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Effect of Types of Cooking Water on the Palatability and Physicochemical Properties of Chinese *Japonica–Type* Rice Cultivars

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This study was undertaken to determine the effect of types of cooking water on the palatability of Chinese *japonica–type* rice cultivars. Changes in physicochemical properties of rice affected by cooking water were also explored. Results showed that all cultivars had improved palatability depending on types of cooking water. When cooked in water with low total hardness and conductivity, the overall eating–quality of cooked rice presented higher palatability compared with cooked in water with high total hardness and conductivity. Moreover, the effect of improved palatability varied with cultivar, with highly palatable cultivar had a smaller effect, whereas poorly palatable cultivar had a greater effect. Hardness/adhesion (H/–H) ratio of cooked rice was declined by using cooking water with low total hardness and mineral content compared with tap water and the effect of changes in types of cooking water on H/–H ratio was small for highly palatable rice but were large for moderately and low palatable cultivars. Correlation analysis showed that total hardness and conductivity of cooking water had a negative tendency with overall eating-quality of cooked rice for the tested cultivars, i.e. the harder and the greater conductivity the cooking water, the poor the palatability. On the other hand, there was no relationship between pH value of cooking water in the range of the experiment and overall eating–quality of cooked rice for the tested cultivars. Total hardness and conductivity of cooking water showed a positive correlation between H/–H ratio and breakdown and there was no constant relationship between pH value and physicochemical properties of rice. The standard partial regression coefficient against overall eating–quality was the highest for H/–H ratio in cooked rice (–0.689). Thus, the improvement in palatability by types of cooking water could be attributed to the reduced H/–H ratio of cooked rice due to the lower calcium content in rice.

Key words: Chinese *japonica–type* rice cultivar, Palatability, Physicochemical properties, Types of cooking water, Varietal difference

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important food crops and is a staple food in China. Eating quality, also known as palatability, is considered by consumers to be a quality trait of primary importance of cooked rice. Internationally, the concept of rice palatability originated in Japan, and recently, accompanied with the diversification of diet, the demand of the consumer for highly palatable rice is increasing and many researches on rice palatability are constantly emerging in China (Qi *et al*., 2019; Lu *et al*., 2019; Dou *et al*., 2018; Xu *et al*., 2018; Bian *et al*., 2018; Gu *et al*., 2015).

Palatability refers to people's evaluation of characteristics of cooked rice, including appearance, aroma, taste, stickiness and hardness of cooked rice. There are many factors that affect the palatability of rice. In addition to cultivar, production environment and cultivation technology, cooking methods also have been confirmed to have an effect on palatability and physicochemical properties of rice (Chmiel *et al*., 2018; Zhou *et al*., 2017; Thuengtung and Ogawa, 2020). Moreover, for rice is consumed after gelatinization by adding water during cooking process, it is also expected that types of cooking water may have an effect on the palatability of cooked rice. At present, in addition to the daily use of tap water, many types of drinking water have been developed on the market for people's health and safety such as drinking pure water, natural water and natural mineral water. With the improvement of people's health awareness, household water purifiers have gradually become popular, and the opportunity to use pure water for cooking rice has increased.

Hardness, pH and conductivity are important physical properties of water. The hardness of water is determined by the amount of calcium and magnesium contained in the water. These metal ions are present in water in the form of carbonate, sulfate and chloride. Among the properties of water, hardness has been proven to have a great influence on the palatability of rice. Mizuno and Takamura (2016) reported that wash-free rice cooked with Ca–rich Vittel (300 mg/L hardness) and Mg–rich deep–sea waters (330 and 700 mg/L hardness) were evaluated to be as delicious as wash–free rice cooked with distilled water. On the other hand, rice cooked with Contrex (1,560 mg/L hardness) and deep–sea water (3,200 mg/L hardness) were evaluated low in

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color and taste. The result by Ogawa *et al.* (2006) suggested that cooking rice with water containing 1.35 mM of calcium lactate inhibited the gelatinization of starch and the hardness of cooked rice was higher than that of rice cooked with distilled water, and the palatability was poor. However, the addition of sodium chloride in cooking water could promote water absorption and swelling of rice, thereby promoting starch gelatinization and improving the palatability of rice. In addition, Ogawa *et al.* (2013) also pointed out that the water absorption and volume increase of rice were facilitated by cooking in ion-exchanged water from which Ca had been removed by the water-softener, giving softer rice. Moreover, the effect of pH of cooking water on the palatability of rice had also been reported. The results of Kasai *et al.* (2001) showed that rice cooked with water containing 0.1 M of acetic acid was more glossy, transparent, sticky and soft than rice cooked only with water (control). As the concentration of acetic acid increased, the hardness of cooked rice decreased and the stickiness increased significantly. On the contrary, An *et al.* (2006) revealed that the edible quality of the milled rice conditioned by using a humidifier with alkaline water was slightly improved. After the condition, the pH of the cooked rice soup increased, the stickiness/hardness and the score of sensory evaluation of the cooked rice increased by 8.8% and 5.4% respectively. Conductivity indicates the ability of an aqueous solution to conduct current, and is closely related to the mineral content in the water. It can be used to detect changes in the concentration of dissolved minerals in water and estimate the amount of ionic compounds in the water. Kazuno *et al.* (2001) examined the effect of four brands of commercial mineral water, tap water and distilled water on rice taste, indicating that many responders had a bad impression on smell, transparency, color and taste of cooking rice with commercial mineral water, which is categorized to hard water and high concentrations of Ca were special attention in cooked rice with commercial mineral water which may affect the taste of cooked rice. Zhu *et al.* (2019) reported that the overall eating-quality of rice cooked with spring water was the best, followed by distilled water, and the palatability of rice cooked with tap water was the worst. The conductivities of the above water were 512.8±7.6, 38.5±1.6, and 483.7±8.7 µS/cm, respectively.

There are many types of drinking water, and their properties are also quite different. However, there is still a lack of systematic research on the effect of types of cooking water on the palatability and physicochemical properties of Chinese *japonica–type* rice cultivars, especially focused on whether the effect exists varietal difference. Additionally, it is generally recognized that the use of hard water with high calcium ion and magnesium ion content to cook rice prevents the rice grains from absorbing water and the gelatinization of starch, resulting in the higher hardness and poor palatability of cooked rice. However, there is controversy regarding the influence of water conductivity and pH on the palatability of rice. Therefore, in the present study, the effect of types of cooking water on the palatability of three Chinese *japonica–type* rice cultivars were determined by the combination of sensory test and physicochemical properties determination, using six types of cooking water. Moreover, the relationship between physical parameters of cooking water and palatability was also illustrated in order to explore the mechanism of the effect of types of cooking water on the palatability of rice, and provide a theoretical basis for selecting suitable rice cooking water to obtain highly palatable cooked rice.

MATERIALS AND METHODS

Materials

Three Chinese *japonica–type* rice cultivars with different palatability were used in this experiment: Jinyuan 45 (low palatability), Jinyuan E28 (a moderately palatable cultivar) and Jinchuan 1 (a highly palatable cultivar). These cultivars were all cultivated at the Tianjin Stock Seed Farm in 2018.

Six types of cooking water were used for each rice cultivar in the present study. Two types of natural mineral water (NMW1 and NMW2) and drinking pure water (DPW) were purchased from a local supermarket in Tianjin. Ultra–pure water (UPW) was obtained from Milli–Q Advantage A10 ultra–pure water system (Millipore, America) and distilled water (DW) was acquired from the laboratory. Tap water (TW) came from the daily use of ordinary households.

Determination of the physical parameters of water used for cooking rice

Physical parameters of cooking water used in the present study such as hardness, pH value and conductivity were determined according to the National Standard of the People's Republic of China (GB/T 5750.4–2006). In brief, pH value was determined by the glass electrode method with a pH meter (FE20–FiveEasy, Mettler Toledo, Switzerland) and the conductivity was measured by a conductivity meter (FE30–FiveEasy, Mettler Toledo, Switzerland).

The hardness of water refers to the degree of precipitation of soap. The main reason for the precipitation of soap is calcium and magnesium ions in the water. The hardness of water is expressed by the content of calcium and magnesium ions in the water. Hardness of cooking water was determined by the ethylenediaminetetraacetic acid disodium (EDTA) titration method, and the result was expressed by the mass of calcium carbonate per liter of water, i.e. mg $CaCO_3$/L.

Determine of total hardness: 100.00 mL of water sample was accurately measured and put into a 250 mL Erlenmeyer flask, added 5 mL of ammonia buffer solution with pH 10, then eriochrome black T (EBT) indicator was added into the flask. The solution was titrated with EDTA standard solution with a concentration of 0.0050 mol/L until the color of the solution changed from wine red to blue, and the volume (V_1) consumed was recorded. Total hardness of water was calculated according to the following formula 1:

$$\text{total hardness (mg CaCO}_3\text{/L)} = \frac{c_{EDTA} \times V_1 \times 100.09 \times 1000}{V}$$

(formula 1)

c_{EDTA}: concentration of EDTA standard solution, 0.0050 mol/L;
V_1: volume of EDTA consumed when titrating total hardness of water, mL;
V: total volume of the water sample, mL.
100.09: molecular mass of calcium carbonate, g/mol.

Determine of calcium hardness: 100.00 mL of water sample was accurately measured and put into a 250 mL Erlenmeyer flask, added 5 mL of 10% sodium hydroxide solution to adjust the pH value of the solution to 12, so that magnesium ions formed magnesium hydroxide precipitates to mask magnesium ions, then calcon–carboxylic acid indicator was added into the flask. The solution was titrated with EDTA standard solution with a concentration of 0.0050 mol/L until the color of the solution changed from wine red to blue, and the volume (V_2) consumed was record. Calcium hardness of water was calculated according to the following formula 2:

$$\text{calcium hardness (mg CaCO}_3\text{/L)} = \frac{c_{EDTA} \times V_2 \times 100.09 \times 1000}{V}$$

(formula 2)

V_2: volume of EDTA consumed when titrating calcium hardness of water, mL;
The meanings of other parameters were the same as formula 1.

The result of magnesium hardness was obtained by subtracting calcium hardness from total hardness. All measurements were repeated three times.

Rice processing and cooking

Rice samples were hulled by an experimental ridge machine (SY–88–TH, Korea Ridge Valley Machinery Industry Co., Ltd., Korea) and polished by a rice milling machine (CBS300AS, Satake Company Co., Ltd., Japan) to the extent of 91~92%. The moisture content of polished rice for the sensory test was 15% determined by the method of AOAC (1990).

For the present study, rice was cooked following the widely practiced traditional methods. Briefly, polished rice (500 g) was accurately weighted and washed with tested cooking water three times. Six types of cooking water were added to each rice cultivar respectively with a ratio of rice and water 1:1.25 (weight ratio). Rice was soaked at room temperature for 30 min and then cooked with an electric cooker (Panasonic, SR–MH 181–R, Hangzhou Matsushita Kitchen Appliance Co., Ltd.) and finally steamed for 20 min, and hereafter tasted.

Physicochemical properties measurement

All of the physicochemical properties were investigated at the International Joint Research Center of Technology Innovation and Achievement Transformation on Palatability of Rice in Tianjin Agricultural University. Hardness and adhesion of cooked rice were measured using a Rice Hardness–Viscosity Meter RHS–1A (SATAKE Co. Ltd., Japan) and hardness/adhesion (H/–H) ratio was calculated. Starch gelatinization properties (maximum viscosity and breakdown) of polished rice flour were monitored by using a Rapid Visco Analyzer RVA–4 (NEWPORT SCIENTIFIC. Ltd., Australia). Rice grains were ground and the rice flours that passed through a 220 µm mesh sieve were collected for the measurement. Briefly, rice flours (3.0 g, dry weight basis) were weighted exactly into the RVA canisters, and six types of cooking water were respectively added to make a total weight of 28.0 g. The rice flour suspension was held in the RVA at 50°C for 1 min then heated from 50°C to 95°C at a rate of 5°C/min, held at 95°C for 2.5 min, cooled from 95°C to 50°C at a rate of 5°C/min, and held at 50°C for 1.5 min. The heating process was accompanied by a constant shear at 960 rpm for the first 10 s followed by a constant shear at 160 rpm until the end of the analysis. Physicochemical properties were measured in triplicate.

Sensory test

Sensory test was conducted by 20 trained panelists at Tianjin Agricultural University (including 10 males and 10 females, aged 23–58) for seven samples in each time according to the method described by Cui *et al*. (2016a). Jinyuan 45 cooked with TW was used as a control. The following sensory attributes such as appearance, aroma, taste, stickiness, hardness and overall eating-quality were evaluated respectively by the panel members. Five sensory attributes were classified into seven stages compared with the control; −3 (very 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 (very weak) ~+3 (very strong) for stickiness; and −3 (very soft) ~+3 (very hard) for hardness. Sensory test was carried out in triplicate for each rice cultivar and each type of cooking water.

Statistical analysis

Analysis of variance (ANOVA) followed by Duncan's multiple range test was conducted to determine the difference. Statistical analysis was performed using the SPSS 22.0 statistical software program (IBM Corp., USA).

RESULTS

The physical parameters of cooking water

The physical parameters of cooking water were presented in Table 1. NMW 2 had the highest calcium hardness and magnesium hardness, so total hardness was highest, followed by TW and NMW 1. Calcium ions and magnesium ions were not detected in UPW, DW and DPW. According to Japanese drinking water standards, water are classified into soft water (total hardness<100), medium–hard water (total hardness 100~299) and hard water (total hardness>300). So

Table 1. The physical parameters of cooking water

Parameter	Cooking water					
	TW	NMW 1	NMW 2	UPW	DW	DPW
Calcium hardness (mg $CaCO_3$/L)	96.96±0.47	14.89±0.15	181.96±0.19	ND	ND	ND
Magnesium hardness (mg $CaCO_3$/L)	36.57±0.41	9.40±0.19	132.30±0.47	ND	ND	ND
Total hardness (mg $CaCO_3$/L)	133.53±0.06	24.29±0.05	314.26±0.58	ND	ND	ND
Type of hardness	medium-hard water	soft water	hard water	soft water	soft water	soft water
pH value	7.82±0.02	7.57±0.02	7.85±0.01	8.42±0.02	7.46±0.03	6.96±0.02
Conductivity（μS/cm）	318.00±0.00	91.33±0.31	693.00±0.00	20.03±0.06	29.67±0.23	10.67±0.06

ND indicated that the hardness of cooking water was not be detected.

NMW 1, UPW, DW and DPW were soft water, TW was medium-hard water, and NMW 2 was hard water. The pH value of DPW was 6.96±0.02, which was neutral water. On the other hand, pH values of other cooking water were within the range of 7.46±0.03 to 8.42±0.02, which were weakly alkaline water. Moreover, the conductivity of NMW 2 was largest, which was 2.18 times and 7.59 times that of TW and NMW 1, respectively, however, conductivities of DW, UPW and DPW were less than 30 μS/cm.

Effect of types of cooking water on the overall eating–quality of cooked rice and physicochemical properties

The overall eating-quality of cooked rice

It could be seen from Fig. 1 that all cultivars had improved palatability depending on types of cooking water. When cooked in soft water such as NMW 1, UPW, DW and DPW, the overall eating–quality were higher than that of TW. On the other hand, compared with TW, NMW 2 caused lower overall eating-quality, except Jinyuan45. As far as Jinyuan 45 was concerned, using NMW 2 to cook rice, the overall eating–quality was higher than TW, but lower than other soft water. In comparison with TW, the average overall eating–quality ratio of DW and NMW 2 of three cultivars were 306 and 240, respectively, indicating that the effect of types of cooking water on palatability was highest for DW and lowest for NMW 2. Additionally, the effect of water type on overall eating-quality was small for highly palatable cultivar (Jinchuan1) and moderately palatable cultivar (Jinyuan E28), but was large for low palatable cultivar (Jinyuan 45).

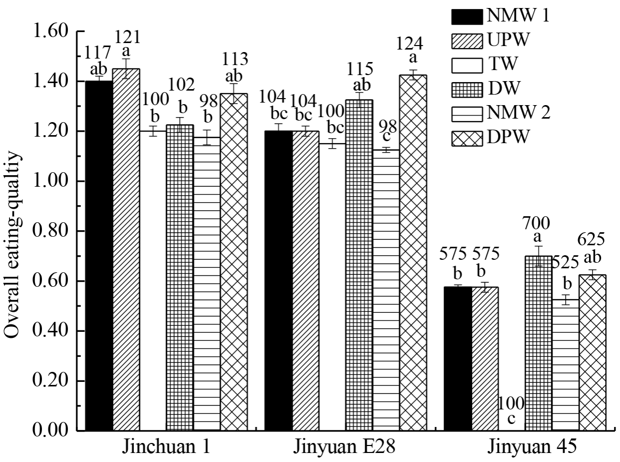

Fig. 1. Effect of types of cooking water on the overall eating–quality of three *japonica–type* rice cultivars.
Values are means ±SD (n=3).
Reference cultivar (0.00): Jinyuan 45 cooked with the TW.
The numerical value on the vertical bar in the same rice cultivar indicated overall eating-quality ratio with the TW as 100.
Different letters in the same rice cultivar corresponded to the significant difference at 0.05 level.

Moreover, the result of Table 2 showed that the overall eating-quality of cooked rice was significantly affected by rice cultivars and types of cooking water (P<0.001) and the effect of cultivar was greater than the type of cooking water, which could be confirmed by the value of mean square, but there was no interaction between rice cultivars and water types.

Physicochemical properties of rice

Effects of water type on physicochemical properties were depicted in Fig. 2 and Fig. 3. It could be seen from Fig. 2 that H/–H ratio of cooked rice was declined by using cooking water with low total hardness and mineral content such as NMW 1 and UPW compared with TW. Additionally, the effect of changes in types of cooking water on H/–H ratio was small for highly palatable rice such as Jinchuan 1 (P>0.05) but were large for moderately palatable cultivar and low palatable cultivar such as Jinyuan E28 and Jinyuan 45 (P>0.05). Fig. 3 revealed

Table 2. Analysis of variance for overall eating-quality cooked rice in three cultivars of six types of cooking water

Factor	Df	Mean Square	F
Cultivar (V)	2	1.257	38.901^{***}
Cooking water (W)	6	0.941	29.117^{***}
V×W	11	0.07	2.155^{ns}
error	20	0.032	

***: Significant at the 0.001 probability level. ns: Not significant.

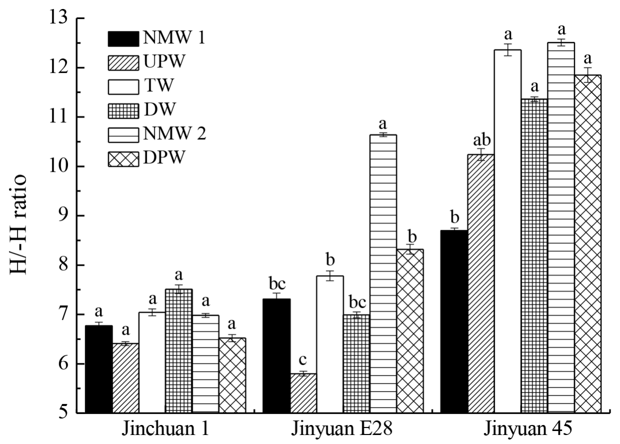

Fig. 2. Effect of types of cooking water on H/–H ratio of cooked rice.
Values are means ±SD (n=3).
Different letters in the same rice cultivar corresponded to the significant difference at 0.05 level.

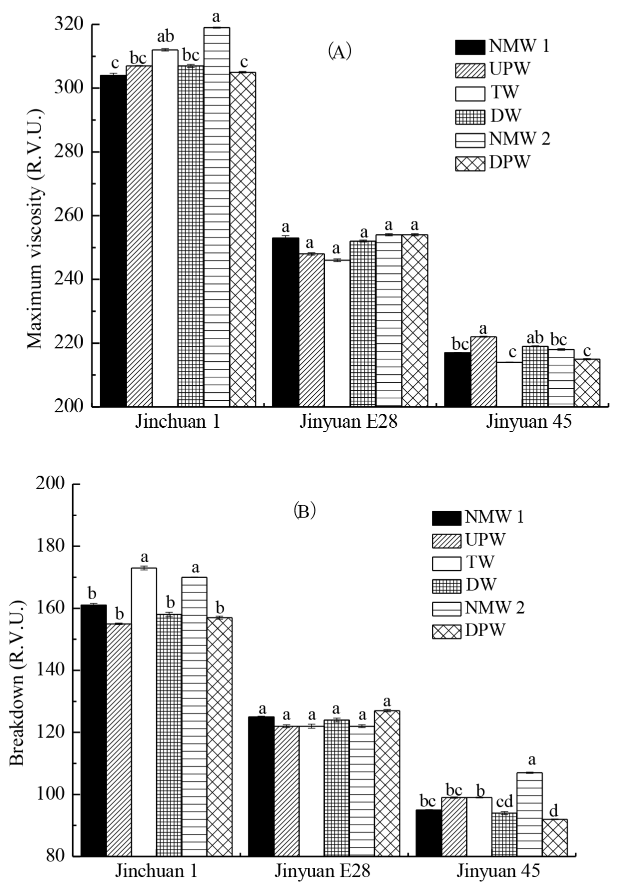

Fig. 3. Effect of types of cooking water on starch gelatinization properties.
Values are means ±SD (n=3).
Different letters in the same rice cultivar corresponded to the significant difference at 0.05 level.

Table 3. Correlation coefficient between physicochemical properties and overall eating-quality of cooked rice

	H/-H ratio	Maximum viscosity	Breakdown
Overall eating-quality	-0.835**	0.752**	0.739**

**: Significant at the 0.01probability level. n=18.

that changes in the type of cooking water did not significantly improve maximum viscosity (except Jinyuan45) and breakdown.

Relationship between physicochemical properties and overall eating-quality of cooked rice

Table 3 showed the relationship between physicochemical properties and overall eating–quality of cooked rice including the three cultivars. H/–H ratio showed a significantly negative correlation with overall eating–quality of cooked rice. Conversely, maximum viscosity and breakdown displayed significantly positive correlation with overall eating-quality of cooked rice.

Relationship between physical parameters of cooking water and overall eating-quality of cooked rice, and physicochemical properties

Overall eating-quality of cooked rice

Fig. 4 showed the correlation of physical parameters of cooking water with overall eating–quality of cooked rice. Total hardness had a significantly negative correlation with overall eating–quality of cooked rice for Jinchuan 1 and Jinyuan E28, but not for Jinyuan 45 (Fig. 4A). Conductivity had a significantly negative correlation with overall eating-quality of cooked rice for Jinchuan 1 and Jinyuan E28, but not for Jinyuan 45 (Fig. 4B). On the other hand, there was no relationship between pH value of cooking water in the range of the experiment and overall eating-quality of cooked rice for the tested cultivars (Fig. 4C).

Physicochemical properties of rice

Table 4 showed the relationship between physical parameters of cooking water and physicochemical properties of rice. Total hardness and conductivity of cooking water showed a positive correlation between H/–H ratio and breakdown, but had nothing to do with maximum viscosity (except Jinchuan 1). Furthermore, there was no constant relationship between pH value and physicochemical properties of rice.

Multiple linear regression analysis of overall eating–quality for H/-H ratio, maximum viscosity, breakdown, total hardness and conductivity

Table 5 showed standard partial regression coefficients for H/–H ratio, maximum viscosity, breakdown, total hardness and conductivity against the overall eating–quality of cooked rice including the three cultivars. The standard partial regression coefficient against palatability was the highest for H/–H ratio (–0.689). On the other hand, the standard partial regression coefficients against palatability were low for maximum viscosity, breakdown, total hardness and conductivity.

DISCUSSION

Many types of drinking water have been developed in the market for people's health and safety and their properties are also quite different. It is generally recognized that the use of hard water with high calcium ion

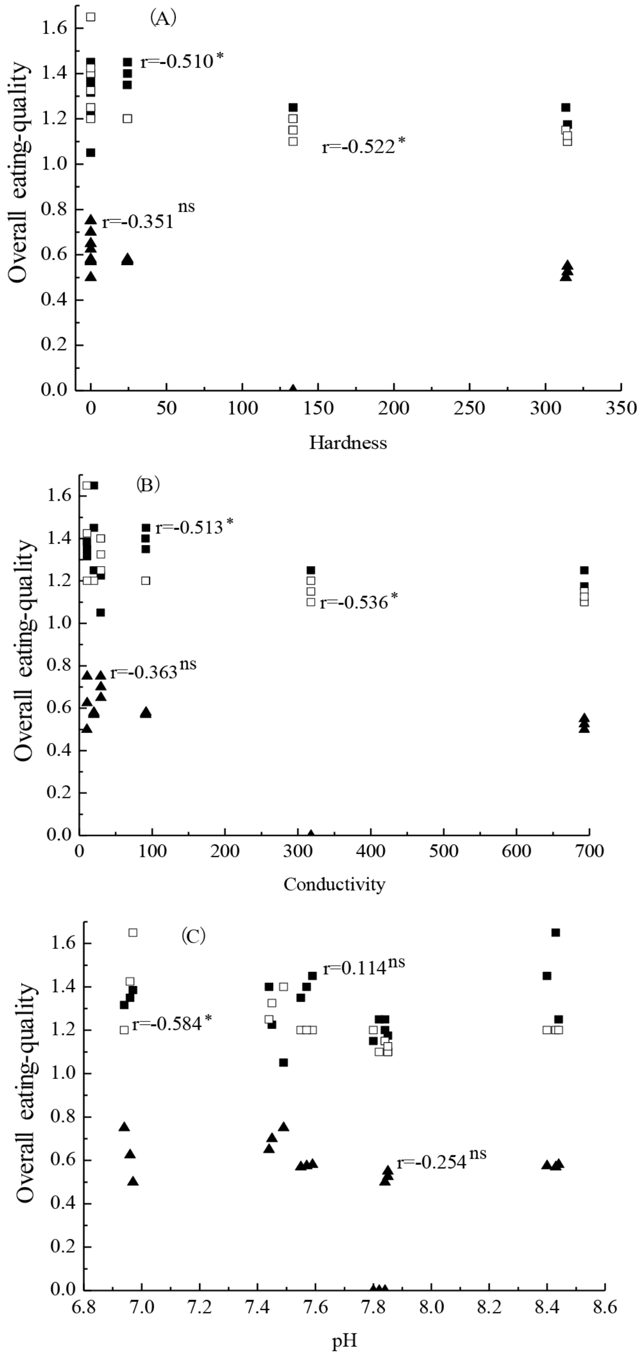

Fig. 4. Correlation coefficient between hardness (A), conductivity (B) and pH (C) of cooking water, and overall eating-quality of cooked rice in each cultivar.
■: Jinchuan 1, □: Jinyuan E28, ▲: Jinyuan 45.
*: Significant at the 0.05 probability level.
ns: Not significant.

Table 4. Correlation coefficient between physical parameters of cooking water and physicochemical properties of rice

Cultivar	Physicochemical Properties	Physical Parameters of Cooking water		
		Total hardness	Conductivity	pH value
Jinchuan 1	H/-H ratio	0.118	0.128	-0.120
	Maximum viscosity	0.823**	0.821**	0.276
	Breakdown	0.693**	0.704**	0.100
Jinyuan E28	H/-H ratio	0.762**	0.754**	-0.263
	Maximum viscosity	0.046	0.040	-0.410
	Breakdown	-0.200	-0.203	-0.391
Jinyuan45	H/-H ratio	0.439†	0.425†	-0.125
	Maximum viscosity	-0.227	-0.230	0.518*
	Breakdown	0.830**	0.831**	0.546*

**, * , †: Significant at the 0.01, 0.05 and 0.1 probability levels, respectively.

and magnesium ion content to cook rice results in higher hardness and poor palatability of cooked rice, however, there is controversy regarding the influence of water conductivity and pH value on the palatability of rice. Moreover, there is still a lack of systematic research on the effect of types of cooking water on the palatability of Chinese *japonica–type* rice cultivars, especially focused on whether the effect exists varietal difference and the mechanism by which the types of cooking water affect the palatability of rice and which water type for cooking can achieve better palatability of rice are still unclear. Therefore, in this study, the effect of types of cooking water on the palatability and physicochemical properties of Chinese *japonica–type* rice cultivars were systematically analyzed.

The results of our test revealed that all cultivars had improved palatability depending on types of cooking water. When cooked in the water with low total hardness and conductivity, the overall eating-quality of cooked rice presented higher score, that was higher palatability, compared with cooked in the water with high total hardness and conductivity, such as TW and NMW 2 (Fig. 1). Ogawa *et al.* (2013) also pointed out that the water absorption and volume increase of rice were facilitated by cooking in ion–exchanged water from which Ca had been removed by the water–softener, giving softer rice. The palatability of rice cooked in soft water is high, which is attributed to the use of soft water to cook rice, the starch gelatinization is more fully, and the pores of the rice grains are smaller, so that the adhesion is increased and the palatability of cooked rice is better (Ramesh *et al.*, 1999). A negative tendency was observed between the total hardness of cooking water and the overall eating–quality of cooked rice for the three tested cultivars, i.e. the harder the cooking water, the poor the palatability (Fig. 4A). When cooked in water with high total hardness, the calcium ions in cooking water may combine with the pectin in rice to form pectin–calcium gel, and eventually result in hard and divergent cooked rice (Fraeye *et al.*, 2009). Similarly, a negative tendency between the conductivity of cooking water and the overall eating–quality was also observed in our study (Fig. 4B). Thompson *et al.* (2012) suggested a positive correlation between the conductivity and total hardness of water, which was consistent with our results. On the other hand, there is no relationship between the pH value of cooking water and the overall eating-quality of cooked rice for the tested cultivars (Fig. 4C). In addition, it is worth noting that the effect of types of cooking water on palatability was highest for DW and lowest for NMW 2, in comparison with TW, which could be seen from the average overall eating–quality ratio of three cultivars. Moreover, we could also see from Fig. 1 that the effect of improved palatability varied with cultivar, with

Table 5. Standard partial regression coefficient (spr) for physicochemical properties against the overall eating- quality of cooked rice

	H/-H ratio	Maximum viscosity	Breakdown	Total hardness	Conductivity
spr R^2=0.879** df=17, n=18	-0.689*	0.229^{ns}	0.008^{ns}	5.125^{ns}	-5.108^{ns}

**, *: Significant at the 0.01 and 0.05 probability levels, respectively. ns: Not significant.

R^2: Coefficient of determination.

highly palatable cultivar had a smaller effect, whereas poorly palatable cultivar had a greater effect, and even if the poorly palatable cultivar was cooked with good quality water, the palatability could not be greatly improved such as Jinyuan 45. In terms of palatability improvement effect, the cultivars were larger than types of cooking water (Table 2), revealing that although the types of cooking water may exert an influence on the palatability of rice, the dominant factor in determining the palatability is the genetic characteristics.

Regarding the effect of types of cooking water on physicochemical properties, H/–H ratio of cooked rice is considered to be an effective indicator for evaluating the palatability. The lower the H/–H ratio, the higher the palatability of rice (Cui *et al.*, 2016b). Our results (Fig. 2) showed that H/–H ratio of cooked rice was declined by using cooking water with low total hardness and mineral content such as NMW 1 and UPW compared with TW. On the other hand, for Jinyuan E28 and Jinyuan 45, cooking in NMW 2, which was highest in total hardness and conductivity, the highest H/–H ratio was obtained compared with other types of cooking water, indicating the worst palatability. Cooking rice with hard water containing more calcium ions will increase the calcium content in the rice, resulting in the increase in hardness of cooked rice and decrease its adhesion, resulting in increased H/–H and decrease palatability. Additionally, the effect of changes in types of cooking water on H/–H ratio was small for highly palatable rice such as Jinchuan 1 (P>0.05) but were large for moderately palatable cultivar and low palatable cultivar such as Jinyuan E28 and Jinyuan 45 (P<0.05). As far as starch gelatinization properties were concerned, the higher the maximum viscosity and breakdown, the better the palatability (Cui *et al.*, 2016a). Changes in the type of rice cooking water did not significantly improve the starch gelatinization properties in our study (Fig. 3). Furthermore, it was worth noting that whether rice was cooked with different types of cooking water, the starch gelatinization properties of three *japonica–type* rice cultivars showed the same trend, e.g. maximum viscosity and breakdown of highly palatable cultivar (Jinchuan 1) had the highest value followed by moderately palatable cultivar (Jinyuan E28), while low palatable cultivar (Jinyuan 45) had the lowest value, showing that the starch gelatinization properties depended on the cultivar. Our result was consistent with the previous studies reported by Cui *et al.* (2016c) and Matsue and Ogata (2000). Overall eating-quality of cooked rice showed significantly negative collection with H/–H ratio, significantly positive correlation with maximum viscosity and breakdown (Table 3). This was consistent with the previous report (Cui *et al.*, 2016a; Matsue, 2001).

To further analyze the relationship between overall eating–quality and physicochemical properties and physical parameters of cooking water, we performed multiple regression analysis using overall eating-quality as a dependent variable and physical parameters of cooking water and physicochemical properties as explanatory variables. The standard partial regression coefficient against overall eating–quality was the highest for the H/–H ratio in cooked rice (Table 5). The generally accepted relationship that the lower the H/–H ratio, the higher the palatability. Therefore, the improvement in palatability by types of cooking water could be attributed to the reduced H/H ratio of cooked rice due to the lower calcium content in rice.

AUTHOR CONTRIBUTIONS

P. Li designed the study, carried out the experiments, collected data, analyzed data and wrote the first draft. Y. Matsue designed the study and wrote the paper. X. Zhang, J. Cui, F. Li and A. Kusutani collected and analyzed the data. T. Mochizuki analyzed the data, wrote and revised the paper. All authors assisted in editing of the manuscript and approved the final version.

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