Feeding Value of Steamed Wood and Explosively Depressurized Wood

By AKIHIRO TAKIGAWA

Department of Nutrition, National Institute of Animal Industry
(Kukizaki, Ibaraki, 305 Japan)

In Japan, the utilization of hard wood that was used as fuel formerly, has decreased with increasing use of petroleum and electric power. At present only a part of hard wood is used as the chips for pulp and as the mushroom culture bedlog. In addition to hard wood, enormous woody resources, i.e. pre-commercial thinning trees, forest residues such as branches and twigs, wood wastes in saw mills, bamboo and bamboo grass, etc. are left unutilized.

On the other hand, a huge amount of grain are imported for feed, and roughage is lacking remarkably for increasing number of cattle in Japan. Recently not only alfalfa hay cube, but also rice straw and sugar cane bagasse come to be imported to a considerable amount. If the above-mentioned woody resources can be used as roughage and energy feed, they will contribute a great deal to stabilize livestock farming in Japan.

Composition and structure of wood

Principal components of wood are cellulose (40 to 50%), hemicellulose (20 to 35%) and lignin (20 to 35%); these three account for more than 90% of wood, while protein, minerals and other components represent only less than 10%. The figures vary from wood to wood; softwood (wood of conifer) has more lignin and less hemicellulose than hardwood (wood of broad leaf tree).

Crystalline cellulose forms the basic structure of the cell walls of tree, surrounded by non-crystalline cellulose and hemicellulose. Lignin has the role of bonding cells and covering and reinforcing cellulose. When we compare this structure to the ferroconcrete structure, cellulose is equivalent to reinforcing rods, lignin to concrete and hemicellulose to wires which help reinforcing rods and concrete to achieve firm bonding.

When not processed, wood is hardly digested by ruminants. This is because the enzymes of microorganisms in the ruminant stomach cannot touch cellulose and hemicellulose, blocked by lignin which is too hard to be decomposed, and because the enzymes cannot break the firm crystalline structure of cellulose. Therefore, if the digestibility of wood is to be increased, the above-mentioned structure of wood needs to be destroyed in some way.

Processing methods to raise the digestibility of wood, and principles of steaming and explosive depressurization treatments

Attempts have been made to increase the digestibility of wood; they include chemical treatment using such materials as acids, alkalis and ammonium, biological treatment including decomposition by such white wood-rotting fungi as *Agricineae lentinus* and *Agricineae pleurotus*, preparation of wood for silage and treatment by fermentation, and physical treatment such as γ-ray radiation for pulverizing and grinding. However, any one of these methods can not be regarded as applicable to practical use. Main reasons are (1) no significant increase in digestibility can be achieved, (2) a high processing cost is required, (3) there is the need to dispose waste liquid after processing and (4) a long period of time is involved in the processing.

The process introduced here involves the steaming and fiber loosening of wood. Wood is steamed using a high-temperature, high-pressure saturated steam of 150 to 200°C and then its fiber is loosened by a double disk refiner. Another process, the explosive depressurization process, involves treatment of wood by saturated steam of 220°C or higher temperature and a high-speed discharge of steamed wood into the air, utilizing the theory of making popcorn.

After treatment for 10 to 20 min in the case of the steaming process and for 1 to 2 min in the case of the explosive depressurization process, hemicellulose of hardwood is hydrolyzed into a low molecular substance and becomes water soluble. Cellulose turns easier to be decomposed by enzymes, while lignin degenerates and a part of it becomes soluble in an organic solvent and a rare alkali. It is considered that these changes occur both by physical destruction under high temperature and high pressure and at the time of vaporization of hot water and by chemical destruction by for example, acetic acid produced by oxidation of acetyl groups contained in hemicellulose. The effect of these treatments considerably varies from hardwood to hardwood, too.[1]

In general, the effect of steaming appears at a relatively low temperature in the case of birches, poplars and oaks, whereas treatment at a higher temperature or for a longer period of time is needed for *Castanopsis cuspidata* and camphor trees.

Nutritive value of steamed and explosive-depressurized woods

1) Improvement in nutritive values by steaming and explosive depressurization treatments

(1) White birch[2]

Studies were conducted using white birch to observe changes in the components and digestibility

Table 1. Nutritive values of white birch chips after differrent treatments[2] (%)

	White birch chips			Alfalfa hay cube
	Crushed	Steamed	Explosive-depressurized	
Water content	7.3	23.1	79.2	10.3
Chemical composition (Dry base)				
Crude protein	0.8	0.8	0.8	18.9
Crude fat	1.0	1.8	3.3	2.2
Crude fiber	60.3	60.4	42.3	32.1
ADF	67.9	60.4	54.4	37.7
Nitrogen free extract	37.7	36.8	53.3	37.3
Lignin (ADL)	17.8	13.0	11.3	9.1
Crude ash content	0.4	0.2	0.3	9.4
Digestion coefficient				
Dry matter	4.7	60.6	60.7	60.4
Organic matter	5.7	61.7	61.1	61.2
Crude protein	0	0	0	75.7
Crude fiber	2.2	62.1	65.0	45.2
ADF	8.0	59.0	60.8	45.9
Nutrient				
DCP	0	0	0	14.3
TDN	8.0	65.5	66.5	56.4

Table 2. Effect of steam treatment on cellulase organic matter digestibility of some hard woods[3]

Species	Unprocessed	Steam treatment	
	Digestibility	Digestibility	Condition
White birch	3.4	64.6	10 kg/cm^2—15 min
Japanese oak	9.4	54.1	15—10
Siebold's beech	4.3	48.9	15—10
Castanopsis cuspidata	3.4	37.0	15—10

resulted from steaming and explosive depressurization. Steaming was carried out at 180°C under 10 kg/cm² pressure for 15 min, while explosive depressurization was carried out at 230°C under 28 kg/cm² pressure for 2 min. In both cases, peeled white birch was used, and the digestion coefficient was measured using goats.

The digestibility of unprocessed white birch is very low even when crushed. As Table 1 shows, the digestion coefficient of dry matter in crushed white birch is less than 5%. In addition, its TDN (total digestible nutrient) content, which indicates the value as an energy source, is only 8%, less than one-fifth of the value for rice straw.

When steaming and fiber loosening treatments were applied, to the white birch, the digestibility of dry matter, crude fibers and ADF (acid detergent fiber) composed mainly of cellulose and lignin showed a remarkable increase, and TDN content rose by about 8 times to 65.5%, although the content of components of the wood did not change greatly.

In the case of explosive depressurization treatment, fibrous and hardly digestible fractions such as ADF, NDF (neutral detergent fiber, contains hemicellulose in addition to ADF), crude fibers and lignin (ADL) decreased remarkably, while nitrogen free extract and other soluble substances greatly increased. Changes in hydrocarbons were caused chiefly by the decomposition of pentosan and the generation of soluble xylose and others. In addition, explosive depressurization treatment markedly increased the digestibility of dry matter, crude fibers and ADF, and the TDN content rose to 66.5%, a level similar to that of steaming treatment. These figures indicate the high energy value equivalent to that of such quality hay as alfalfa and orchard grass.

White birch chips steamed or subjected to explosive depressurization contain virtually no protein and minerals. Thus, special attention should be paid to add these nutrients to the chips before feeding them to cattle.

(2) Broad leaf trees[3)]

Effect of steaming in improving digestibility of various hard woods was studied. As Table 2 shows, in all kinds of wood examined, their digestibility increased more than 5 times by steaming.

2) *Nutritive value of steamed hard woods*[4)]

Among various hard woods, species which are abundant in Japan and represent each region were selected, and subjected to the digestibility test using goats.

(1) Chemical composition of various steamed woods

Lignin, NDF and ADF content of steamed woods varied with species and steaming conditions, as Table 3 shows. With the increase of temperature and pressure in steaming, NDF content decreased considerably, while ADF content showed no marked change. Hence, it is presumed that hemicellulose was decomposed and that it changed to soluble carbohydrate by steaming.

(2) Digestion trial using goats

Digestibility of various steamed woods was measured by the indirect methods that used alfalfa hay cube as a basal diet, as Table 4 shows. Digestibility of

Table 3. Chemical composition of some steamed woods[3)] (%)

Species	White birch	Siebold's beech			Japanese oak	*Castanopsis cuspidata*		*Castanopsis cuspidata var Sieboldii*	*Sasa kurilensis*	
Treatment (kg/cm²·min)	10—15	10—20	15—10	17—15	15—10	15—10	17—15	10—20	10—20	17—15
Moisture	23.1	36.6	36.5	18.3	29.9	48.0	37.1	42.9	38.9	49.2
Dry base										
Crude protein	0.8	1.0	0.8	0.9	0.8	1.1	1.1	1.9	3.0	3.5
Crude fat	1.8	0.4	0.6	0.3	0.5	0.7	0.8	0.7	1.5	1.9
NDF		89.7	71.3	68.4	66.6	75.1	71.7	88.7	80.7	58.9
ADF	60.4	67.5	64.3	66.2	61.7	68.1	67.4	69.4	57.3	58.6
Lignin (ADL)	13.0	15.6	14.0	14.9	12.7	17.1	15.8	17.8	16.0	12.6
Crude ash	0.2	0.8	0.6	0.8	0.5	0.5	0.5	1.0	3.7	4.0
Energy (Mcal/kg)		4.51	4.54	4.68	4.49	4.49	4.64	4.49	4.48	4.62

Table 4. Digestibility and nutrient contents of some steamed woods[4)] (%)

Species	White birch	Siebold's beech			Japanese oak	*Castanopsis cuspidata*		*Castanopsis cuspidata var Sieboldii*	*Sasa kurilensis*	
Treatment (kg/cm² · min)	10—15	10—20	15—10	17—15	15—10	15—10	17—15	10—20	10—20	17—15
Digestibility										
Dry matter	60.6	36.5	39.2	45.7	46.9	32.7	41.0	15.0	23.4	41.1
Organic matter	61.7	36.7	42.2	45.9	48.7	35.2	41.6	16.1	24.1	41.8
NDF		36.9	35.0	43.3	44.6	30.9	37.1	14.6	21.2	33.8
ADF	59.0	34.9	32.4	42.9	43.5	28.7	34.8	14.0	38.7	42.2
Energy		36.1	39.2	41.6	48.3	32.0	36.9	16.6	24.7	36.0
Nutrients										
DCP	0	0	0	0	0	0	0	0	0	0
TDN	65.5	39.6	45.3	47.0	52.9	38.5	43.5	18.9	26.6	43.6
DE (Mcal/kg)		1.63	1.78	1.95	2.17	1.44	1.71	0.74	1.11	1.66

organic matter of Japanese oak, Siebold's beech and *Castanopsis cuspidate* was lower than that of white birch. That of *Castanopsis cuspidatas var Sieboldii* was much lower than others. With raising temperature and pressure in the steaming treatment, all kinds of wood examined increased their digestibility. Particularly in the case of *Sasa kurilensis,* this tendency was remarkable. As steamed woods are mostly composed of carbohydrate and lignin containing only a little protein, fat and minerals, the digestion coefficient of organic matter relates closely to TDN content in dry matter. By this coefficient, it is possible to estimate the nutritive value of steamed wood.

3) *Nutritive value of steamed soft wood*[3)]

Soft wood is difficult to raise its digestibility by steaming and explosive depressurization treatment. The effect of steaming and other treatments greatly differs between hardwood and softwood; these processing methods hardly work for the latter. Reasons include the fact that softwood contains more lignin than hardwood and the quantity of lignin which becomes soluble in an organic solvent by means of steaming is less and that the acetyl group content of softwood is less than that of hardwood.

Table 5. Effects of steam treatment on organic matter digestibility of Japanese larch[3)] (%)

Digestibility by cellulase		Digestibility by goat
Unprocessed	Steam treatment*	Steam treatment*
5.4	15.34	17.87

* After soaking by 0.5% NH_4Cl solution

Table 6. Chemical composition and digestibility of steamed Japanese larch[3)] (%)

	Chemical composition	Digestibility
Dry matter	51.6	20.7
Dry base		
Organic matter	99.8	17.9
Crude protein	1.3	0
Crude fat	1.0	100
Crude carbohydrate*	97.9	18.1
NDF	81.9	3.9
ADF	79.4	2.5
Lignin (ADL)	33.3	0
Energy, Mcal/kg	4.53	8.7
DCP	0	
TDN	19.0	

* Crude fiber+Nitrogen free extract

To improve digestibility, treatments with chemical agents are needed in addition to steaming. Effects of steaming on digestibility of Japanese larch are shown in Tables 5 and 6.

4) *Nutritive value of steamed bark*[3)]

In utilizing steamed wood as feed, it must be considered that the wood is steamed without peeling bark with an aim of saving processing cost. Bark contains extractable components, so that bark is more digestible than wood, when unprocessed.

However, as bark contains much more lignin than

Table 7. Effect of steam treatment on digestibility of some barks and woods[3] (%)

Species	Steam Treatment kg/cm min	Bark		Wood	
		Unprocessed	Steamed	Unprocessed	Steamed
White birch	10—20	9.3	18.9 (19.0)	3.4	64.6 (65.5)
Japanese oak	15—10	12.8	22.3 (28.1)	9.4	54.1 (52.9)
Castanopsis cuspidata	15—10	14.2		3.4	37.0 (38.5)

Figures show digestibility by cellulase and figures in parentheses that by goat.

Table 8. Chemical composition and digestibility of steamed bark of Japanese oak[3] (%)

	Chemical composition	Digestibility
Dry matter	63.9	26.8
Dry base		
Organic matter	94.2	28.1
Crude protein	3.3	0
Crude fat	3.7	48.5
Crude carbohydrate*	87.2	30.0
NDF	66.8	15.7
ADF	67.2	16.1
Lignin (ADL)	39.6	0
Energy, Mcal/kg	4.76	24.3
DCP	0	
TDN	28.1	

* Crude fiber+Nitrogen free extract

wood, the effect of steaming on digestibility is little. Organic matter digestibility of steamed bark was much lower than that of wood as Tables 7 and 8 show.

Feeding experiments with steamed white birch

1) Feeding experiments of Holstein steers

The experiment was undertaken to clarify productivity and upper limit of feeding, and to extract the problems from long term feeding with steamed wood. Feeding level of steamed wood was designed 60, 30 and 0% (control). The 60% level was presumed an upper limit, judged by chemical composition, and the 30% level was considered the practical level. Feed composition of each ration is given in Tables 9 and 10.

The rations were adjusted as to their TDN and DCP content. Performances during the first stage (18 weeks) and the last stage (15 weeks) are presented in Table 11.[5,6]

Table 9. Composition of experimental rations fed to Holstein steer during 10 months growth trial (Dry base)[5,6]

	Treatment		
	Wood 0%	Wood 30%	Wood 60%
Steamed white birch	0	30	60
Alfalfa hay cube	56	32	5
Rice straw	8	5	4
Concentrate 1	30	—	—
Concentrate 2	—	33	—
Concentrate 3	—	—	31

Table 10. Composition of concentrate 1,2 and 3 fed to Holstein steer during 10 months growth trial (Dry base)[5,6] (%)

	Concentrate 1	Concentrate 2	Concentrate 3
Corn	85.9	51.1	15.5
Soybean meal	11.1	36.0	66.7
$CaCO_3$	—	2.0	4.3
$CaHPO_4$	2.4	3.5	4.4
MgO	—	0.3	0.6
KCl	—	3.0	6.3
NaCl	0.4	0.8	1.1
Mineral mixture	0.1	0.2	0.3
Vitamin mixture	0.1	0.2	0.3

After the first stage trial, respiration experiment was carried out, and metabolizable energy and net energy for maintenance of steamed white birch were measured.[7]

In the first stage, daily body weight gains on both rations, 30 and 60% level were 1.4 kg, and in the last stage, they were 1.1 kg. As these values were not inferior to the standard growth of Holstein steer, it is considered that the steamed white birch has the feeding value corresponding to its TDN content. Intake of steamed wood (dry matter) was 1.5–1.6% per body weight.

Table 11. Performance of Holstein steers fed rations containing steamed white birch in growth trial[5,6]

Experimental term	The first term			The last term		
Steamed wood in rations (Dry base)	0%	30%	60%	0%	30%	60%
Starting weight (kg)	196	191	225	411	413	455
Finishing weight (kg)	343	355	389	518	530	566
Daily gain (kg/day)	1.3	1.4	1.4	1.0	1.1	1.1
Dry matter intake (kg/day)	7.6	8.0	8.3	9.8	12.5	12.6
Dry matter intake per body weight (%)	2.9	2.9	2.7	2.1	2.6	2.5
Steamed wood intake (dry matter kg/day)	0	2.4	5.0	0	3.8	7.6
Feed conversion*	6.2	5.9	6.2	9.7	10.6	10.9
TDN conversion*	3.9	3.7	.6	7	6.6	6.4

* Feed (TDN)/body weight gain

Table 12. Effect of steamed white birch on milk production, milk composition and body weight change in the first stage of lactation[8]

Treatment	0% Wood		15% Wood		30% Wood	
	Starting period	Average during the experiment	Starting period	Average during the experiment	Starting period	Average during the experiment
Body weight (kg)	665	647	634	643	681	657
Milk yield (kg/day)	29.2	26.8	30.5	28.6	30.1	26.7
Milk fat (%)	3.74	3.50	3.58	3.64	3.71	3.46
Solid-not-fat (%)	8.73	8.29	8.27	8.16	8.62	8.33

Table 13. Effect of streamed white birch on milk production, milk composition and body weight change in the last stage of lactation[8]

Treatment	0% Wood		20% Wood		40% Wood	
	Starting period	Average during the experiment	Starting period	Average during the experiment	Starting period	Average during the experiment
Body weight (kg)	661	669	664	691	651	658
Milk yield (kg/day)	15.8	16.1	12.5	13.8	13.2	13.1
Milk fat (%)	3.16	3.44	3.63	3.73	3.64	4.01
Solid-not-fat (%)	8.32	8.43	8.69	8.70	8.51	8.81

Total feed intake (dry matter) was 2.5–2.7% (per body weight). These values exceed dry matter intake indicated in Japanese feeding standard. The palatability of steamed white birch to cattle offered no problem after habituation. After the experiment was finished, all cattle were slaughtered. No abnormality related to the ration was observed in rumen-reticulum, livers, and meat quality. Development of ration-related diseases[5,6] was not recognized.

2) *Feeding experiment of lactating cows with steamed white birch*[8]

Habituation of lactating cows to steamed white birch, and the intake limit of steamed white birch were studied. Cows fed with steamed wood for the first time needed 2 weeks to take 3.0 kg per day. More than 2 weeks were required to increase TDN substituted by the steamed wood from 10 to 40% of the ration. Individual differences were recognized in the wood intake.

The feeding trial was conducted at 3 stages of lactation; i.e. a dry period, the first stage of lactation and the last stage of lactation. Before each stage, the adaptation period of 1 week was given. Test terms were 7, 10, and 6 weeks for the dry period, the first stage and the last stage, respectively. Twelve to 14

Holstein cows were allotted to 3 groups at each stage. The cows were fed 100% based on Japanese feeding standard about TDN and more than 100% about DCP, respectively.

The rations used were composed of hay, formula feed, soybean meal, minerals and vitamins. With or without steamed white birch (treated 20 min with 187°C, 11 kg/cm² saturated steam and then defibrated by double disk refiner).

During the dry period and the last stage of lactation, the cows were fed the rations in which 0, 20 or 40% of TDN was substituted by the steamed wood. For the first stage of lactation, showing very high TDN requirement 0, 15 or 30% of TDN was substituted by the steamed wood.

Results of the trial are given in Tables 12 and 13. Body weight gain, milk yield, milk fat and solid-not-fat showed no significant difference between the values of the starting period and the average values during the experiments in each stage. No adverse effect of feeding the steamed wood on the cow's health was recognized.

Table 14. Effect of streamed white birch on body weight gain of Japanese black steers in fattening[a)]

Treatment	100% Wood	50% Wood	0% Wood
Head of steer	3	3	3
Starting body weight (kg)	280.7±13.7	279.7±15.3	278.7±22.9
Finishing body weight			
First stage	415.1±15.5	414.6±19.4	403.9±31.7
Middle stage	531.7±35.8	523.4±29.7	504.7±39.9
Last stage	654.0±42.9	650.3±26.3	627.8±56.8
Daily body weight gain (kg/day)			
First stage	0.87±0.01	0.88±0.03	0.81±0.07
Middle stage	0.76±0.16	0.71±0.07	0.65±0.06
Last stage	0.75±0.13	0.77±0.04	0.75±0.10
Whole term	0.79±0.08	0.79±0.03	0.74±0.08

Table 15. Feed intake of Japanese black steers fed steamed white birch in fattening[9)]

Treatment	100% Wood	50% Wood	0% Wood
Head of steer	3	3	3
White birch (kg)			
First stage	1139.3±38.9	556.1± 37.0	—
Middle stage	1125.1±15.1	419.2±115.7	—
Last stage	927.4±53.5	368.0±161.5	—
Whole term	3191.9±69.1	1343.2±295.4	—
Hay (kg)			
First stage	—	348.6±21.7	627.2±57.2
Middle stage	—	257.0± 5.9	448.2±25.3
Last stage	—	212.6± 4.1	306.7±24.0
Whole term	—	818.2±31.6	1382.2± 9.5
Concentrate (kg)			
First stage	515.6± 11.0	532.6±28.1	539.7± 41.7
Middle stage	863.4± 72.7	886.4±36.9	828.5± 28.7
Last stage	1072.6±267.9	1161.5±83.0	1178.0± 89.8
Whole term	2451.9±348.3	2580.6±93.2	2546.3±149.4
Feed intake per day (kg) (whole term)			
White birch	6.76±0.14	2.85±0.63	—
Hay	—	1.73±0.06	2.93±0.02
Concentrate	5.19±0.73	5.47±0.18	5.40±0.31

3) *Feeding experiment of fattening steers with steamed white birch*

The trial was conducted to know the feeding limit of steamed white birch and effect of feeding on meat production and meat quality.

White birch was treated with 180°C, 10 kg/cm^2 saturated steam for 20 min and its fiber was loosened with a double disk refiner. A fattening period was divided into 3 stages, the first stage (154 days), the middle stage (154 days) and the late stage (164 days). The ratios of roughage to concentrate in the rations for these stages were 50:50, 40:60 and 25:75, respectively. The roughage used was orchard grass hay and the concentrate used was formula feed. At each stage, 12 Japanese black steers were allotted to 3 groups. Each group fed the ration in which 100, 50 or 0% (control) of roughage was substituted by the steamed white birch. Results of the experiment are shown in Tables 14 and 15. The 100% substitution of roughage by the steamed white birch gave no adverse effect on fattening steers, giving 0.8 kg/day of gain as planned.[9]

Intake of steamed wood in the 100% group was satisfactory. In the first stage of fattening, more than 50% of the total dry matter intake was met by the steamed wood. Therefore it is expected that the wood can be used in winter rearing and in a fattening program that consumes a good deal of roughage.[9]

Behavior of the steers was compared among the feeding plots. At the first stage, it was observed that the higher the percentage of the steamed wood in the ration, the shorter the eating time and the rumination time significantly. At the middle stage, only the rumination time became shorter significantly, and at the last stage, any difference in the behavior was not observed (Table 16). This result suggests that the steamed white birch has a little roughage effect. Therefore, forms of steamed wood have to be studied for the purpose of using the wood as roughage.[10]

Growth trial of kids with steamed Japanese oak and Siebold's beech[11]

Japanese oak and Siebold's beech are the promising species to be used as feed. Growth trial of kids was made to clarify whether they have the productivity corresponding to digestibility and nutrient contents measured with goats. Japanese oak and Siebold's beech were treated with 17 kg/cm^2 saturated steam for 15 min, crushed by cutter mills, and then used after passing through a 20 mm screen. The feed composition of the rations fed is shown in Table 17.

Twelve Japanese native kids (meat type) of 5 months old, showing body weight of 7.8–13.0 kg, were allotted to 3 groups. After the 7-day preliminary period, the kids were fed the experimental rations during 10 weeks. Digestion trial was carried out with the same rations after the growth trial.

Table 16. Effect of steamed white birch on behavior of Japanese black steers in fattening[10]

Treatment	100% Wood	50% Wood	0% Wood	Difference between treatments
First stage				
Eating (min)	133±49	144±59	251±21	*
Rumination (min)	149±71	275±17	351±29	**
Standing (min)	521±40	474±39	443±20	*
Middle stage				
Eating (min)	143±48	174±51	221±21	N. S.
Rumination (min)	261±20	273±75	363±46	*
Standing (min)	498±36	521±48	480±98	N. S.
Last stage				
Eating (min)	161±41	153±40	194±15	N. S.
Rumination (min)	168±49	254±38	236±69	N. S.
Standing (min)	579±74	558±89	594±129	N. S.

* $p<0.05$, ** $p<0.01$, N. S.: Not significant

Table 17. Composition of experimental rations fed to Japanese native kids in growth trial[11)]

(dry base, %)

Group	Italian rye grass	Siebold's beech	Japanese oak
Italian rye grass wafer*	48.2	—	—
Steamed Siebold's beech**	—	44.9	—
Steamed Japanese oak**	—	—	47.4
Corn	21.8	35.6	17.9
Soybean meal	6.8	4.8	7.8
Isolated soybean protein	—	7.2	4.1
Wheat bran	21.8	5.0	20.8
Mineral, vitamin***	1.5	2.5	2.0

* Regrowth, full bloom
** Crushed with cutter mill and passed through 20 mm screen
*** $CaCO_3$, $CaHPO_4$, KCl etc.

Table 18. Performance of Japanese native kids fed rations containing steamed wood in growth trial[11)]

Group	Italian rye	Siebold's beech	Japanese oak	S.E.
Head of kid	4	3	4	
Starting body weight (kg)	11.3	10.8	10.8	1.0
Daily body weight gain (g/day)	68.0	68.8	61.6	2.7
Dry matter intake (g/day)	484	470	461	29
DM intake (g/$W^{0.75}$kg/day)	68.6	68.6	68.1	0.3
TDN intake (g/day)	329	311	295	21
Feed conversion (dry matter)*	7.1	6.8	7.5	0.4
Feed conversion (TDN)*	4.8	4.5	4.8	0.2

* Feed/body weight gain(g/g)

The result of the growth trial is shown in Table 18. The body weight gain of the Siebold's beech group was not significantly different from the control, while that of Japanese oak group was inferior to the control.

This is because TDN content of Japanese oak ration was lower than that of the control. As the TDN conversion of the group was not significantly different. Development of ration-related disease was not observed during the experimental term.

Conclusion

Results of the feeding experiments clearly demonstrated that steamed hard wood, especially steamed white birch, can express feeding values higher than high quality grass hay, when protein and minerals are supplied.

At present, steamed wood undergoes fiber loosening treatment after steaming. Consequently, it tends to be too bulky and lacking hardness. It is necessary to add hardness and other roughage factors to the steamed wood. To make such improvements, further studies are needed to find out the optimum processing condition in consideration of digestibility, the forms of feed, and economic factors. In addition, to utilize wood resources as much as possible, studies are needed to find appropriate processing methods for improved digestibility of *Castanopsis cuspidate* and other kinds of hardwood hard to be digested, soft woods, bamboo grass, and others.

Considerations from many viewpoints are also required as to the development of processing plants, collection and transport of wood materials, storing and distribution of products and other related problems.

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