벼의 物理的 및 熱的 特性에 關한 硏究*

— 物理的 特性에 關하여 —

Study on the Physical and Thermal Properties of Rice Kernels

— Physical Properties —

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要 約

우리가 소비하는 식량의 확보는 단위 수량의 증대뿐만 아니라, 생산이후 수확, 조제가공 및 건조·저장과정에서의 곡물 손실 방지 또는 감소로 인한 간접 증산으로도 이룩될 수 있는데, 현재 우리나라에서는 수확 이후의 곡물 손실량이 전체 생산량의 약 11%에 달하는 것으로 추정되고 있다(12).

여기서 식량의 중요 손실원으로 기계적 원인과 곡물 자체의 특성에 의한 두가지 요인을 고려할 수 있다. 따라서 쌀의 물리적 특성이 규명되면 각 과정에서 발생되는 기계적 손실을 더욱 줄일 수 있을 것이다. 이러한 중요성에도 불구하고 지금까지 우리나라에서는 벼의 물리적 특성에 관한 연구가 거의 없는 실정이다. 특히 우리나라에 많이 보급되고 있는 통일계 품종은 관행 품종에 비하여 물리적 특성이 크게 다르다고 인정되고 있다.

따라서 본 연구는 벼와 현미의 특성을 기계적 및 유동학적 측면에서 함수율 및 품종별로 규명하여, 농업기계의 설계 및 작동조건, 그리고, 조제가공의 기초적 자료로 제시하고자 하였다.

실험결과를 요약하면 다음과 같다.

1. 준 정하중의 압축시험에서 함수율은 벼와 현미의 기계적 및 유동학적 특성에 큰 영향을 미쳤으며, 특히 높은 함수율에서는 점성적인 특성이, 낮은 함수율에서는 탄성적인 특성이 나타났다.

2. 벼와 현미의 함수율이 24-12%(습량기준)의 범위에 있을 때 현미의 항복점은 2.0-7.2kg, 벼의 항복점은 2.5-7.6kg을 나타냈으며, 전반적으로 현미보다 벼의 항복점이 0.5-1kg 더 높았다.

또한 함수율이 18%(습량기준) 이하에서는 일반계 품종이 통일계 품종보다 압축 강도가 더 높았으나 18% 이상의 높은 함수율에서는 더 낮게 나타났다. 그리고 낮은 함수율에서 현미의 항복점은 현미 두께 대 길이의 비의 증가에 따라 직선적으로 감소하였다.

3. 현미의 최대압축 강도는 함수율 24-12%(습량기준)의 범위에서 2.94-10.4kg을 나타냈으며, 14% 수준의 낮은 함수율에서는 현미의 최대 압축 강도는 5.66-11.4kg으로 품종간에 높은 유의성이 있었다. 따라서 벼와 현미의 크기가 최대 압축 강도에 큰 영향을 미친 것으로 사료된다.

4. 함수율 12-24%(습량기준)의 범위에서, 현미의 항복점에서 변형은 0.20∸0.40mm를 나타냈으며, 함수율이 약 17%일 때 최소치를 보였다., 벼의 항복점에서 변형은 0.20-0.41mm였으며 통일계 품종이 일반계 품종보다 변형이 더 많이 생겼다.

5. 함수율 24-12%(습량기준)의 범위에서, 일반계 품종의 레질리언스(resilience)는 0.142-0.603 kg·mm, 통일계 품종의 레질리언스는 0.229-0.601kg·mm로 나타났다. 함수율이 19% 이하에서는 일반계 품종이 통일계 품종보다 더 높게 나타났으며 19% 이상에서는 반대 현상이 일어났다. 또한 14%의 낮은 함수율에서, 현미의 레질리언스는 현미 두께 대 길이의 비의 증가에 따라 감소하였다. 벼의 레질리

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언스는 함수율의 감소에 따라 증가했으며, 그 범위는 0.285-0.850 kg·mm 이었다.

6. 현미의 터프니스(toughness)는 함수율 24-12%(습량기준)의 범위에서 0.841-2.795 kg·mm 이었다. 또한 일반계 품종과 통일계 품종 사이에는 유의성이 없었으나, 품종간에는 높은 유의성이 있었다.

7. 현미의 탄성계수와 스티프니스(stiffness)는 함수율의 감소에 따라 직선적으로 증가하였다. 현미의 함수율이 24-12%(습량기준)의 범위에 있을 때 탄성계수는 7-40 kg/mm^2, 스티프니스는 8-34 kg/mm를 나타냈다.

I. Introduction

The security of food-stuffs which we consume will be accomplished primarily by an increase in the unit-production, and secondarily by the reduction in the losses incurred in the processing channel. The total loss of rice occurred during the harvesting, drying and milling was estimated at about 11 percent point of the total yield in Korea (12).

The losses are caused by several factors such as improper design and operation of the machinery, careless handling of the products, etc. For the designs and operations of the agricultural machinery the mechanical and physical properties of the grains themselves are indispensible data.

Since the high yielding rice varieties were introduced in this country in early 1970's, the modification and/or development of the conventional harvesting and processing machinery, and their systems have been emphasized in reducing the losses. However, researches on the mechanical properties of the new rice varieties have rarely been conducted up to now.

This study was attempted to find the physical properties of rice grains which can be classified into (1) the mechanical and rheological, (2) the electrical, (3) the thermal, (4) the optical and (5) the particle statistics. Especially, for the study of stress cracking due to drying and milling of rice, it is essential to understand the variation of compressive strength, modulus of elasticity and the toughness of grain kernels depending on the moisture contents and rice varieties.

The specific objectives of this study are as follows:

(1) to determine the bioyield point and maximum compressive strength of both rough and brown rice.

(2) to obtain the variation of modulus of elasticity of both rough and brown rice,

(3) to determine the moduli of resilience and toughness of both rough and brown rice.

II. Review of Literatures

According to Hertz theory of contact stresses, stress distribution and deformation of the compressed material are influenced by the shape of the contact surfaces. If the convex body under load is not spherical, the radii of curvatures characterizing the shape of the material are to be measured and considered in the calculations. For the case where a product is loaded with a steel flat plate, Hertz proposed a semi-empirical equation to compute the modulus of elasticity (1).

ASAE Standard S368.1 proposed the standard procedures for compression test of food materials of convex shape. This standard is intended to use in determining mechanical attributes of food texture, resistance to mechanical injury and force-deformation behavior of food materials of convex shape, such as fruits and vegetable, seeds and grains, and manufactured food materials (2).

Arora et al. (3) found that rice kernels were fairly elastic in axial compression up to a load of 10kg. However, their maximum compressive strengths lie between 15 and 18 kg. Above 10 kg, the load-deformation plot did not remain linear; kernels started yielding with loads greater than about 10 kg. Average modulus of elasticity of rice kernels was found to be 2.448x10^4 kg/cm^2 from the linear portion of the load-deformation curve. Average tensile strength of rice kernel was found to be 117.84 kg/cm^2.

Hiroshi et al. (4) reported that the relation of breaking load in grains of milled rice to moisture content, M, was expressed as two different exponential functions which were divided at the point of M = 14.5 %.

Prasad and Gupta (5) studied the behavior of paddy grain under quasi-static compressive loading.

Kim and Koh (6) determined experimentally the physical properties of rice such as volume, bulk density, true density, and porosity of the grain. The regression equations of the physical properties were determined as a function of moisture content.

Arnold et al. (7) tested the variation in the deformation of a wheat kernel due to the variation in the Poisson's ratio. They used Poisson's ratio of 0.3, 0.4 and 0.5 to study the variation in deformation, and found that variations in Poisson's ratio had relatively little effect on the load deformation curves.

Misra et al. (8) proposed a functional relationship for describing the effect of moisture content on the modulus of elasticity of remoistened soybeans. Samples were checked for cracks by a simple handling process.

Bilanski (9) applied compressive loads at the rate of 1.27 mm/min. to soybeans and measured force and work required to initiate seedcoat rupture. Average force to initiate seedcoat rupture dropped from 57.8 N (13 lb) at 1 percent moisture (w.b) to 44.4 N (10 lb) at 16 percent moisture (w.b) for a soybean loaded in the horizontal hilum position.

Paulsen (10) determined an average compressive force, deformation, and toughness at soybean seedcoat rupture under quasi-static loading as a function of moisture content and loading position. He also found the effect of deformation rate and soybean size on compressive force, deformation, and toughness at seedcoat rupture depending on moisture content and loading position.

Yamaguchi et al. (11) made the compression test using the test pieces of the rice endosperm formed into a cylindrical shape to investigate the viscoelastic property of a rice kernel.

III. Materials and Methods

A. Experimental Apparatus

The equipment used for compression test is a parallel plate equipped with a ring type load cell, which is easy to measure the quasi-static loading (Fig. 3-1). The equipment was driven by a variable speed motor, which can be controlled from 1500 rpm to 150 rpm with a speed variation of 2 percent.

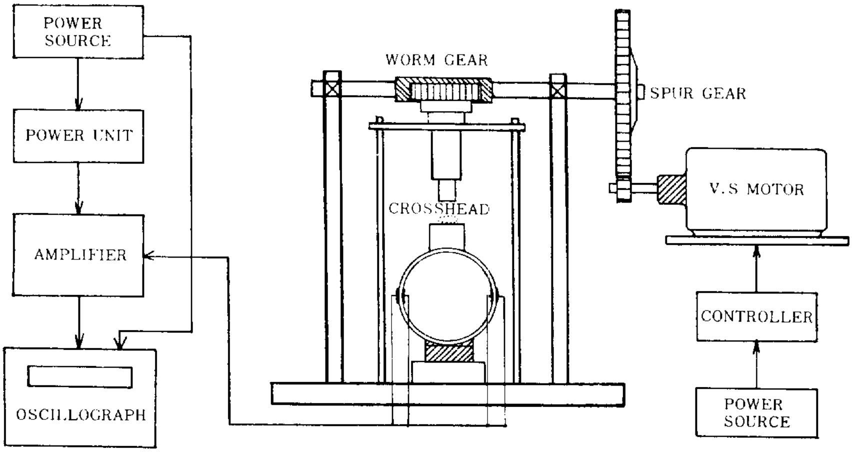

Fig. 3-1. Schematic diagram of compression test equipment

To reduce the speed of the motor, a gear transmission having a reduction ratio of 1/180 was used. The crosshead was driven by a worm gear set.

An oscillograph was used to record the force-time relationship on the chart. The speeds of crosshead and the recording chart were synchronized in order for the force-time curve to become the force-deformation curve.

B. Methodology

The rice varieties used for this study are shown in Table 3-1. Two Japonica and two Indica rice varieties which were grown at the University farm and harvested in September 1983 were used for the test runs to investigate the moisture effect on the mechanical properties. These Samples having relatively high moisture contents at harvest were dried with the natural air drying method at the laboratory until the desired moisture contents were obtained for each test run. The moisture contents of the samples adopted in this experiment were varied from 24% to 12% with about 2% intervals. More than ten replications were made for each treatment.

To investigate the effect of rice varieties on the mechanical properties another tests were done with 9 rice varieties, which were harveested in 1982 and stored, and with two rice varieties harvested in 1983. These varieties had about 14% moisture content.

Table. 3-1. The rice varieties used for the experiment.

Type	Variety	Year of harvest	Remarks
Japonica	Akihikari	1983	harvested and hulled manually
	Nongbag		
	Samnam	1982	
	Gwanak		
	Jinheung		
	Palgeum		
Indica	Milyang 23	1983	
	S312		
	Yusin	1982	
	Taebag		
	Nampoong		
	Milyang 23		
	Hangangchal		

A completely randomized design was used for the test runs and each treatment was replicated more than 10 times.

In compression test the load was applied to the rice kernel, which was placed on the plate with flat position, with a constant speed of 1.25 mm/min.

Room temperature and relative humidity of the air were 23±2°C and 75±5%, respectively, during the experiment.

From the force-deformation curves obtained from compression tests, the followings were analyzed and compared among the samples: bioyield point, maximum compressive strength, deformation at bioyield and rupture points, moduli of resilience and toughness, and moduli of elasticity and stiffness.

The deformations at bioyield point and at maximum compressive strength can be obtained from the speed ratio of the crosshead and chart, and the distance moved from the origin of the curve to the bioyield point and rupture point.

The moduli of resilience and toughness can be analyzed by measuring the coresponding area under the force-deformation curve with a planimeter.

The modulus of elasticity is calculated from a formula based on the Hertz theory for a convex body loaded with a steel flat plate. The equation proposed by ASAE Standard 368.1. is as follows.

$$E = \frac{0.531\ F\ (1-u^2)}{D^{3/2}}\ (1/R + 1/R')^{1/2}$$

where

E = modulus of elasticity (kg/mm^2), F = force (kg)

D = elastic deformation, u = Poisson ratio

R, R' = radii of curvature of convex body at the points of contact (mm)

0.531 = constant valid for the case where the angle between the normal planes containing the principle curvatures of the convex body is 90° deg. and the difference between the curvatures in each plane is small.

Poisson's ratio was assumed to be 0.3 in this case because it varies from 0.25 to 0.49 in biological materials. The radii of curvature of rice were calculated approximately by the following formula (ASAE S 368.1).

$$R \cong H/2 \quad , \qquad R \cong \frac{H^2 + L^2/4}{2H}$$

where H = thickness of rice, L = length of rice

The variation in each property mentioned above was studied for various varieties and moisture content levels.

IV. Results and Discussion

A typical force-deformation curve obtained from oscillograph in compression test is shown in Fig. 4-1. From these curves, the physical properties of of rice were analyzed and compared among the samples.

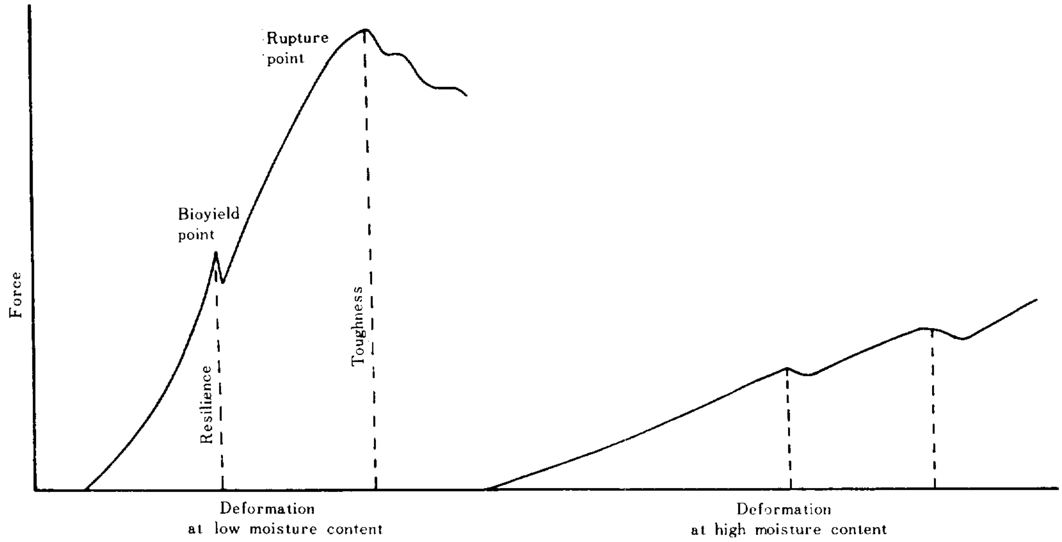

Fig. 4-1. Typical force-deformation curves obtained from oscillograph

A. Bioyield point

Bioyield point is a point on the force-deformation curve at which there occurs an increase in deformation with a decrease or no change in force.

1) Effect of moisture content

The effect of moisture content on bioyield point of brown & rough rice at constant rate of deformation is shown in Fig. 4-2.

The bioyield point of brown & rough rice increases with decrease in moisture content and the difference of bioyield point between brown and rough rice is about 0.5-1 kg. There was a great change in the values of bioyield point between 14 to 18 percent moisture content of brown rice as compared with those between 20 to 24 percent moisture content. This may be due to the elastic behavior of rice at lower range of moisture content. As evident from Fig. 4-2, the values of bioyield point of Japonica type were higher than Indica when the moisture content was below 18%, but those were lower when it was above 18%.

2) Effect of rice varieties at low moisture content

The comparison of bioyield point of brown rice is shown in Fig. 4-3 with the result of Cramer's multiple-range test. There was no significant difference in the bioyield points among the varieties of Japonica

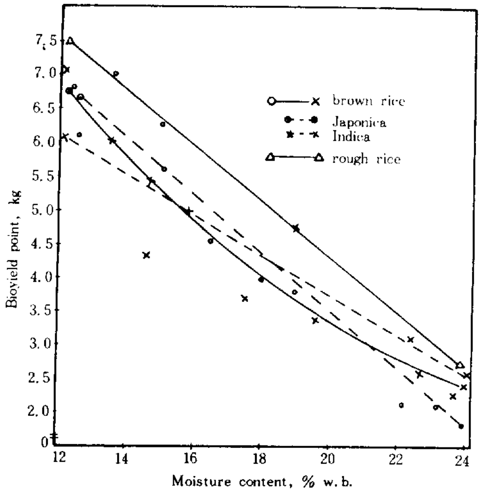

Fig. 4-2. Effect of moisture content on bioyield point of brown and rough rice in quasi-static compression test

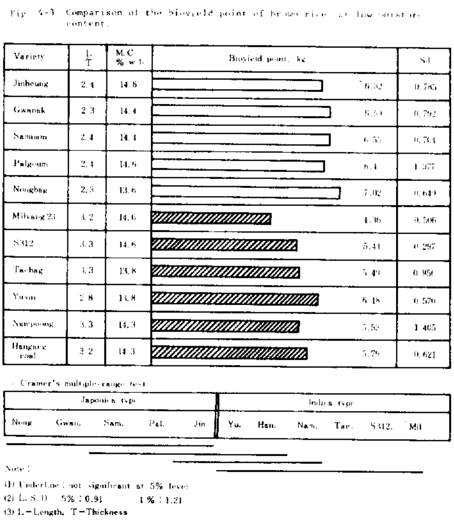

Fig. 4-3. Comparison of the bioyield point of brown rice at low moisture content

type as well as among Indica type except Milyang 23. However, Cramer's multiple-range test indicates a highly significant difference between Japonica and Indica types at 5% level.

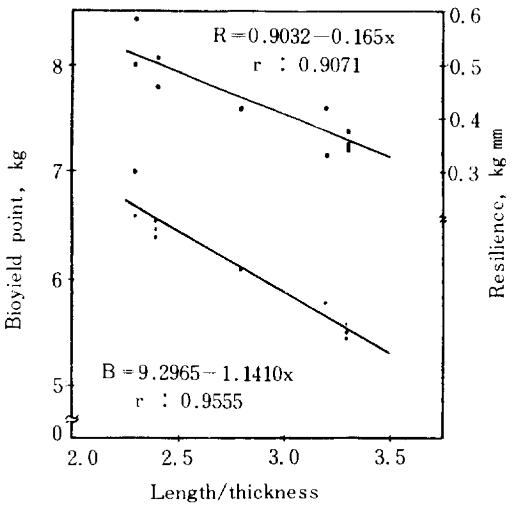

Fig. 4-4. The variation of bioyield points, resilience of brown rice with the ratio of length to thickness at low moisture content

Particularly, highly significant difference in the bioyield point appeared in Milyang 23, one of the Indica types. Also, Yusin which belongs to a medium type rice with the ratio of length to thickness is 2.8 has higher bioyield point than any other variety of Indica type. Hangangchal has high value of bioyield point due to its special chemical composition. Fig. 4-4 shows the effect of ratio of length to thickness on the bioyield point and the modulus of resilience of brown rice.

B. Maximum Compressive Strength

The maximum compressive strength is a value of rupture point, which is the maximum load during a compression test. Rupture point is a point on the force-deformation curve at which the loaded specimen shows a failure in the form of breaks or cracks.

1) Effect of moisture content

The effect of moisture content on maximum compressive strength of brown rice is shown in Fig. 4-5 and Fig. 4-6. The highest maximum compressive strength was obtained at the moisture content between 13.5 to 15.0 percent, presenting appreciable variations among the varieties. At high moisture content levels, the variation in maximum compressive strength was

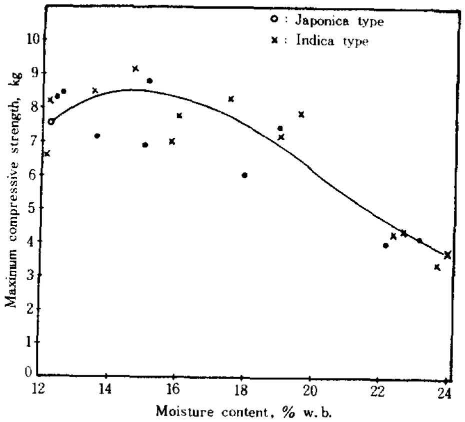

Fig. 4-5. Effect of moisture content on max. compressive strength of brown rice

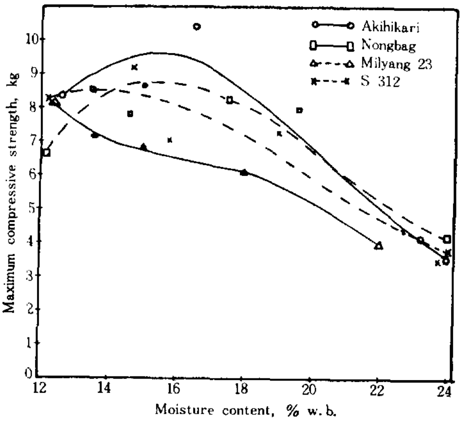

Fig. 4-6. Effect of moisture content on max. compressive strength of the varieties of brown rice

not appreciable.

2) Effect of rice varieties at low moisture content

Table 4-1 presents the values of maximum compressive strengths of brown rice kernels obtained from the 11 rice varieties having low moisture contents. The maximum compressive strength ranged from 5.66 to 11.4 kg, indicating significant differences among the varieties.

Table 4-1. Cramer's multiple-range test of the maximum compressive strength of brown rice at low moisture content

Type	Variety	$\frac{L}{T}$	M. C % W. b	Max. Com strength, kg	Sd
Japonica	Jinheung	2.4	14.6	11.40	0.86
	Gwanak	2.3	14.4	9.94	1.43
	Samnam	2.4	14.4	6.70	0.58
	Palgeum	2.4	14.6	10.81	1.37
	Nongbag	2.3	13.6	7.08	0.78
Indica	Milyang 23	3.2	14.6	7.81	0.30
	S 312	3.3	14.6	9.22	0.82
	Taebag	3.3	13.8	5.66	0.67
	Yusin	2.8	13.8	7.70	0.75
	Nampoong	3.3	14.3	7.83	1.11
	Hangangchal	3.2	14.3	8.87	0.33

Jin. Pal. Gwan. S312. Han. Nam. Mil. Yusin. Nong. Sam. Taebag

Note:

(1) underline : not significant at 5% level.

(2) L. S. D 5% : 1.2 1% : 1.49

(3) L = Length, T = Thickness

In neglecting the slight differences in moisture contents of the samples, Cramer's multiple-range test was made to identify any significant differences in the maximum compressive strength among the varieties. According to the result, Jinheung and Palgeum have higher compressive strength than any other variety and Milyang, Yusin, Nongbag, Samnam and Taebag have lower strength. It is also noted that there is no significant difference between Japonica and Indica types.

C. Deformation at Bioyield and Rupture Points

The effect of moisture on the deformation at bioyield and rupture points of rice is shown in Fig. 4-7 and Fig. 4-8, respectively. These curves reveal that with increase in the moisture content, deformation at bioyield point first decreased slightly and then increased after reaching a minimum value at the moisture content of around 17 percent, and deformation at rupture point increased gradually. This may be due to the viscous behavior of rice with higher moisture content.

As shown in Fig. 4-8, the effect of moisture content on deformation at bioyield point of rough rice has a similar trend to brown rice. Rough rice of Indica type generally has higher deformation than Japonica type at bioyield point.

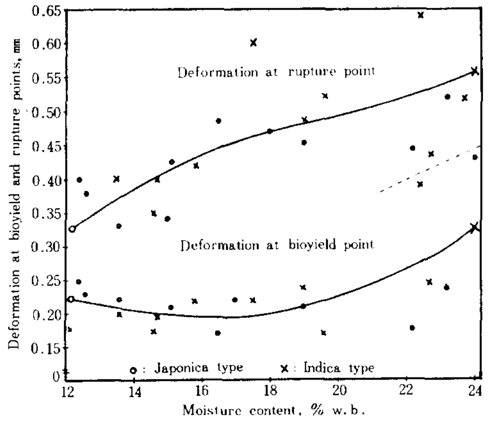

Fig. 4-7. Effect of moisture content on deformation bioyield and rupture points of brown rice

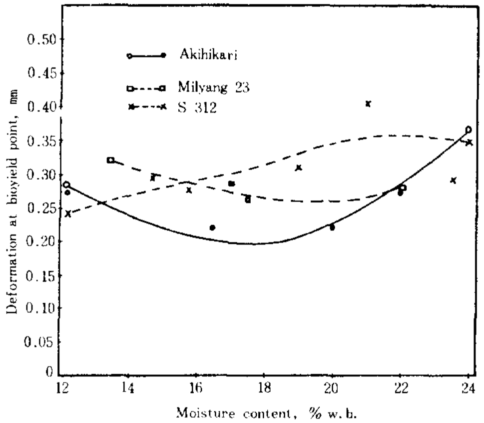

Fig. 4-8. Effect of moisture content on deformation at bioyield point of the varieties of rough rice

D. Moduli of Resilience and Toughness

The modulus of resilience is defined as the energy required to deform a grain to its bioyield point. The modulus of toughness is the energy required to deform a grain to its maximum strength.

1) Effect of moisture content

The variation in modulus of resilience of brown rice with moisture content is shown in Fig. 4-9. The values of the modulus of resilience of Japonica type were higher than those of Indica type at the moisture content below 19 percent, and lower above 19 percent. In case of Japonica type, the values of the modulus of resilience decreased with increase in the moisture content. However, Indica type rice indicated a minimum value at around 19 percent moisture content.

Fig. 4-10 shows the effect of moisture content on the modulus of toughness of brown rice. In general, the modulus of toughness first increases, attains peak value and then decreases with increase in the moisture content. Its values are maximum between 15 to 17 percent moisture content. The

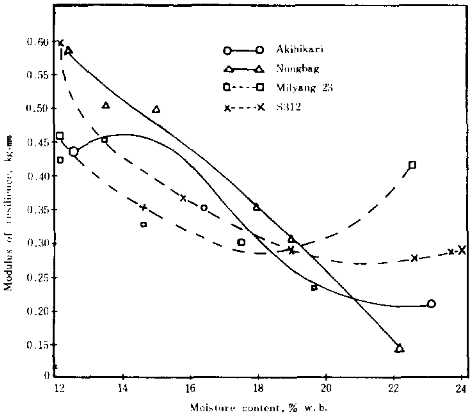

Fig. 4-9. Effect of moisture content on the modulus of resilience of the varieties of brown rice

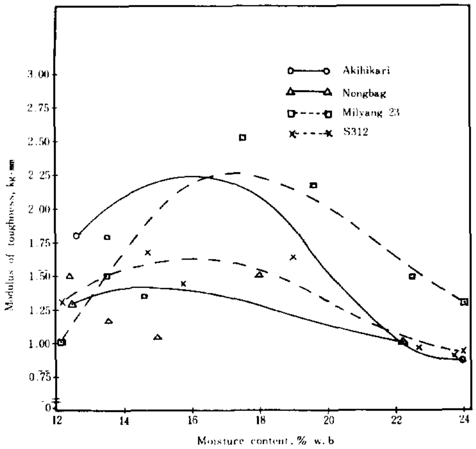

Fig. 4-10. Effect of moisture content on the modulus of toughness of the varieties of brown rice

maximum values of Akihikari and Milyang 23 are higher than those of Nongbag and S312.

2) Effect of rice varieties at low moisture content

Cramer's multiple-range test of the modulus of resilience and toughness of brown rice at low moisture content is shown in Table 4-2. The modulus of resilience of Japonica type was higher than that of Indica type, in general. The values of Japonica type vary from 0.460 to 9.592 kg.mm, and those of Indica type from 0.327 to 0.428 kg.mm. It was noted that the modulus of resilience was proportional to the bioyield point. Similar trend was observed in the modulus of toughness but there was no distinct significance between Japonica and Indica types. It varies from 1.096 to 2.512 kg.mm for Japonica type and from 0.172 to 1.713 kg.mm for Indica type at the moisture content of about 14% (w.b.).

E. Moduli of Elasticity and Stiffness

The ratio of stress to strain in more or less elastic region of the force-deformation curve may be referred to as the modulus of elasticity or Young's modulus.

The modulus of stiffness is indicated by the slope of the initial straight line portion of force-deformation curve. In the case of nonlinear force-deformation behavior, stiffness can be defined in terms of initial tangent modulus, secant modulus, or tangent modulus. In this study secant modulus was used as stiffness, which was the ratio of force to deformation at bioyield point.

1) Effect of moisture content

As shown in Fig. 4-11, the moduli of elasticity and stiffness of brown rice decreased linearly with increase in the moisture content. The effect of moisture content on the modulus of elasticity of Japonica and Indica types of brown rice is shown in Fig. 4-12, in which the modulus of elasticity of Japonica type was higher than that of Indica type at the moisture content above 14.2 percent.

2) Effect of rice varieties at low moisture content.

Cramer's multiple-range test of the moduli of elasticity and stiffness of brown rice at low moisture content is presented in Table 4-3. The moduli of elasticity and stiffness showed high significant differences among the varieties at 1 % level, but no significant difference between Japonica and Indica types.

Table 4-2. Cramer's multiple-range test of the moduli of resilience and toughness of brown rice at low moisture content

Type	Variety	L/T	M. C %w. b	Resilience kg. mm	Sd	Toughness kg. mm	Sd
Japonica	Jinheung	2.4	14.6	0.46	0.09	2.51	0.51
	Gwanak	2.3	14.4	0.59	0.20	1.76	0.31
	Samnam	2.4	14.4	0.50	0.10	1.09	0.11
	Palgeum	2.4	14.6	0.51	0.15	2.23	0.59
	Nongbag	2.3	13.6	0.50	0.13	1.14	0.18
Indica	Milyang 23	3.2	14.6	0.32	0.04	1.30	0.16
	S 312	3.3	14.6	0.34	0.06	1.65	0.12
	Taebag	3.3	13.8	0.35	0.09	0.71	0.13
	Yusin	2.8	13.8	0.42	0.07	1.21	0.26
	Nampoong	3.3	14.3	0.38	0.10	1.35	0.23
	Hangangchal	3.2	14.3	0.42	0.07	1.71	0.14

Resilience :

Gwan. Pal. Nong. Sam. Jin. Yusin. Han. Nam. Taebag. S312. Mil.

Toughness :

Jin. Pal. Gwan. Han. S312. Nam. Mil. Yusin. Nong. Sam. Taebag.

Note :

(1) Underline : not significant at 5% level.
(2) Resilience L. S. D 5 % : 0. 15 1 % : 0. 19
(3) Toughness L. S. D 5 % : 0. 39 1 %0. 51
(4) L = Length, T = Thickness

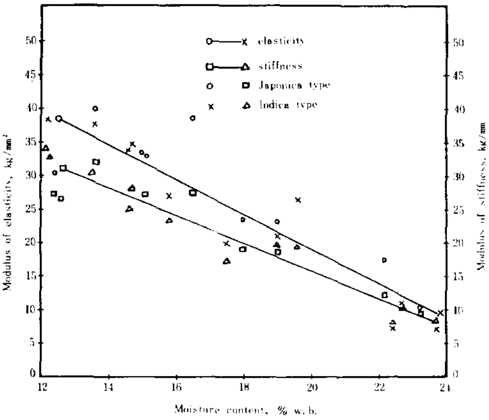

Fig. 4-11. Effect of moisture content on the moduli of elasticity and stiffness of brown rice.

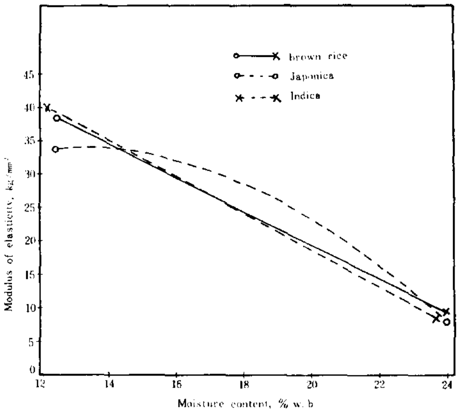

Fig. 4-12. Effect of moisture content on the modulus of elasticity of brown rice

Table. 4-3. Cramer's multiple range test of the moduli of elasticity and stiffness of brown rice at low moisture content.

Type	Variety	L / T	M. C. % w. b.	Elasticity kg / mm²	Sd	Stiffness kg / mm	Sd
Japonica	Jinheung	2.4	14.6	42.30	4.98	33.46	3.06
	Gwanak	2.3	14.4	40.98	5.46	32.64	2.37
	Samnam	2.4	14.4	42.06	2.97	32.88	2.55
	Palgeum	2.4	14.6	37.56	4.47	30.64	3.64
	Nongbag	2.3	13.6	39.88	8.69	32.33	4.73
Indica	Milyang 23	3.2	14.6	33.79	3.28	25.04	5.47
	S312	3.3	14.6	34.87	4.03	28.22	1.92
	Taebag	3.3	13.8	48.77	5.88	33.83	1.81
	Yusin	2.8	13.8	51.03	6.62	36.58	3.05
	Nampoong	3.3	14.3	45.10	5.54	32.25	3.40
	Hangangchal	3.2	14.3	40.10	5.98	31.22	4.47

Elasticity :

Yusin. Tae. Nam. Jin. Sam. Gwan. Han. Nong. Pal. S312. Mil.

Stiffness :

Yusin. Tae. Jin. Sam. Gwan. Nong. Nam. Han. Pal. S312. Mil.

Note :

(1) Underline : not significant at 5% level.
(2) Elasticity L. S. D 5% : 7.30 1% : 9.69
(3) Stiffness L. S. D 5% : 4.16 1% : 5.53
(4) L = Length, T = Thickness

V. Conclusions

The following conclusions were drawn from the results of the investigation:

1. Of all the parameters investigated, moisture content has the greatest influence on the mechanical and rheological properties of brown & rough rice under quasi-static compressive loading. Viscous properties dominated at high moisture content while elastic properties dominated at low moisture content of brown and rough rice.

2. The value of bioyield point of brown rice varied from 2.0 to 7.2 kg between 24 to 12% moisture content. Also, the value of Japonica type was higher than that of Indica at the moisture content below 18%, but lower above 18%. The bioyield point of rough rice varied from 2.5 to 7.6 kg between 24 to 12% moisture content. The bioyield point of brown rice at the low moisture content decreased linearly with an increase in the ratio of length to thickness of the grain.

3. The maximum compressive strength of brown rice ranged from 2.94 to 10.43 kg between 24 to 12% moisture content, and from 5.66 to 11.4 kg at about 14% moisture content. There is no significant difference in the maximum compressive strength bet-

ween Japonica and Indica types, but highly significant differences among the varieties.

4. Deformation at bioyield point of brown rice varied from 0.17 to 0.43 mm between 12 to 24% moisture content, indicating a minimum at about 17%. Deformation at rupture point of brown rice increased with moisture content, and ranged from 0.33 to 0.64 mm between 12 to 24% moisture content. Deformation at bioyield point of rough rice was 0.20 to 0.41 mm when the moisture content ranged from 12 to 24 percent.

5. The modulus of resilience of brown rice ranged from 0.142 to 0.603 kg·mm for Japonica type and from 0.229 to 0.601 kg·mm for Indica type between 24 to 12% moisture content.

6. The modulus of toughness of brown rice ranged from 0.841 to 2.795 kg.mm between 24 to 12% moisture content. There is no significant difference between the Japonica and Indica types, but highly significant diffenences among the varieties.

7. The moduli of elasticity and stiffness of brown rice decreased linearly with increase in the moisture content; and their values ranged from 7 to 40 kg/mm^2 and from 8 to 34 kg/mm between 24 to 12% moisture content, respectively.

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