect rice grains of 60% or more), or third grade (percentage of perfect rice grains of 40% or more). In this study, it was found that the first grade did not adversely affect palatability within the same cultivar, whereas the second grade had inferior palatability. For this reason, it is necessary to ensure that the percentage of perfect rice grains is 70% or more for the production of highly palatable rice. The harvesting time has a great influence on appearance quality and palatability, and there is a difference among cultivars in the range of the optimum harvesting time in terms of quality (Matsue *et al*., 1991). Therefore, large-scale rice farmers with long paddy rice cultivation periods need to introduce cultivars with a wide range of harvesting times to carry out the optimum harvesting. Regarding the grain thickness of brown rice, the thicker the grain, the higher the palatability. Therefore, it is useful to implement Matsue et al.'s (2021) saturated irrigation, which is effective for brown rice thickening under high-temperature during the ripening period. In rice cultivated under certain cultivation conditions, it has been shown that the thicker the grain, the lower the H/-H ratio (Matsue *et al*., 2001). Since the present study showed a positive correlation between palatability and grain thickness and a negative relationship between palatability and the H/-H ratio, it is considered that one of the reasons for the excellent palatability due to the thickening of brown rice is the decrease in the H/-H ratio. Therefore, to produce highly palatable rice, it is important to improve the percentage of ripened grains and to produce brown rice with a thick grain thickness. Furthermore, the percentage of perfect rice grains and grain thickness are suitable as indicator traits to assess eating quality even under a high temperature during the ripening period.

### *4.2. Relationship between palatability and physicochemical properties*

In general, protein and amylose contents are negatively correlated with palatability (Chikubu *et al*., 1983; Inatsu, 1988; Matsue, 1993), however, this relationship was not observed in this study. It has been reported that the upper limit of the suitable value of protein content from the viewpoint of palatability is approximately 7% (Kondo and Nozoe, 1993; Iwabuchi *et al*., 2001). Most of the brown rice tested in this study had a protein content of < 7.0%. It has also been shown by Matsue *et al*., (2024) that protein content dose not affect on eating quality among highly palatable rice cultivars. Therefore, the reason why the significant relationship between the protein content and palatability was not established in this study is that the protein content of brown rice was within the range of the suitable value according to palatability. Until now, the range of variation in amylose content, when a significant relationship with palatability has been observed so far, mostly ranged from 16-23% (Inatsu, 1988; Matsue, 1993). The variation in amylose content in the present study was smaller than previously reported, ranging from 16-19%. In addition, it has been found that the amylose content is not suitable as an indicator trait for evaluation of palatability because the amylose content remarkably decreases under a high temperature during the ripening period (Matsue, 2012). Therefore, the reason that this significant relationship between amylose content and palatability was not established in this study is because of the small fluctuation range and a decrease in amylose content due to a high temperature during the ripening period. The H/-H ratio was negatively correlated with eating quality, which is consistent with previously reported results (Endo et al., 1980; Matsue *et al*., 2004; Matsue, 2012). Thus, the H/-H ratio can be an effective indicator for the evaluation of palatability across a wide area under high-temperature conditions. In addition, since the H/-H ratio is affected by the appearance quality and grain thickness of brown rice (Matsue and Ogata, 1997), the thickening of grain-thickness and the increase of percentage of perfect rice grains are important for improving the H/-H ratio.

### *4.3. Relationship between palatability and moisture content of brown rice after harvesting, drying and processing*

Although many studies on drying temperature, drying method, and palatability have been reported (Shimura *et al*., 1974; Kasahara *et al*., 1989; Fukai *et al*., 2007), there have been no reports on the relationship between MR and palatability. Although it has been empirically stated that the optimal MR is 15%, for the first time this study clarified the relationship between MR and palatability. Based on the results of this study, it was concluded that MR was neither too high nor too low for palatability and that the suitable moisture content from the viewpoint of palatability is 14.0-15.0%. It has been reported that cultivars are the most important factors influencing palatability at the rice production stage, followed by the production area and climatic conditions (Chikubu, 1987). However, as a result of a comparative study of the production area and MR in this undertaking, the influence of the MR was greater than that of the production area. This suggests that MR is the main cause of the locational differences in palatability across in a wide area under high temperatures during the ripening period. Therefore, awareness that MR is not just water, but rather is one of the most important elements of palatability, and is more important than other physicochemical properties, is necessary. In addition, the reason for the decrease in eating quality due to lower MR is thought to be that as MR decreases, the H/-H ratio increases, resulting in a weaker stickiness and poor texture, as shown in Figure 10.

## 5. Conclusion

Under the high temperature during the ripening period in Japan, effective indicator traits for evaluating the eating quality of rice produced over a wide range of areas are the percentage of perfect rice grain and brown rice grain thickness for grain characteristics, and MR and the H/-H ratio of texture characteristics of cooked rice for physicochemical properties. Rice protein and amylose content are not suitable as indicator traits.


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**Authors' Contributions**

*All authors contributed in this research*

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**Institutional Review Board Statement**

*All Institutional Review Board Statements are confirmed and approved.*

**Data Availability Statement**

*Data presented in this study are available on fair request from the respective author.*

**Ethics Approval and Consent to Participate**

*Not applicable*

**Consent for Publication**

*Not applicable.*

**Conflicts of Interest**

*The authors disclosed no conflict of interest.*


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