（様式５）(Style5)

学位論文全文に代わる要約
Extended Summary in Lieu of Dissertation

氏名：
Name　Zhang Xin

学位論文題目：
Title of Dissertation　Study on the Palatability of Chinese *Japonica-type* Rice Varieties
（中国産ジャポニカ型水稲品種の食味に関する研究）

学位論文要旨：
Dissertation Abstract

In China, yield has been a central issue in studies of the breeding and cultivation of paddy rice. However, the diversification of eating habits associated with economic development means that consumer demand is increasing for the higher quality and palatability of *japonica-type* rice. For this reason, studies of rice palatability are also increasing. However, studies on rice palatability in China have not yet reached the stage for applying to breeding and cultivation techniques.

Breeding palatable rice varieties requires scientific methods of palatability evaluation and popular sensory testing, and an effective selection method must be constructed on the basis of physicochemical properties. However, no unified evaluation method has yet been established in China, and practical sensory testing has rarely been used. In addition, studies on the relationship between physicochemical properties and sensory test are extremely limited.

Against this background, the present study sought to clarify the palatability characteristics of Chinese *japonica-type* paddy rice, and to construct a breeding method for palatable rice varieties in China. The results obtained are summarized below.

1. Palatability evaluation in the sensory test by the Chinese panel and Japanese panel

To construct an effective breeding method for palatable rice varieties, it is important to understand the taste preferences of the Chinese consumer, and a scientific evaluation method for rice palatability must be established based on the preference of consumer. To this end, the Japanese sensory test (appearance, aroma, taste, stickiness, hardness, overall eating-quality) were applied to 10 Chinese and Japanese varieties by the Chinese panel and Japanese panel.

The evaluation scores of the Chinese and Japanese panels differed most for appearance and least for hardness. On the whole, the Chinese and Japanese panels tended to be similar in their evaluations of palatability, with a significant positive correlation in overall eating-quality of Chinese and Japanese varieties for both panels (Fig.1).

A similar correlation was observed for appearance, taste, stickiness and hardness. However, in contrast to the Japanese panel, the Chinese panel's evaluation scores for some varieties were extremely low.

There were differences between the Chinese and Japanese panels in the estimated contribution ratio of each evaluation item to overall eating-quality (Table 1). For Chinese varieties, the Chinese panel rated the contribution ratio as high in hardness and stickiness while the Japanese panel rated the contribution ratio as high in stickiness and appearance. The Chinese panel rated Japanese varieties as high in taste and appearance while the Japanese panel rated them as high in appearance

and stickiness. While the Chinese panel tended to prefer hard rice, the Japanese panel favored soft rice.

These results indicate little difficulty in applying the Japanese sensory test for palatability studies in China. However, to successfully introduce the Japanese method to Chinese sensory testing, it will be necessary to determine more precise evaluation standards for each item and to construct a sensory test method that takes adequate account of Chinese consumer preferences.

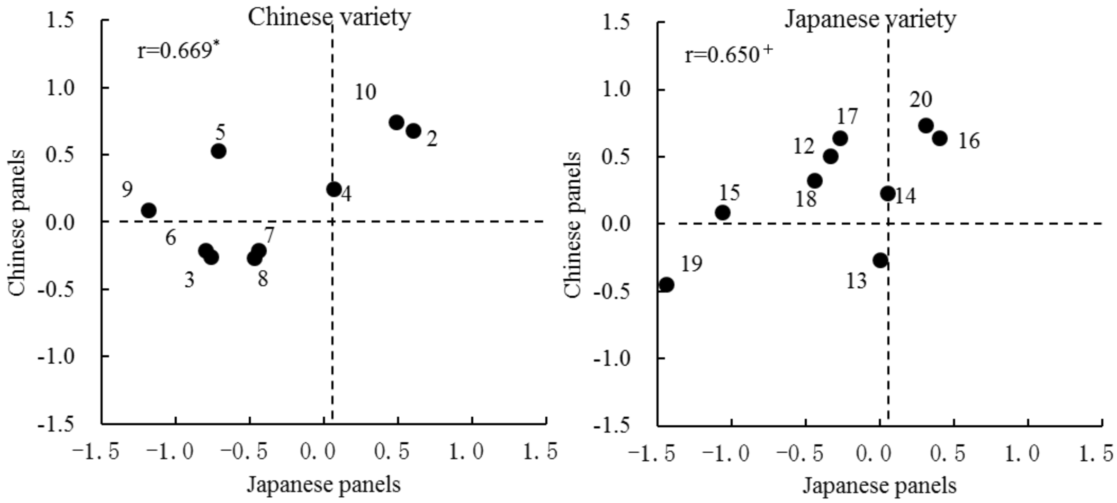

Fig. 1　Correlation of overall eating quality scores in the sensory test in the Japanese and Chinese panels

Numerals in this figure are numbers of varieties.

†，*: Significant at the 10% and 5% levels, respectively.

Table 1　Standard partial regression coefficient of each item in the sensory test for overall eating quality.

	Panel	Multiple correlation coefficient	Coefficient of determination	Standard partial regression coefficient (ratio)			
				Appearance	Taste	Stickiness	Hardness
Chinese varieties	CP	0.972***	0.944	0.323(19.9)	0.151(9.3)	0.528(32.5)	0.623(38.3)
	JP	0.999***	0.998	0.345(32.3)	0.116(10.9)	0.567(53.1)	-0.040(3.7)
Japanese varieties	CP	0.903**	0.815	0.396(32.1)	0.437(35.4)	0.256(20.8)	0.144(11.7)
	JP	0.998***	0.996	0.399(38.8)	0.268(26.1)	0.314(30.5)	-0.047(4.6)

CP: Chinese panel, JP: Japanese panel.

, *: Significant at the 1% and 0.1% levels, respectively.

2.　Varietal difference of physicochemical properties in Chinese varieties

As basic information on the physicochemical properties of rice varieties in China remains extremely limited, 260 varieties bred in different regions of China were collected and their physicochemical properties (amylose content and protein content of polished rice, maximum viscosity and breakdown value of polished rice flour, hardness/adhesion ratio of cooked rice) were examined.

Genetic variation within properties and genetic correlation among properties were also analyzed.

A wide range of genetic variation was found in the physicochemical properties of the 260 examined varieties, from those of superior quality (exceeding Japanese palatability standards) to those of very low quality (Table 2). Genetic variation was largest for hardness/adhesion ratio and smallest for amylose content. In the examined varieties, amylose content showed significant negative correlations with protein content and breakdown value and a significant positive correlation with hardness/adhesion ratio. Protein content showed a significant positive correlation with breakdown value (Table 3).

Palatability increased with lower amylose content, protein content and hardness/adhesion ratio, and with higher maximum viscosity and breakdown value. These results suggest that the physicochemical properties of Chinese varieties are not well balanced, especially as low protein content is often accompanied by other inferior physicochemical properties.

Table 2　Variation of physicochemical properties in 260 examined varieties.

	Minimum value	Maximum value	Mean value	Standard deviation	Coefficient of variation (%)
Amylose content (%)	15.1	20.1	18.1	0.95	5.3
Protein content (%)	6.5	13.4	9.8	1.44	14.7
Breakdown value(RVU)	48	140	93	16.3	17.6
Hardness/adhesion ratio	7.2	57.9	23.8	8.9	37.5

Table 3　Correlation coefficients among physicochemical properties.

	PC	BD	H/-H
Amylose content (AC)	-0.387***	-0.444***	0.307***
Protein content (PC)		0.228***	-0.087
Breakdown value (BD)			-0.332***

***: Significant at the 0.1% level.

3. Comparison of physicochemical properties between Chinese varieties and Japanese varieties

There are few existing studies comparing Chinese and Japanese varieties in terms of genetic variation and genetic correlation of physicochemical properties. To clarify objectives for breeding of palatability in China, the physicochemical properties of 10 Chinese varieties were compared to those of Japanese varieties, examining any issues arising from the physicochemical properties of Chinese varieties.

Chinese and Japanese varieties did not differ significantly in amylose content. However, for Chinese varieties, maximum viscosity and breakdown value were significantly lower than for Japanese varieties, and protein content and hardness/adhesion ratio were significantly higher. The average physicochemical properties of Chinese varieties were similar to those of Japanese varieties cultivated in the 1970s.

In both Chinese and Japanese varieties, amylose content showed a significant negative correlation with maximum viscosity and breakdown value. In Japanese varieties, a positive but non-significant correlation was observed between amylose content and protein content, which is preferable for palatability. In contrast, a significant negative correlation was observed in Chinese varieties between amylose content and protein content, which is unfavorable for palatability

(Fig.2, Table 4).

These results show that the most considerable physicochemical property of Chinese rice varieties is their protein content, and it is therefore necessary to improve the correlation of protein content with other physicochemical properties. In particular, disruption of the negative genetic correlation between protein content and amylose content is the most important issue for palatability breeding in China. In Japanese varieties, on the other hand, when the negative genetic correlation between protein content and amylose content was disrupted, varieties with low amylose content were found to have low protein content.

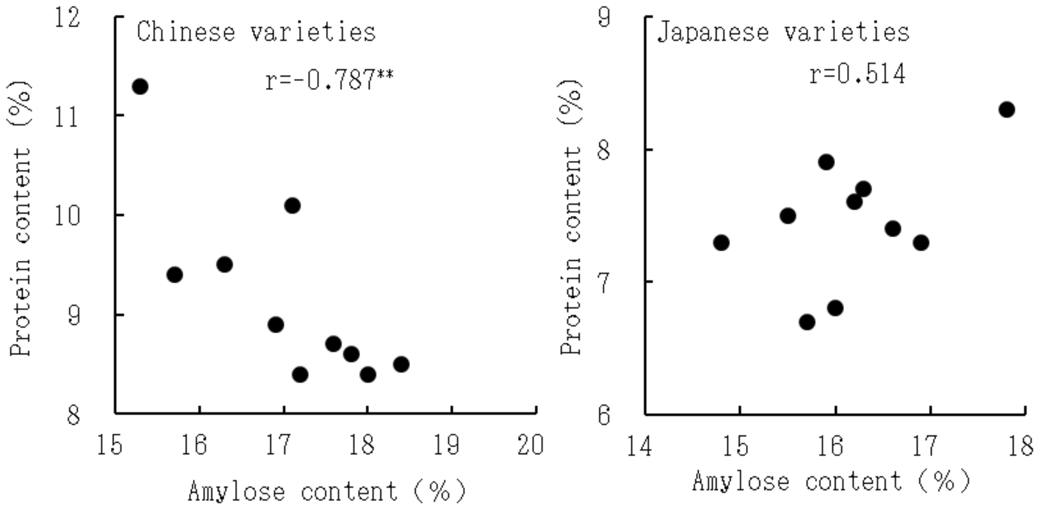

Fig. 2　Correlation between amylose content and protein content
**: Significant at the 1% level.

Table 4　Correlation coefficients among physicochemical properties.

		PC	MV	BD	H/-H
Chinese varieties	Amylose content (AC)	0.787**	-0.874**	-0.841**	0.343
	Protein content (PC)		0.529	0.588	-0.121
	Maximum viscosity (MV)			0.932***	-0.305
	Breakdown value (BD)				-0.190
	Hardness/adhesion ratio (H/-H)				
Japanese varieties	Amylose content (AC)	0.514	-0.670*	-0.797**	0.849**
	Protein content (PC)		-0.327	-0.474	0.492
	Maximum viscosity (MV)			0.668*	-0.536
	Breakdown value (BD)				-0.591
	Hardness/adhesion ratio (H/-H)				

*, **, ***: Significant at the 5%, 1% and 0.1% levels, respectively.

4. Effect of the amount of nitrogen application on physicochemical properties

The distinguishing physicochemical property of Chinese rice is its high protein content. This is because Chinese varieties primarily have high protein content. However as large amounts of nitrogen fertilizer are applied in China, the effects of this fertilizer on protein content and other physicochemical properties were analyzed in five plots of Jinchuan 1 and Yanfeng 47, using different amounts of nitrogen.

Amylose content decreased with increased nitrogen application, but the difference between plots was not significant. Protein content, maximum viscosity and breakdown value varied significantly by plot; while protein content increased with increased nitrogen application, maximum viscosity and breakdown value decreased. The taste value of Jinchuan 1 was highest for the 7.5g N m^{-2} plot, but the taste value of Yanfeng 47 decreased with increased nitrogen application.

Protein content showed a linearly positive correlation with amount of nitrogen application; the slope of the regressed line was steeper for Yanfeng 47 than for Jinchuan 1. Protein content showed a linearly positive correlation with amount of applied nitrogen per grain and a linearly negative correlation with 1000-grain weight.

Based on taste value and yield relative to maximum plot, the appropriate amount of nitrogen application for high palatability and high yield in China was estimated at about 15–20 g N m^{-2} (Fig.3).

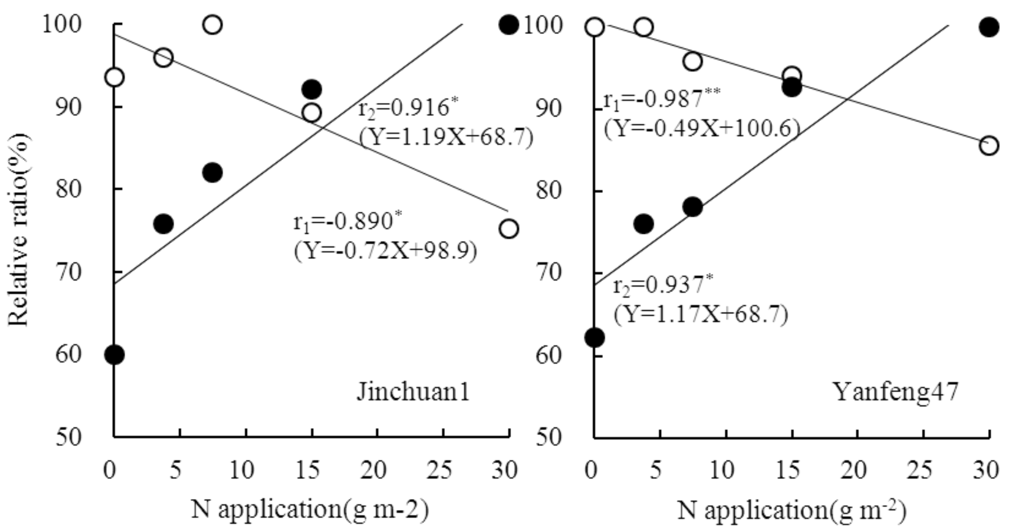

Fig. 3 Correlation of relative value with the amount of nitrogen (N) application

-○- : Taste value, -●- : Yield. Relative ratio is the percentage to the maximum value.

r_1: Correlation coefficient in taste value, r_2: Correlation coefficient in yield

*, **: Significant at 5%, 1% levels, respectively.

5. Correlation between physicochemical properties and cooked rice properties

Varietal differences in physicochemical properties and cooked rice properties (water absorption ratio, swelling ratio, elongation ratio) were investigated in 65 varieties produced in northern China, and correlations between them were analyzed.

Amylose content showed a significant negative correlation with maximum viscosity and breakdown value. Protein content showed a significant positive correlation with breakdown value and hardness/viscosity ratio. There was a significant negative correlation between protein content and amylose content.

Cooked rice properties (water absorption ratio, swelling ratio and elongation ratio) showed small varietal differences, with no significant correlation (Table 5). There was no significant correlation between physicochemical properties and cooked rice properties, and their correlation coefficient was very small (Table 6).

These results show that, for the varieties of rice used in this experiment, physicochemical properties and cooked properties are independent, making it difficult to evaluate cooked rice properties in terms of physicochemical properties.

Table 5 Variation of cooked rice properties in 65 examined varieties.

	Maximum value	Minimum value	Mean value	Standard deviation	Coefficient of variation(%)
Water absorption ratio (%)	135	125	131	2.0	1.5
Swelling ratio (%)	213	169	185	8.9	4.8
Elongation ratio (%)	179	123	158	11.9	7.5

Table 6 Correlation coefficients between cooked rice properties and physicochemical properties.

	Amylose content	Protein content	Maximum viscosity	Breakdown value	Hardness/ adhesion ratio
Water absorption ratio	0.047	-0.118	0.068	-0.055	0.212
Swelling ratio	0.035	-0.110	-0.134	-0.197	0.062
Elongation ratio	-0.056	0.126	-0.099	0.003	0.086

6. Correlation between palatability evaluation in the sensory test and physicochemical properties

In Japan, the relationship between sensory test evaluation items and physicochemical properties has been analyzed in detail and an effective breeding system for palatable rice varieties has been established by using physicochemical properties as indicators for selection. In China, on the other hand, there has been little investigation of the relationship between physicochemical properties and sensory test items. For that reason, the correlation between evaluation items in sensory test and physicochemical properties was examined here, using 28 varieties produced in northern China.

Overall eating-quality showed highly positive correlations with appearance and taste but not with hardness. Overall eating-quality, appearance, aroma, taste and stickiness were negatively correlated with protein content and hardness/adhesion ratio, and positively correlated with maximum viscosity and breakdown value. Amylose content was not significantly correlated with any sensory test evaluation item (Table 7).

About 47% of the varietal difference in overall eating-quality was explained by protein content, maximum viscosity and hardness/adhesion ratio. The contribution ratio of protein content, maximum viscosity and hardness/adhesion ratio to overall eating-quality was estimated at about 36%, 38% and 26%, respectively. Varietal differences on other evaluation items were 30–50% explained by these three physicochemical properties (Table 8).

From these results, in the early generation of selection involving many lines, the lines should be roughly selected on the basis of these physicochemical properties; in middle to late generation, with a smaller number of lines, effective selection of palatable lines should be based on a sensory test.

Table 7 Correlation coefficient between physicochemical properties and evaluation items in the sensory test.

	Amylose content	Protein content	Maximum Viscosity	Breakdown value	Hardness/ adhesion ratio
Overall eating quality	-0.060	-0.530**	0.571**	0.499**	-0.597***
Appearance	-0.060	-0.487**	0.538**	0.451*	-0.536**
Aroma	0.138	-0.431*	0.422*	0.404*	-0.550**
Taste	-0.008	-0.557**	0.538**	0.503**	-0.632***
Stickiness	-0.127	-0.514**	0.606***	0.581**	-0.694***
Hardness	0.202	0.048	-0.615***	-0.341	0.451*

*, **, ***: Significant at 5%, 1%, 0.1% levels, respectively.

Table 8 Standard partial regression coefficient of physicochemical properties with each item in the sensory test.

	Multiple correlation coefficient	Coefficient of determination	Standard partial regression coefficient (ratio)		
			Protein content	Maximum viscosity	Hardness/ adhesion ratio
Overall eating quality	0.688***	0.473	-0.300(36)	0.317(38)	-0.224(26)
Appearance	0.636***	0.404	-0.284(36)	0.331(43)	-0.163(21)
Aroma	0.578**	0.334	-0.194(29)	0.103(15)	-0.377(56)
Taste	0.701***	0.491	-0.310(37)	0.217(25)	-0.320(38)
Stickiness	0.740***	0.548	-0.203(23)	0.262(30)	-0.410(47)
Hardness	0.657***	0.432	-0.265(25)	-0.561(54)	0.220(21)

, *: Significant at 1% and 0.1% levels, respectively.

7. The palatability and yield performance of Jinchuan 1 in different producing area.

Jinchuan 1 is a highly palatable rice variety bred at the China-Japan Joint Center of Palatability and Quality of Rice and planted mainly in Tianjin and surrounding rice growing areas. Because of its high palatability and stability, it is hoped to introduce Jinchuan 1 into other provinces. To verify the theoretical possibility of its introduction and promotion in Jiangsu Province, Jinchuan 1 was planted in the Tianjin and Baoying County areas of Jiangsu Province, and respective yields, yield components and physicochemical properties were compared. For comparison purposes, Jinyuan 45 (the check variety for rice regional trials in Tianjin) was also planted.

For both varieties, the number of days from transplanting time to full heading time was shorter in Baoying County than in Tianjin—that is, the vegetative growth stage was shortened by the transfer of planting location from high latitudes (Tianjin) to low latitudes (Jiangsu Province). Yield for the two varieties introduced from Tianjin to Baoying County visibly decreased—by 12% for Jinchuan 1 and by 11% for Jinyuan 45. Among yield components, filled spikelet numbers were most affected by the shortening of vegetative growth by the change of latitude (Table 9).

In terms of physicochemical properties, Jinchuan 1 planted in Baoying County displayed significant lower amylose content and protein content while maximum viscosity was significant higher than for the same variety planted in Tianjin. Jinyuan 45 planted in Baoying County displayed significantly higher maximum viscosity and breakdown value than when planted in Tianjin. As evaluated by a taste analyzer, taste values were higher for the two varieties planted in Baoying County, but no significant difference was observed between locations. For both varieties, the palatability of rice produced in Baoying County tended to improve. It can be assumed that these results are an effect of temperature, which is higher in Jiangsu Province than in Tianjin (Table 10).

Based on these results, it may be concluded that Jinchuan 1 cannot be introduced into Jiangsu Province because of its low yield but can serve as the parent material for breeding palatable rice. As the yield of Jinyuan 45 planted in Baoying County was nearly 1t $10a^{-1}$, it can be used as a common variety in Jiangsu Province.

Table 9　Yield and yield components.

Variety	Location	Panicle number (m^{-2})	Spikelet number ($panicle^{-1}$)	Number of ripened grain ($panicle^{-1}$)	Percentage of ripening (%)	1000-grain weight (g)	Yield (gm^{-2})
Jinchuan1	Tianjin	325	109	105	96.3	25.8	720
	Baoying	315	77	73	94.2	25.6	636
Jinyuan45	Tianjin	289	143	139	97.0	25.9	1040
	Baoying	312	132	114	86.4	26.0	930

Table 10　Physicochemical properties.

Variety	Location	Amylose content (%)	Protein content (%)	Maximum viscosity (RVU)	Breakdown value (RVU)
Jinchuan1	Tianjin	16.5	8.8	212	102
	Baoying	15.5	8.3	302	108
	Analysis of variance	*	*	**	ns
Jinyuan45	Tianjin	17.3	7.7	152	72
	Baoying	17.8	7.8	241	93
	Analysis of variance	ns	ns	**	**

*, **: Significant at 5% and 1% levels, respectively.　ns: Not significant.

(注)　要約の文量は，学位論文の文量の約１０分の１として下さい。図表や写真を含めても構いません。
(Note)　The Summary should be about 10% of the entire dissertation and may include illustrations