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Antongiovanni M., Sargentini C.

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M. ANTONGIOVANNI AND C. SARGENTINI
DIPARTIMENTO DI SCIENZE ZOOTECNICHE
UNIVERSITA DI FIRENZE
VIA DELLE CASCINE, 5 - 50144 FIRENZE, ITALY

SUMMARY - The variability in chemical composition of different cereal straws is considered. Structural carbohydrates of cell-walls are potential energy sources to the ruminant animals, but their utilization is impaired by the negative effects on digestibility exerted by lignin, its soluble phenolic compounds and silica.

RESUME - "Variabilité de la composition des pailles". La variabilité de composition des différentes pailles est considérée. Les polyholosides constituants des parois cellulaires sont des sources énergétiques potentielles pour les ruminants, mais leur utilisation est limitée par les effets negatifs sur la digestibilité déterminés par la lignine, ses acides phénoliques solubles et par le bioxyde de silicium.

Introduction

Fibrous by-products such as cereal straws are very abundant and likely to increase in quantity in the future because of the urging need to produce more and more cereal grains for human consumption.

Straws are almost entirely made of cell-walls. And cell-walls are made of highly lignified structural carbohydrates and of small amounts of structural proteins and minerals.

Straws are actually under-utilized as animal feed, due to their low digestibility.

There are technical possibilities of upgrading the nutritive value of straws both by means of treatments and of the proper association with other ingredients in balanced diets. Therefore, it is very useful to look at the chemical composition of straws in order to optimize its use as animal feed.

Composition of straws

Botanical fractions

The main botanical fractions are: nodes, internodes and leaves (blades and sheaths). The relative proportions of these fractions vary with species and with many other factors such as maturity at harvest, soil and climate conditions, etc.. Since the chemical composition of the various fractions is different, the overall chemical composition of the straw changes as a consequence.

Table 1 shows the composition of some straws. If Table 1 is compared with Table 2, it is very evident that, apart from the differences among crops, there are differences of proportions of botanical fractions among different varieties of the same cereal crop as well: internodes of wheat varieties vary from 41 to 51%; nodes from 5 to almost 8%; leaves from 29 to more than 36%.

Table 1. Botanical fractions of some cereal straws.

Crop	Internode, %	Node, %	Leaf, %
Barley	58	7	35
Oat	53	4	43
Rice	40		60
Rye	72	5	21
Wheat (6 varieties)	54-73	4-8	20-41

Reference: Theander and Aman, 1984.

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Table 2. Botanical fractions of straws of some varieties of oat and wheat.

Crop	Internode, %	Node, %	Leaf, %	Chaff, %
Oat varieties:				
Ballad	56.4	6.3	33.1	4.2
Cabana	59.9	7.1	29.6	3.4
Dula	57.2	7.1	29.7	6.0
Leanda	56.8	7.4	32.1	3.7
Matra	56.1	7.2	28.8	7.9
Trafalgar	55.2	8.5	32.7	3.6
RANGE	55.2-59.9	6.3-8.5	28.8-33.1	3.4-7.9
Wheat varieties:				
Aquila	45.8	5.6	31.4	17.2
Avalon	45.8	5.3	35.9	13.0
Boxer	45.0	5.8	34.9	14.3
Brigand	43.7	6.1	36.5	13.7
Brimstone	49.3	7.6	28.7	15.3
Brock	49.1	6.0	36.6	8.3
Galahad	40.9	5.5	36.0	17.6
Longbow	46.8	5.4	33.1	14.7
Mission	46.3	5.1	36.5	12.1
Norman	46.8	5.7	35.9	11.6
Renard	51.0	5.7	33.9	9.4
Stetson	48.3	5.1	30.4	16.2
RANGE	40.9-51.0	5.1-7.6	28.7-36.5	8.3-17.6

Reference: Shand et al., 1988.

Table 3. Chemical composition of straw botanical fractions.

Constituent	Wheat			Barley		
	Internode	Node	Leaf	Internode	Node	Leaf
	(g/kgDM)					
N * 6.25	29	45	48	17	40	37
Cellulose	411	327	323	433	332	364
Hemicellulose	245	286	256	242	331	283
Ash	38	51	96	16	31	94
Silica	14	15	39	3	4	11

Reference: Aman and Nordkvist, 1983 (cited by Theander and Aman, 1984).

Constituent	Rice (long variety)			Rice (short variety)		
	Internode	Node	Leaf	Internode	Node	Leaf
	(g/kgDM)					
N * 6.25	34	70	38	26	39	35
Cell-wall	782	737	787	766	773	800
Ash	100	162	211	184	182	190
Silica	28	26	103	29	55	67

Reference: Walli et al., 1988.

Chemical composition

Leaves and nodes are very similar in terms of nitrogen and structural carbohydrates contents (see Table 3): there are more nitrogen and hemicellulose in leaves and nodes and less cellulose than in internodes; the highest silica content is that of leaves, while the most lignified fraction is internodes (De S. Thiago and Kellaway, 1982).

1.- Carbohydrates and lignin

Cell-walls are made of three types of structural carbohydrates: cellulose, hemicellulose and pectic polysaccharides. Other components are residues of the storage polysaccharides glucans, fructans and mannans.

In straws cellulose and xylan hemicellulose are the predominant components. Few pectic compounds and few mannans are also present. Ethanol extracts contain the low molecular weight sugars, fructose, glucose, sucrose, arabinitol and mannitol.

Lignin is the well-known complex substance covalently bound to side chains of xylans of cell-walls. It represents an obstacle to microbial digestion of structural carbohydrates both because it is a physical barrier and because of the depressing effect on microbial activity, due to the phenolic compounds it contains. As shown in Table 4, average cell-wall content is about 80%, with a narrower range in barley and rice and a broader range in the case of wheat (65% reported for a Canadian variety and 84% reported by Italian researchers). The cellulose content is higher in barley and lower in wheat. The hemicellulose fractions are quantitatively comparable between barley, rice and wheat, with a great variability within figures reported for wheat. Wheat straws appear more lignified but, again, the variability is quite large.

Simple phenolic monomers, which are constituents of lignin, easily solubilized within the rumen, depress significantly the nutritive value of straws. The most important phenolics are p-Coumaric Acid (PCA)and Ferulic Acid (FA), but other compounds are present, as shown in Table 5. The antinutritive activity of phenolic compounds has been clearly demonstrated (Jung and Fahey, 1983; Jung et al., 1983; Kerley et al., 1988; Jung, 1988). Lignin is not so an inert material as it was thought.

Table 4. Cell-wall composition of straws.

Crop	Cell-wall	Cellulose	Hemi-cellulose	Lignin	Ref.
	(g/kgDM)				
Barley	810	440	270	70	(1)
Barley (winter var.)	875	–	296	90	(2)
Barley (winter var.)	864	–	310	77	(2)
Barley (spring var.)	840	–	328	63	(2)
Barley (spring var.)	850	–	295	73	(2)
Barley	845	445	275	97	(4)
Barley	809	413	296	98	(7)
Barley	845	–	318	39	(13)
Barley	812	–	278	82	(14)
RANGE	809-875	413-445	270-328	63-98	
Maize (stover)	769	–	243	51	(9)
Oat	730	410	160	110	(1)
Rice	790	330	260	70	(1)
Rice (long var.)	784	–	–	–	(3)
Rice (short var.)	818	–	–	–	(3)
RANGE	784-818				
Wheat	800	390	360	100	(1)
Wheat	807	–	287	80	(2)
Wheat	744	362	218	97	(4)
Wheat	765	406	235	74	(5)
Wheat	827	384	278	103	(6)
Wheat	840	391	299	95	(6)
Wheat	829	390	280	102	(6)
Wheat	838	385	297	96	(6)
Wheat	806	400	314	99	(7)
Wheat	654	–	228	68	(8)
Wheat	758	–	302	49	(9)
Wheat	826	–	240	–	(10)
Wheat (hard)	751	–	–	–	(11)
Wheat (winter var.)	777	–	244	–	(12)
Wheat (winter var.)	690	–	256	–	(12)
RANGE	654-840	362-406	218-360	49-103	
Sorghum (stover)	740	300	310	110	(1)

References: (1) Theander and Aman, 1984;
(2) Reid et al., 1988;
(3) Walli et al., 1988;
(4) Cottyn and de Boever, 1988;
(5) Antongiovanni et al., 1983;
(6) Andrighetto e Cavalli, 1988;
(7) Givens et al., 1989;
(8) Mann et al, 1988;
(9) Adebowale et al., 1989;
(10) Michalet-Doreau and Guedes, 1989;
(11) Chermiti et al., 1989;
(12) Chenost, 1989;
(13) Wanapat et al. 1985;
(14) Abidin and Kempton, 1981.

Table 5. Phenolic compounds content of cereal straws.

Crop	PHBA	VA	PCA	FA
	(mg/kgDM)			
Barley:				
Wing (1)	92	110	3190	2550
Sarla (1)	26	93	640	529
Cilla (1)	37	13	959	1170
Ingrid (1)	28	20	1880	1000
Senat (1)	170	120	3190	3520
– (2)	–	600	4000	2000
Oat:				
Titus (1)	290	79	3500	2940
Rice:				
– (1)	–	17	2720	1340
Rye:				
Petkus (1)	62	33	3430	3260
Wheat:				
Starke II (1)	26	13	1160	860
Holme (1)	42	24	1740	1700
Drabant (1)	91	180	1910	1670
– (2)	–	80	4900	2900

References: (1) Salomonsson et al., 1978;
(2) Jung and Fahey, 1983;

Legenda: PHBA = p-Hydroxybenzoic Acid;
VA = Vanillic Acid;
PCA = p-Coumaric Acid;
FA = Ferulic Acid.

2.- Proteins

Structural proteins of the primary cell-wall of the live plant remain as a part of lignified cell-walls in straws. Variations are due to soil conditions, to fertilization, to harvest time, to climate conditions during the crop growth, etc.. Most of the proteins are associated with the other cell-wall constituents (lignin, structural carbohydrates, silica), thus resulting poorly degradable and digestible.

Theander and Aman (1984) report very low crude protein values for cereal straws (Table 6), ranging from 24 up to 54 g/kg DM. Other literature sources confirm the data: INRA, 1978; Piccioni, 1989, in the same table 6; Walli et al., 1988 (44 and 36 g/kg DM in barley); Reid et al., 1988 (74 g/kg DM in wheat and 42-53g/kg DM in barley);Cottyn and de Boever,1988 (25 g/kgDM in

Table 6. Crude protein content of cereal straws.

Crop	Sweden (1)	USA and Canada (1)	UK (1)	France (2)	Italy (3)
	(g/kgDM)				
Barley	54	41	38	38	32
Oat	45	44	34	32	29
Rice	–	42	40	–	37
Rye	32	32	36	–	–
Wheat	39-52	36	24-34	35	35-48

References: (1) Theander and Aman, 1984;
(2) INRA, 1978;
(3) Piccioni, 1989.

barley and 56 g/kg DM in wheat); Shand et al., 1988 (28 g/kg DM in wheat and 47 g/kg DM in oat); Adebowale et al., 1989 (48 g/kg DM in wheat); Chenost, 1989 (29-45 g/kg DM in wheat); Mann et al., 1988 (31 g/kg DM in wheat); Silva et al., 1989 (31-37 g/kg DM in barley).

3.- Minerals

Minerals represent another barrier to the attack of rumen microbes to structural carbohydrates. The mineral fraction vary a great deal due to the different soil conditions and possible soil contaminations of analyzed samples. One of the major mineral components of straws is silica, particularly in rice and in the leaves fraction.

Table 7. Minerals in cereal straws.

Mineral	Barley	Oat	Rice	Rye	Wheat (spring)	Wheat (winter)
	(g/kgDM)					
Ash	60	59	189	39	61	50
Silica	15	11	130	34	31	32
Ca	2.9	3.9	2.4	2.8	3.2	2.1
P	0.8	0.9	0.9	1.0	0.8	0.8
Mg	1.0	1.5	1.2	0.9	0.9	1.1
K	14.0	21.9	13.2	9.8	11.8	10.0
Na	–	–	–	0.5	0.5	0.5
Cl	7.7	8.1	–	2.5	6.1	3.5
S	1.4	2.5	1.3	1.2	1.4	1.6

Reference: Theander and Aman, 1984.

Quite interesting in this respect is Table 7, reported by Theander and Aman (1984). It must be emphasized the negative effect of high concentrations of silica, as in rice straw, inversely correlated with polysaccharides degradability in the rumen (van Soest and Jones, 1968).

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