Effect of the Silica Content on Digestibility of Rice Straw

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Introduction

Silica and lignin contained in cell wall of rice straw are considered as indigestible fractions of cell wall since their percent recoveries were found about 100% in the feces, and they were suspected to be the factors restricting digestibility of cell wall[12].

Effect of silica in forages upon digestibility was estimated at a 3.0% decrease of dry matter digestibility per 1.0% increase of the silica content, and this relationship has been recommended for calculation of digestible dry matter of forages[5]. On the other hand, Minson[8] observed that there was no correlation between silica contents and organic matter digestibility of Panicum species.

Lignin has been reported as negatively correlated significantly to dry matter digestibility, voluntary food consumption, and cellulose digestibility in ryegrass[3] and was assumed as the main inhibitor of plant hemicellulose digestion in ruminants[4].

In view of the high content of silica in rice straw, this study was done to observe the effect of various silica percentages on the digestibility of CW fractions. Since lignin is associated with silica like a complement to silica, effect of lignin was also studied.

Materials and methods

Forty-four sorts of rice straw were collected from five different places in Japan. Silica content was determined from successive determination of dry matter and ash. The ash in a crucible was added twice with 10 m*l* of 50% HCl solution (v/v) and dehydrated in a boiling water bath. The dried silica was transferred to a filter paper in a filter manifold, washed with water 3–4 times, put into the same crucible, dried and ashed at 600°C.

Twelve out of 44 sorts of rice straw were chosen as the representative samples to be used in this study, with silica contents ranging from 5.5 to 19.6% (Table 1b). Their chemical composition is presented in Table 1a.

Fractionation of dry matter samples into cell wall (CW) and cellular content (CC) and CW into a and b fractions was done following the method of enzymatic analysis[1]. Organic fractions were obtained by subtracting ash from DM. Lignin of CW was determined by the hydrolysis treatment of CW with 72% sulfuric acid for 4 hr. Lignin remained unaffected, and the hydrolyzed solution was used for measurement of glucose by glucose oxidase on photometer 420 nm. Cellulose value was calculated as glucose × 0.9.

Digestibility tests were done for 30 hr by *in vitro* and *in situ* methods. Medium used in the *in vitro* test was a mixture of artificial saliva[4] and rumen juice (4:1). The artificial saliva solution was prepared by bubbling with CO_2 gas for 15 hr before use. Cysteine-HCl

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Table 1a. Chemical composition of samples

(% DM)

No.	OM	DM		OM		CW		OCW	
		CC	CW	OCC	OCW	a	b	Oa	Ob
2	83.8	26.3	73.7	14.9	68.9	6.9	66.8	5.8	63.1
7	82.7	29.1	70.9	18.4	64.3	8.4	62.5	6.5	57.9
8	81.6	28.2	71.8	17.2	64.4	9.9	61.9	7.9	56.5
23	78.9	34.4	65.6	20.7	58.2	6.3	59.3	5.4	52.8
22	77.0	35.2	64.8	20.8	56.2	8.7	56.1	7.5	48.7
24	76.3	35.4	64.6	20.5	55.8	8.2	56.4	7.1	48.7
27	75.8	32.5	67.5	17.8	58.0	6.3	61.2	4.9	53.1
34	72.3	37.7	62.3	20.5	51.8	9.5	52.8	7.9	43.9
41	75.3	31.3	68.7	17.5	57.8	7.1	61.6	6.1	51.7
16	71.4	32.4	67.6	16.2	55.2	6.5	61.1	5.0	50.2
39	71.2	32.7	67.3	17.2	54.0	9.8	57.5	8.2	45.8
14	67.7	31.6	68.4	16.8	50.9	6.3	62.1	3.8	47.1

Note: Fraction a and fraction b are soluble and insoluble fractions, respectively, obtained by cellulase treatment of CW.

Table 1b. Chemical composition of samples

(% DM)

No.	Lignin	Silica	Cellulose	Hemicellulose*
2	18.0	5.5	31.7	18.5
7	16.4	7.2	30.4	16.9
8	15.2	8.4	29.3	18.9
23	16.6	8.7	27.6	12.7
22	16.3	10.0	25.8	12.7
24	16.5	10.6	26.1	11.4
27	19.4	11.2	24.0	12.9
34	14.6	11.9	26.4	9.4
41	14.1	13.2	30.3	11.1
16	15.9	13.4	25.6	12.7
39	13.6	15.4	25.4	12.9
14	13.4	19.6	24.1	11.3

* Hemicellulose = CW − (cellulose + lignin + silica)

and 0.1% resazurin solution were added at the rate of 0.25 g/l and 1 ml/l, respectively, prior to gas bubbling. Urea, 0.12% (w/v), was added before use. Rumen juice was a mixture of the liquid and filtrated solid fraction and centrifuged for 5 min at 1000 rpm. Approximately 1 g sample was placed in a 100 ml Erlenmeyer flask and 50 ml medium was added. Incubation was carried out in a shaking incubator (at 40°C).

Approximately 2 g of the straw sample was enclosed in a nylon bag and put into the rumen of cattle, fed 6 kg/day of hay and 1 kg/day of corn. Calculation of the digestibility value was corrected by a blank sample which was incubated in a shaking incubator.

The residual dry matter of samples from digestibility trial was determined for their CW, lignin, silica and cellulose by the procedure described above.

Calculation of the digestibility of Ob was as follows:

$$\frac{\text{digestible OCW} - \text{digestible Oa}}{\text{Ob content}} \times 100\%$$

where, digestible OCW = OCW digestibility × OCW content (%)
digestible Oa = Oa content, because Oa was assumed as a fraction which is completely digested.

Digestible organic matter (DOM) was predicted from a summative equation adopted from the study of Abe and Nakui on forages[2],

$$\text{DOM} = \text{digestible OCC} + \text{digestible Oa} + \text{digestible Ob}.$$

Regression equations for each of the above fractions are as follows:

$Y = 1.042X - 8.1$ for OCC ($r = 0.993$),
$Y = 1.114X - 3.2$ for Oa ($r = 0.996$) and
$Y = 0.502X - 6.6$ for Ob ($r = 0.993$).

Table 2. Distribution of silica to various fractions and digestion residue

(% DM)

No.	Fibrous fraction		Digestion residue *in vitro* 30 hr	30 hr nylon bag
	CW	Ob		
2	3. 8(69. 1)	3. 3(60. 0)	3. 9(71. 0)	3. 2(58. 2)
7	6. 4(88. 9)	4. 2(58. 9)	4. 5(63. 0)	3. 7(51. 4)
8	6. 5(77. 4)	5. 3(62. 6)	5. 7(67. 9)	4. 4(52. 4)
23	6. 5(74. 7)	6. 0(68. 1)	6. 0(69. 0)	4. 5(51. 7)
22	8. 0(80. 0)	7. 0(70. 0)	7. 3(73. 0)	4. 4(44. 0)
24	8. 5(80. 2)	7. 4(69. 9)	7. 4(69. 8)	4. 0(37. 7)
27	8. 5(75. 9)	7. 7(68. 6)	8. 3(74. 1)	5. 2(46. 4)
34	9. 8(82. 4)	8. 6(72. 0)	8. 8(73. 9)	6. 0(50. 4)
41	10. 7(81. 1)	9. 4(71. 8)	10. 2(80. 3)	6. 0(45. 5)
16	11. 3(84. 3)	10. 4(78. 0)	10. 6(79. 1)	6. 8(50. 7)
39	12. 6(81. 8)	11. 1(72. 3)	11. 6(75. 3)	5. 9(38. 3)
14	16. 1(82. 1)	14. 4(73. 6)	15. 1(77. 0)	8. 3(42. 3)
Mean±SE	(79. 8±5. 1)	(68. 8±5. 7)	(72. 8±4. 9)	(47. 4±6. 1)

Numerals in parentheses: Percent to the total amount of silica.

Results and discussion

Silica deposited in cell wall varied from 69.1 to 88.9% with a mean of 79.8% and that in Ob varied from 58.9 to 78.0% with a mean of 68.8% (Table 2). A portion of silica was lost during the preparation of CW (19.5%) and of Ob from CW (13.2%). The difference in percent of the lost silica may be due to different pH of buffer solution used during preparation of CW and Ob.

Solubilization of silica during incubation in the rumen was higher than that of *in vitro* incubation. In animal body, silica is absorbed, flew through alimentary tract and recovered in the feces or carried in the blood stream to the kidney[6].

Lignin is deposited in CW and Ob in a smaller extent and with smaller variation than that of silica as shown in Table 3. In CW it varied from 62.3 to 73.3% with a mean of 67.3%, while in Ob it varied from 45.6 to 63.3% with a mean of 51.6%.

Table 4 shows the correlation coefficients and regression equations between percentages of silica or lignin and structural or chemical components (%) of samples. Silica percentage was negatively correlated with the percentage of OCW (r=−0.832) and Ob (r=−0.745).

Table 3. Lignin distribution

(% DM)

No.	CW	Ob
2	13. 2(73. 3)	11. 4(63. 3)
7	11. 6(70. 7)	9. 5(57. 9)
8	10. 9(71. 6)	8. 6(56. 6)
23	10. 9(65. 7)	8. 8(53. 0)
22	10. 6(65. 0)	7. 9(48. 5)
24	10. 7(64. 8)	8. 0(48. 5)
27	12. 1(62. 4)	10. 3(53. 1)
34	9. 1(62. 3)	6. 4(43. 8)
41	9. 7(68. 8)	7. 3(51. 8)
16	10. 8(67. 9)	8. 0(50. 3)
39	9. 1(66. 9)	6. 2(45. 6)
14	9. 2(68. 7)	6. 3(47. 0)
Mean±SE	(67. 3±3. 5)	(51. 6±5. 6)

Numerals in parentheses: Percent to the total amount of lignin.

The higher the silica percentage, the lower was the percentages of lignin, cellulose and hemicellulose as shown by r=−0.662, r=−0.680 and r=−0.655, respectively. Lignin percentage was not correlated to any other chemical components except negatively to silica.

Based on the negative correlation between lignin and silica it seems that only one of them may have effect on digestibility of CW fractions.

CW fractions were tested for their digesti-

Table 4. Relationship of silica and lignin content to structural and chemical components of samples

Item	Correlation coefficient	Regression equation
Silica and CC	0.333	Y=29.05+0.28X
Silica and CW	−0.333	Y=70.95−0.28X
Silica and OCC	−0.121	Y=18.91−0.06X
Silica and OCW	−0.833**	Y=71.14−1.17X
Silica and a	−0.133	Y= 8.38−0.05X
Silica and b	−0.240	Y=62.57−0.23X
Silica and Oa	−0.291	Y= 7.54−0.11X
Silica and Ob	−0.745**	Y=63.64−1.07X
Silica and lignin	−0.662*	Y=19.29−0.31X
Silica and cellulose	−0.680*	Y=32.41−0.46X
Silica and hemicellulose	−0.655*	Y=19.25−0.52X
Lignin and CC	−0.166	Y=37.04−0.30X
Lignin and CW	−0.233	Y=70.01−0.16X
Lignin and OCC	−0.019	Y=17.88+0.02X
Lignin and OCW	0.521	Y=32.96+1.58X
Lignin and a	−0.378	Y=12.62−0.30X
Lignin and b	0.290	Y=50.34+0.61X
Lignin and Oa	−0.234	Y= 9.27−0.19X
Lignin and Ob	0.572	Y=23.67+1.77X
Lignin and cellulose	−0.275	Y=29.35−0.14X
Lignin and hemicellulose	0.350	Y= 4.05+0.59X

* $P<0.05$, **$P<0.01$.

Table 5. Digestibility of some CW fractions by *in vitro* and *in situ* methods (% DM)

No.	*in vitro* (30 hr)			*in situ* (30 hr)			Cellulose	Hemicellulose
	CW	OCW	Ob	CW	OCW	Ob		
2	20.3	20.5	13.2	20.1	21.1	13.8	28.6	11.0
7	22.4	23.3	14.7	24.9	26.3	18.0	39.7	28.6
8	23.9	23.2	12.4	22.2	23.4	12.7	36.8	29.8
23	20.3	22.5	14.6	28.9	24.7	17.0	41.9	29.1
22	21.3	22.3	10.3	19.5	27.8	16.6	40.0	40.7
24	23.1	24.2	13.1	25.6	26.8	16.2	40.2	32.2
27	14.9	15.1	7.3	18.3	19.6	12.2	11.6	23.9
34	22.0	26.0	12.8	22.1	24.4	10.7	49.2	25.2
41	18.8	23.2	14.1	22.3	22.6	13.5	43.5	18.0
16	21.9	23.6	15.9	21.3	23.5	15.9	40.7	27.1
39	20.6	22.6	8.7	24.5	26.6	13.5	42.7	39.6
14	17.9	19.3	13.6	14.8	16.9	11.0	27.2	20.5
Mean	20.6	22.2	12.6	22.0	23.6	14.3	36.8	27.1
±SE	±2.5	±2.8	±2.6	±3.7	±3.2	±2.4	±10.0	±8.4

bility with the *in vitro* or *in situ* method and the digestibility values are presented in Table 5. It can be seen that CW, OCW and Ob were digested almost to the same extent by the two methods. However, values obtained *in situ* were slightly higher. Higher solubilization of silica occurred in the rumen (Table 2) may account for higher values of *in situ* digestibility.

Silica in CC was highly correlated to water-

Table 6. Correlation between silica in CW and digestibility of CW fractions

Item	*in vitro*	*in vivo*
Silica and CW dig.	r=−0.309	r=−0.416
Silica and OCW dig.	r=−0.059	r=−0.326
Silica and Ob dig.	r=−0.054	r=−0.440
Silica and cellulose dig.	—	r= 0.037
Silica and hemicellulose dig.	—	r= 0.113

Table 7. Correlation between lignin in CW and digestibility of CW fractions

Item	*in vitro*	*in vivo*
Lignin and CW dig.	r=−0.082	r= 0.012
Lignin and OCW dig.	r=−0.419	r=−0.105
Lignin and Ob dig.	r=−0.006	r= 0.359
Lignin and cellulose dig.	—	r=−0.201
Lignin and hemicellulose dig.	—	r=−0.358

Table 8. Digestible OM estimated using the summative equation

No.	% DOM
2	35.8
7	37.6
8	37.2
23	36.2
22	36.6
24	35.8
27	32.8
34	34.3
41	33.1
16	29.8
39	32.1
14	27.5

soluble fraction and hence it is logical to neglect it and take up only the silica in CW. Table 6 gives the correlation between silica in CW and digestibility of CW fractions. It shows that silica did not influence digestibility of CW fractions (low correlation coefficients between them). The same degree of correlation was also observed between lignin and digestibility of CW fractions (Table 7).

Digestible OM (DOM) is generally used as one of the parameters to evaluate the nutritive value of feed, so that percentage of DOM of the samples calculated using the summative equation is presented in Table 8.

Silica in CW was negatively correlated to DOM ($r=-0.875$, $P<0.01$) and expressed by the regression equation $Y=41.55-0.83X$, while lignin was not correlated significantly to DOM ($r=0.456$).

Regarding the prediction of *in vitro* organic matter digestibility (IVOMD) of forages, Smith et al.[9] reported that the decrease of the digestibility by 0.98% occurred for 1% increase of silica content.

Nutritive value (expressed in DOM) of the rice straw is also predictable from the above equation. The increase of silica content by 1% decreases DOM by 0.83%.

This relationship (1% increase of silica vs. 0.83% decrease of DOM) implies that the effect of silica on DOM is merely a direct physical outcome from the fact that the presence of silica reduces the amount of digestible components in the straw. Other specific effect of silica on straw digestibility was hardly recognized in this study.

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