Studies on the Utilization of Forage and the Digestion of Cellulose and Hemicellulose by Pigs

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Abstract Utilization by pigs of brassicas (Shimofusa turnip leaves and cabbage leaves), legumes (alfalfa and Ladino clover) and grasses (orchard-tall fescue mixture and Italian rye grass) and the digestibilities of cellulose and hemicellulose were studied using a total of 28 head of 76~88 kg pigs. 1. The dry matter of all forages except orchard-tall fescue mixture was rich in protein (15~26%). The percentages of total digestible nutrients were higher (over 50%) in cabbage leaves, Shimofusa turnip leaves and Ladino clover than in the other three forages. 2. The cell wall contents were high in the grass and alfalfa, and were low in Ladino clover and the brassicas. 3. The cellulose contents were higher than the hemicellulose contents in all forages. Cellulose in the brassicas and Ladino clover was easily digestible. 4. Digestibility of hemicellulose was higher than that of cellulose for all forages. 5. Shimofusa turnip leaves, cabbage leaves and Ladino clover are useful forages for the pig. Early cut alfalfa may also be useful. Grasses with high cell wall content have limited usefulness.

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Recently, the nutritive value of forage has been revalued and high levels of green grass, silage or hay are fed to non-herbivora^{1,2,3)}. Since methods for the analysis of forage fiber were developed by VAN SOEST^{4,5)}, the terms acid detergent fiber (ADF) and neutral detergent fiber (NDF) have become widely used instead of crude fiber. It is also desirable to determine the contents of mono- and oligo-saccharides, fructosan and starch in nitrogen free extracts.

The dry matter of forage can be divided into the fibrous part (cell-wall constituents, i.e., cellulose, hemicellulose and lignin) and the soluble part (organic cellular constituents, i.e., sugars, soluble carbohydrates, starch, pectin, nonprotein nitrogen, proteins and lipids) to facilitate more precise evaluation of the chemical fractions of plant tissues. The ratios of cell wall constituents to organic cellular contents may range from 40:60 in legume forages to 60:40 in grass forages⁶⁾. While the digestibility in pigs of the cell wall fraction is limited, that of the soluble fraction is generally high⁵⁾.

SULLIVAN indicated a lower digestibility of hemicellulose as compared with cellulose by using ruminants⁷⁾, but KEYS reported that the digestion coefficients for hemicellulose in pigs were higher than those for cellulose⁸⁾.

The purpose of this research was to study the utilization of brassicas, legumes and grasses for the pig and to compare the digestibilities of hemicellulose and cellulose in pigs fed these forages.

Experimental Procedures

Six species from three families of forage: brassicas (Shimofusa turnip leaves and cabbage leaves), legumes (alfalfa and Ladino clover) and grasses (one to one mixture of orchard grass and tall fescue, and Italian rye grass) were used in this experiment. Shimofusa turnip leaves were harvested before bloom in April. Cabbage leaves were collected immediately after harvesting the cabbage heads in May. The alfalfa used was imported from foreign countries. Ladino clover was of the 5th cutting harvested before bloom in October. The one to one mixture of orchard grass and tall fescue was the 3rd crop harvested in July, and Italian rye grass was cut in the early heading stage in May. The experimental composition of diets of each forage and the number of pigs used in this experiment are shown in Table 1. To prepare the experimental diets, each kind of forage was mixed with either basal feed A or basal feed B at proportions indicated in Table 1. The meal of the mixture of orchard grass and tall fescue (orchard-tall fescue mixture) were made by the sun curing system, and other meals were made by the pneumatic drying system with hot air. The meals were ground through a 1.0 mm Wiley mill screen. The digestion tests were conducted using a total of 28 pigs weighing 76 kg to 88 kg (Landrace and Landrace $\times$ Hampshire). Pigs were held individually in metabolism crates, and were fed a diet of equal amounts three times each day at 09:00 hr., 13:00 hr. and 17:00 hr. by standard ration for performance test on meat production of pigs. The digestibilities

Table 1. Forages and experimental diets

Forage ¹⁾	Experimental diet		Number of pigs	
	———— % Air dry matter ————			
Brassica				
S. turnip leaves	S. Turnip l. meal	40 + Basal feed A ²⁾	60	3
Cabbage leaves	Cabbage l. meal	40 + Basal feed A	60	3
Legume				
Alfalfa	Alfalfa meal	50 + Basal feed B ³⁾	50	6
Ladino clover	L. clover meal	50 + Basal feed B	50	5
Grass				
O. grass+t. fescue	O. g.+t. f. meal	50 + Basal feed B	50	6
Italian rye grass	I. rye g. meal	50 + Basal feed B	50	5

1) S. turnip leaves=Shimofusa turnip leaves. O. grass+t. fescue=one to one mixture of orchard grass and tall fescue. The meal of orchard grass+tall fescue mixture was made by sun curing system, and others were made by pneumatic drying system. The meals were ground through a 1.0 mm Wiley mill screen. 2) Basal feed A was a mixture of 60% of formula feed and 40% of wheat bran. 3) Basal feed B was a mixture of 40% of glucose, 30% of casein, 30% of tallow and traces of vitamins and minerals.

Table 2. Chemical composition of forages

Forage	Moisture	Dry matter						
		Crude	Crude	Mono-oligo	Fructosan	Crude	Organic	matter
		protein	fat	saccharide	or starch	ash	OCC	NDF
% Dry matter								
S. turnip leaves	11.4	20.2	3.0	10.0	1.2 ^{a)}	18.6	43.8	37.6
Cabbage leaves	13.8	15.0	5.3	2.6	0.7 ^{a)}	20.0	50.1	29.9
Alfalfa	10.7	19.2	3.5	5.1	1.1 ^{a)}	10.5	41.3	48.2
Ladino clover	8.6	26.3	3.6	2.2	0	13.2	55.1	31.7
O. grass+t. fescue	10.7	12.4	2.9	2.5	0.6 ^{b)}	12.8	18.3	68.9
Italian rye grass	12.3	18.2	2.7	1.3	0.9 ^{b)}	12.3	24.6	63.1

a)=Starch, b)=Fructosan. OCC=Organic cellular contents. NDF=Neutral detergent fiber=cell wall.

were examined by the total collection method during a 5-day collection period following 4-day preliminary period.

Chemical compositions of the forages were analysed by conventional methods⁹⁾. Cell wall constituents and cell contents were precisely analyzed by an improved method^{10,11)} of the detergent procedures of VAN SOEST⁵⁾. The cellulose contents were determined by subtracting lignin contents from the ADF value and hemicellulose contents were determined by subtracting the ADF value from the NDF value. Mono-saccharide, oligo-saccharide and fructosan were determined by anthrone colorimetry methods, and starch content was determined by the glucoseoxidase method¹²⁾. Digestibility of basal feed A had been measured before giving these experimental diets, and basal feed B was considered to be digested perfectly.

Results

Chemical compositions of the forages are presented in Table 2. All forages except the orchard-tall fescue mixture showed high percentages (15~26%) of protein content in their dry matter. The mono- and oligo-saccharide content of Shimofusa turnip leaves was as high as 10%. As can be calculated from the figures shown in Table 2, the ratios of organic cellular contents to the total organic matter were 0.54 for Shimofusa turnip leaves, 0.63 for cabbage leaves and 0.63 for Ladino clover. The ratio for alfalfa was comparatively low (0.46). Both of the grasses, orchard-tall fescue mixture and Italian rye grass, contained large amounts of cell wall (NDF): 79% and 72% respectively.

The digestibilities of forages are as presented in Table 3. The digestibility of organic matter of the brassica family was higher than the other two families. Alfalfa and Italian rye grass showed the same digestibility, but that of orchard-tall fescue mixture was low. Digestibility of protein was similar to that of organic matter. Precise determination of fat digestibility for both legumes and grasses was not possible because of the presence of large amount of tallow that was mixed in these experimental diets. Organic cellular contents of the brassica leaves and Ladino clover were

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Table 3. Digestibility of forages in pigs

Forage	Organic matter	Crude prot.	Crude fat	Organic matter	
				OCC	NDF (CW)
				%	
S. turnip leaves	70.1±4.4	79.8±4.1	66.7±5.9	76.5±3.6	65.5±5.1
Cabbage leaves	74.5±5.3	68.7±3.7	67.7±3.1	67.6±4.9	86.2±9.6
Alfalfa	41.6±3.2	57.8±2.6	0	46.1±3.6	37.9±4.2
Ladino clover	59.1±1.3	66.8±1.7	0	61.4±1.8	56.6±0.5
O. grass+t. fescue	27.5±0.8	42.7±2.3	4.9±5.7	12.1±0.9	31.6±1.0
Italian rye grass	42.3±2.3	63.4±1.6	8.9±7.7	36.9±1.6	44.3±3.1

Table 4. Digestible nutrients of forages for pigs

Forage	Organic matter	Crude protein	Crude fat	Soluble carbohydrate	Organic matter		TDN*
					OCC	NDF(CW)	
% Dry matter							
S. turnip leaves	57.1	16.1	2.0	11.2	33.5	24.6	59.6
Cabbage leaves	59.6	10.3	3.6	3.3	33.9	25.8	64.1
Alfalfa	37.2	11.1	0	6.2	19.0	18.3	37.2
Ladino clover	51.3	17.6	0	2.2	33.8	17.9	51.3
O. grass+t. fescue	24.0	5.3	0.1	3.1	2.2	21.8	24.1
Italian rye grass	37.1	11.5	0.2	2.2	9.1	28.0	37.4

*TDN=total digestible nutrients.

Table 5. Structural carbohydrate contents in forages

Forage	NDF(CW)	Cellulose	Hemicellulose	Lignin
% Dry matter				
S. turnip leaves	37.6	26.8	4.7	6.1
Cabbage leaves	29.9	14.4	7.8	7.7
Alfalfa	48.2	24.4	14.1	9.7
Ladino clover	31.7	14.1	11.3	6.3
O. grass+t. fescue	68.9	32.2	30.1	6.6
Italian rye grass	63.1	33.5	24.4	5.2

more digestible than those of alfalfa and Italian rye grass. The orchard-tall fescue mixture was the least digestible.

Digestible nutrients of forages were shown in Table 4. High digestible crude protein (DCP) contents were observed for Shimofusa turnip leaves (16.1%) and Ladino clover (17.6%). The DCP contents of alfalfa, cabbage leaves and Italian rye grass were lower (11.1%, 10.3% and 11.5% respectively). The value for orchard-tall fescue mixture was approximately half of that for Italian rye grass, which belongs to the same family.

The total digestible nutrients (TDN) was most abundant in cabbage leaves (64.1%),

Table 6. Digestibility of cellulose and hemicellulose in forages in pigs

Forage	Cellulose	Hemicellulose
		%
S. turnip leaves	71.4±0.2	79.3±26.7
Cabbage leaves	84.9±5.0	94.3±9.9
Alfalfa	43.5±3.7	56.7±5.7**
Ladino clover	60.8±1.8	69.5±3.2**
O. grass+t. fescue	29.4±2.0	50.5±0.4**
Italian rye grass	41.6±3.1	50.1±3.9**

**P < 0.01

followed by Shimofusa turnip leaves and Ladino clover (over 50%). Alfalfa and Italian rye grass showed the low value of 37%. The lowest value was obtained with orchard-tall fescue mixture (24%).

The results of analysis of structural carbohydrate contents are summarized in Table 5. Cell wall content was high in the grasses and alfalfa, but low in Ladino clover and brassica forages. The cellulose contents were higher than the hemicellulose contents in all forages. Hemicellulose content was lowest in the brassicas (less than 8%), moderate in the legumes (11~14%) and highest in the grasses. Among all forages, alfalfa showed the highest lignin content.

Table 6 shows digestibilities of cellulose and hemicellulose in forages. The cellulose of brassica meals was most easily digestible, and that of Ladino clover was the next. Digestibility of cellulose in alfalfa and Italian rye grass was comparatively low, and that of orchard-tall fescue mixture was the lowest. Digestibility of hemicellulose in brassica forages and Ladino clover was comparatively high (70~94%) but that of the other forages was only slightly over 50%. Hemicellulose was more digestible than cellulose for all forages.

Discussion

The literature^{1,2,13,14)} on utilization and digestion of forages by the pig states that legumes are efficiently digested by pigs¹⁵⁾. In particular, high quality alfalfa meal can be utilized similarly by the pig as by ruminants^{3,8)}. In this study, we compared the chemical compositions and the digestibilities of the constituents of forages: two species each of three families, i. e., brassica, legume and grass. The results indicated that the orchard-tall fescue mixture is not a useful forage for the pig because of its low digestible crude protein (DCP) content, low total digestible nutrients (TDN) content and high cell wall content.

The alfalfa had an unexpectedly low TDN value with the highest lignin content among all the forages, even though the DCP content was reasonable. Judging from the report by MIAKI¹⁶⁾ that DCP and TDN values of alfalfa rapidly decline while contents of crude fiber and lignin increase after the blooming stage, the alfalfa sample

used in the present study was probably of rather late stage. It has been reported by SMITH *et al.*¹⁷⁾ that the pig could digest the cell walls of immature rye while digestibility of cell walls of mature timothy was very poor. The Italian rye grass used in our experiments had been harvested in May, when the grass was in the early heading stage. The high crude protein content was comparable to that of alfalfa and the digestibilities of organic matter, crude protein and cell walls of this grass were higher than those of alfalfa. This indicates that early cut Italian rye grass could be a useful meal for the pig.

The data presented in Table 5 and 6 show that there is a general tendency that the digestibility of cellulose is better when their content in the diet (except Shimofusa turnip leaves) is lower, although it is probable that the digestibility of cellulose is influenced by the character of cellulose in forages.

This is in agreement with the report by FARRELL *et al.*¹⁸⁾ who found that cellulose was more digestible when the diet contained 8%, rather than 26%, of cellulose.

Digestion of fibrous materials depends on digestibilities of cellulose and hemicellulose. According to SULLIVAN⁷⁾, in ruminants, namely sheep and calves, cellulose is more easily digested than hemicellulose when examined with forages including alfalfa, legume silage and several species of grass. In contrast, KEYS, *et al.*¹⁹⁾, who conducted digestion tests for cellulose and hemicellulose of orchard grass hay with pigs and rats, reported that hemicellulose was more digestible than cellulose in these non-ruminant animals. The results of our experiments showing that digestibility in pigs of hemicellulose contained in all of the six species of forage in higher than that of cellulose, further support the report by KEYS.

Using ruminants fed Italian rye grass, timothy and rye, ABE and HORII²⁰⁾ observed considerably strong negative correlations between the lignin content and the digestibilities of neutral detergent fiber and of acid detergent fiber ($r=0.994$, 0.999 , respectively, $P<0.01$). However, with the pig, we found only weak correlations ($r=0.244$, 0.187). It is assumed that some factors other than lignin content affect digestion of cell walls by the pig.

In conclusion, Shimofusa turnip leaves, cabbage leaves and Ladino clover are well digestible and useful forages for the pig. They should serve as a useful diet. Hemicellulose is more digestible than cellulose in pigs.

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豚における牧草およびそ菜茎葉の利用性と セルロース、ヘミセルロースの消化性

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アブラナ科作物であるシモフサカブ葉とキャベツ外葉，マメ科作物であるアルファルファとラジノクローバー，イネ科作物であるオーチャードグラス・トールフェスク混合草とイタリアンライグラスについて，豚における飼料としての利用性を検討し，特にそれらの作物についてセルロースとヘミセルロースの消化性を比較した。

各作物は収穫後，乾燥し，ミール状にして供試した。消化試験は延 28 頭の豚（体重：76～88 kg）を用い，全ふん採取法によって行なった。細胞壁と細胞内容物の分析は VAN SOEST によるデタージェント処理の改良法によって分析した。その結果は次のようであった。

1. 乾物中の粗蛋白質含量はオーチャードグラス・トールフェスク混合草以外は 15～26% と高い値を示した。可消化養分総量はキャベツ外葉，シモフサカブ葉およびラジノクローバーにおいて比較的高く，50% 以上を示し

た。

2. 細胞壁含量はイネ科とアルファルファが高く，ラジノクローバーとアブラナ科は低かった。

3. セルロース含量はすべての作物においてヘミセルロースよりも多かった。

4. アブラナ科とラジノクローバーのセルロースは消化しやすかった。

5. ヘミセルロースはすべての作物においてセルロースより高い消化率を示した。

6. 以上の結果から，アブラナ科作物の葉部，ラジノクローバーおよび若いステージのアルファルファは豚にとって消化しやすく，有益な作物であるが，イネ科作物および成熟したアルファルファは細胞壁含量が高く，豚においては利用性が低いと推論された。

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