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Ruminal digestion kinetics of citrus peel

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Abstract

Three experiments were conducted to investigate digestion kinetics of citrus peel in the rumen of cows fitted with rumen canulae. In the first experiment silage of orange peel was studied, while in the second experiment fresh peels from two lemon varieties were studied in conjunction with orange peel. The third experiment included silage of orange peel and sugar cane prepared in mixture with broiler litter. Corn silage was used as a reference. Treatment samples, dried at 50°C, were placed in heat sealed nylon bags, which were suspended in the rumen for varying times up to 48 h of incubation. A lag phase was observed with orange peel silage, showing residual DM decay commencing at 4 h of incubation. Rates of degradation did not differ significantly between citrus peel, neither between orange peel and orange peels' silage, and averaged 2.9% h^{-1}. Effective degradability was also similar for citrus peel fresh or as silage, ranging from 51% to 58% at an outflow rate of $k = 0.05$. Addition of calcium hydroxide to peels showed some negative effect on ruminal digestibility, depressing effective degradability by 5 to 10%, but did not affect rates of degradation. For all citrus peels, the constants (a + b) of the non linear regression (NLIN) models by least square summate very near to unity. This shows high potential degradable DM in the rumen, suggesting high energetic value for cattle. © 1997 Elsevier Science B.V.

Keywords: Orange peel; Broiler litter; In situ technique

1. Introduction

The in situ technique has been widely used to study ruminal digestion kinetics of feeds for cattle. Although in this technique the incubated feed is not subject to mastication and passage, it is no better way to simulate the rumen environment to study ruminal digestion kinetics (Nocek, 1988). This technique has been reported to be well

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correlated with animal performance (Orskov, 1989; Khazaal et al., 1993), with voluntary feed intake and in vivo dry matter digestibility (Khazaal et al., 1995). In Brazil, researchers have used the in situ method to evaluate tropical forages, agricultural residues and industrial by-products for feeding cattle (Wanderley and Silva, 1993; Vilela et al., 1994; Gomes et al., 1994; Aroeira et al., 1995).

Among the industrial by-products in Brazil, citrus peels have significant economic importance especially in Sao Paulo, where most of the citrus industries are located. A large quantity of a by-product (citrus peel) from the citrus industry that can be used for feeding cattle is available in Brazil (Silva et al., 1995). The majority are orange peels, but peels of lemon and grapefruit are also available. Orange peels comprise about 50% of the whole fruit by weight (Ashbell and Donahaye, 1984). Citrus peels can be fed to cattle in form of silage, fresh, or dried in pellet form. The latest is the most common type available in Brazil because it is more adequate for shipping to long distances. Brazil exported 1.5 million metric tons of dried citrus peel in pellet form to Europe as feed for cattle in 1994. Calcium hydroxide is often added to peels in the citrus industry, to speed up the drying process when peels are being pellet-processed.

Because of the high moisture and sugar content, the huge load of mold and yeast, citrus peel is a very sensitive product that deteriorates rapidly (Ashbell et al., 1988). Therefore, preservation must be considered. The common technology for preserving citrus peel in Brazil is by drying, but preserving it by ensiling the citrus peel would be possible and save in drying costs. Due to the low dry matter content of the fresh peels, a great loss may occur during the ensiling (Ashbell and Donahaye, 1986). However, it is possible to ensile citrus peel with poultry litter and obtains a suitable and nutritive preserved product for ruminants (Pedroso et al., 1995; Ashbell et al., 1995).

For ruminants, cereals can be largely replaced by energy-rich by-products, including those from the fruit processing industries, reducing the competition between animal and human nutrition (Deaville et al., 1994). Dried citrus pulp (similar to citrus peels) has been used for feeding dairy cows (Wing, 1974; Belibasakis and Tsirgogianni, 1996), fattening cattle (Pinzon and Wing, 1975; Hadjipanayiotou and Louca, 1976; Wanderley et al., 1994), and sheep (Zervas et al., 1994; Karalazos et al., 1992). Nutritive value and digestibility of citrus pulp have been reported (Schaibly and Wing, 1974; Hadjipanayiotou and Louca, 1976), but it should be realized that most data were obtained on pulp made using citrus varieties and processing methods different from the ones prevailing today. Moreover, as feed evaluation methods move toward more dynamic approach, further research is needed on the energy-rich by-products available to determine the degradation characteristics in the rumen (Deaville et al., 1994).

Three experiments were conducted with the objective of studying the ruminal degradation kinetics of citrus peels in dairy cattle.

2. Material and methods

2.1. Methods of incubation

Approximately 6 g of oven-dried (at 50°C) feed-treatment samples were placed in triplicated heat sealed nylon bags and incubated in the rumen of cows for 2 h, 4 h, 6 h, 12 h, 24 h, and 48 h. Feed-samples were ground using a 5-mm screen in Wiley Mill. The bags, with pore size of 40 μm, measured 7.0 × 14.5 cm to allow a ratio of 32 cm^2 per g of samples. Before incubation, the bags containing the samples were rinsed with tap water (39°C) for 15 min. The dry matter lost during washing was considered the potentially soluble fraction (P_{sol}) and the remaining the slow degradable fraction (SDF). The total dry matter disappeared in 48 h of incubation, including P_{sol}, was assumed to be the potential maximum degradable dry matter (P_{max}) in the rumen.

Bags were placed into the rumen of cows in reversed sequential order, according to incubation time, and were removed all at same time. After removal, the bags were rinsed with tap water during 15 min and dried at 50°C in a forced-draft oven. Unincubated bags containing feed samples were also rinsed and dried to make the zero incubation time.

2.2. Animals

Three crossbred Holstein/Zebu cows, fitted with permanent rumen cannulae, were used in three experiments. Lactating cows were milked twice daily at 5:00 a.m. and 4:00 p.m. Lactating cows (producing an average 17 kg of milk daily in mid-lactation) received 3 kg of a dairy concentrate per 10 kg of milk yield, while the dry cows received 2 kg daily. Dairy concentrate was made of 18% ground corn grain, 18% soybean meal, 18% cotton seed meal, 38% wheat mill runs, 4% limestone, 4% premix (dicalcium phosphate 48%, sodium chloride 48% and 4% of magnesium oxide, zinc oxide, copper sulfate, sulfur, cobalt sulfate, and sodium selenite).

2.3. Experiment 1

Two trials were conducted to investigate the ruminal digestion kinetics of silage of orange peel (OP). Two rumen cannulated cows in mid-lactation were used in trial 1, while three cows (one lactating and two dry) were used in trial 2. The cows were kept grazing on Brachiaria decumbens pasture, receiving a supplement of well-eared corn silage (10 kg) and dairy concentrate.

OP was prepared in a bunker silo and on dry matter basis had 28.2% DM, 5.8% CP, 28.0% NDF, 5.5% EE, with a pH of 3.9. Approximately 6 g of oven-dried (at 50°C) OP silage was the amount placed in each bag for the in situ incubation.

Analysis of variance was used to compare differences between trials using the general linear model procedures of Statistical Analysis System Institute (1995).

2.4. Experiment 2

An in situ trial was conducted to compare ruminal degradation of whole citrus peel from two lemon varieties (Tahiti and Sicilian), and whole orange peel as the reference. The effect of adding calcium hydroxide to peels on ruminal digestion kinetics, was investigated in the two lemon varieties.

Three rumen cannulated cows (two dry and one lactating) were used. Management and diet were the same as in Section 2.3.

Fresh citrus peels were oven-dried (at 50°C) and approximately 6 g samples were placed in heat sealed nylon bags for the in situ incubation.

Analysis of variance was used to compare differences between treatments using the general linear model procedures of Statistical Analysis System Institute (1995).

2.5. Experiment 3

To reduce losses during ensiling, orange peels (OP) and sugar canes (SC) were mixed with broiler litter (BL) made with peanut hulls (pods) to increase dry matter (DM) to 40–50%. Silages were prepared in 200 kg plastic barrels, which were stored for 40 days. Compaction for ensiling was done by stepping on every 20-cm layer. Chemical composition of silages is in Table 1. An in situ trial was conducted with three rumen cannulated cows in late lactation. Corn silage (well-eared) was used as reference silage. The cows were fed daily 15 kg chopped sugar cane + 120 g urea and 15-kg corn silage as roughage, and 7 kg of the dairy concentrate mixture.

Dried silages (at 50°C) were ground using a 5-mm screen in a Wiley Mill. Six gram samples were then placed in heat sealed nylon bags for the in situ incubation. Before incubation, the bags with samples, were soaked in tap water (39°C) for 15 min.

Analysis of variance was used to compare differences between treatments using the general linear model procedures of Statistical Analysis System Institute (1995).

2.6. Calculations

Ruminal degradation was calculated using two approaches: (1) by logarithmic transformation (Mertens and Loften, 1980), regressing the natural log of the dry matter (DM) residues by incubation time, and using the linear portion of the decay of the residual DM, and (2) by the non linear least square (NLIN), based on Marquardt method (Statistical Analysis System Institute, 1995) and using the exponential model described by Orskov and MacDonald (1979), constraining the asymptote to 100.

The model described by Orskov and MacDonald (1979) was: $D = a + b\ (1 - \exp(-ct))$, where D is the degradation after t hours and a, b and c are constants peculiar to each feed source. The constant 'a' represents the soluble fraction, assumed

Table 1
Chemical composition of broiler litter (BL), orange peel (OP), sugar cane (SC) and silages of OP + BL and SC + BL

	BL	OP	SC	BL + OP[a]	BL + SC[b]
DM (%)	84	21	31	41	52
CP (%)	31	8	3	22	22
NDF (%)	50	24	49	39	50
ADF (%)	29	20	33	30	32
ASH (%)	16	3	2	11	13
Energy (cal/g DM)				3923	4110

[a]BL 30% and OP 70% on as is basis (BL 63% and OP 37% on DM basis).
[b]BL 40% and SC 60% on as is basis (BL 64% and SC 36% on DM basis).

Table 2
Least square means of parameters describing ruminal degradation of silage of orange peels (OP)

	Trial 1	Trial 2
P_{sol} (%)	27.76A	21.35B
P_{max} (%)	95.00A	89.31B
SDF[a] (%)	68.43	68.34
Rd[b] (% p/h)	2.40B	2.66A
Constants of NLIN[c]:		
a	21.5A	12.8B
b	78.2B	86.4A
c^{d}	3.29	3.96
Ed[e]:		
$k = 0.04$	56.8	55.8
$k = 0.05$	52.5	51.0
$k = 0.06$	49.2	47.2

A, B in the same row, significant at $P < 0.05$.
[a]Degradability of slow degradable fraction at 48 h incubation.
[b]Rate of degradation of the SDF, calculated by logarithmic transformation of DM residue decay.
[c]Non linear regression model by least square.
[d]Rate of dry matter degradation by NLIN.
[e]Effective degradability at different ruminal outflow rates (k).

instantly degradable and equivalent to P_{sol}, and it is the intercept of the degradation curve at time zero; the constant '*b*' is the potential, not soluble, degradable fraction; and '*c*' is the rate constant of degradation, while '*t*' is the incubation time.

To compare treatments, effective degradability (Ed) in the rumen was calculated based on ruminal outflow rates of $k = 0.04$, $k = 0.05$ and $k = 0.06$. Ed was calculated

Table 3
Observed (Obs)[a] and estimated (Est)[b] values of ruminal degradation of silage of orange peel

Incubation time	Trial 1		Trial 2		Pooled[c]
	Obs	Est	Obs	Est	
0	27.8	21.5	22.9	12.8	17.2
2	27.8	26.5	–	19.4	22.9
4	28.3	31.1	23.7	25.5	28.2
6	31.8	35.5	–	31.1	33.3
8	–	39.6	31.0	36.3	37.9
12	44.4	47.0	44.3	45.5	46.3
24	58.8	64.2	65.5	65.8	65.0
36	–	75.8	85.2	78.5	77.1
48	93.8	83.6	89.3	86.3	84.8

[a]Mathematical mean of observed values for two cows in trial 1 and three cows in trial 2, and three replicates by incubation time in each trial.
[b]Non linear estimated by least square, using Marquardt method.
[c]Pooled values (trial 1 + trial 2).

Table 4
Composition of citrus peel expressed as % of DM

	DM	CP	NDF	Ca	P
Tahiti (C)	23.09	4.80	32.62	3.18	0.18
Tahiti (No)	23.81	5.19	29.61	0.83	0.17
Sicilian (C)	20.76	6.77	36.36	3.69	0.21
Sicilian (No)	18.47	6.64	36.33	0.80	0.20
Orange (No)	24.92	6.53	27.13	0.73	0.17

(C) = treated with calcium hydroxide; (No) = not treated.

using the model suggested by Orskov and MacDonald (1979): $Ed = a + [(b * c)/(c + k)]$, where k is the fractional outflow rate of digesta from the rumen (h^{-1}).

3. Results

3.1. Experiment 1

The values of P_{sol} and P_{max} were higher in trial 1 than in trial 2 ($P < 0.05$). Disappearance of SDF at 48 h was similar in both trials, but rates of degradation (Rd) of SDF were higher in trial 2 than trial 1 ($P < 0.05$). A lag phase was observed, with

Table 5
Mean ruminal degradation values for citrus peel[a], Tahiti lemon (Tah), Sicilian lemon (Sic) and orange (OP)

	Tah (C)	Tah (No)	Sic (C)	Sic (No)	OP (No)
P_{sol} (%)	13.79B	12.43B	19.22A	20.98A	20.50A
P_{max} (%)	83.74	82.70	86.01	88.91	86.69
SDF[b] (%)	69.49	71.59	67.43	68.43	67.27
Rd[c] (%/h)	2.32	2.38	2.14	1.96	2.16
Constants of NLIN[d]:					
a	21.60	24.74	26.11	40.28	30.06
b	78.40	75.26	73.89	59.72	69.94
c[e]	2.83	2.84	2.86	3.04	3.07
Ed[f]:					
$k = 0.04$	54.09	55.99	56.93	66.05	60.42
$k = 0.05$	49.95	52.00	53.01	62.84	56.66
$k = 0.06$	46.74	48.92	49.97	60.35	53.73

A, B in the same row, different at $P < 0.05$.
(C) = treated with calcium hydroxide; (No) = not treated.
[a]Least square mean of three cows and three replicates by incubation time in each cow.
[b]Degradability of slow degradable fraction (SDF) at 48 h of incubation.
[c]Rate of degradation of SDF calculated by using the LN of DM residue decay.
[d]Non linear regression model by least square.
[e]Rate of dry matter degradation by NLIN.
[f]Effective degradability at different ruminal outflow rates (k).

residual dry matter decay commencing at 4 h incubation. Estimates by NLIN produced smaller values for the soluble fraction than observed ones (Table 2), but the same tendencies in progressive dry matter disappearance (Table 3). Difference between trials occurred mostly for the soluble fraction. After 12 h of incubation, estimated degradability values were similar between trials. Moreover, estimated 'c' and effective ruminal degradability (Ed), did not differ ($P > 0.10$) between trials. The summation of constants $a + b$ (potential dry matter degradability) was 99%.

3.2. Experiment 2

Chemical composition of the citrus peels (Table 4), shows both lemons having higher neutral detergent fiber (NDF) than orange peels, while Tahiti also has a slight lesser CP. As expected, higher Ca content reflected the addition of calcium hydroxide to the lemon peels.

Tahiti lemon showed lower P_{sol} ($P < 0.05$) than Sicilian lemon and orange peels (Table 5). Dry matter disappeared in 48 h (P_{max}) in the rumen, averaged 83% for Tahiti and 87% for both Sicilian lemon and orange peels. However, potential dry matter degradability ($a + b$) from NLIN estimates, was near to unity.

Non significant difference ($P > 0.10$) was detected between the citrus peels for the rate of degradations nor effective degradability.

Table 6
Ruminal degradation parameters of silages of orange peel (OP + BL) and sugar cane (SC + BL) mixtured with poultry litter, and of corn silage[a]

	OP + BL	SC + BL	Corn
P_{sol} (%)	22.21B	29.62A	23.46B
P_{max} (%)	75.93A	60.97B	58.77B
SDF[b] (%)	54.80A	30.65C	34.43B
Rd[c] (%/h)	1.64A	0.69B	0.75B
Constants of NLIN[d]:			
a	25.16C	33.85A	28.70B
b	73.89A	32.84B	45.55B
c[e]	2.53B	3.72A	2.16B
Ed[f]:			
$k = 0.04$	53.79A	49.67B	44.68C
$k = 0.05$	49.99A	47.86A	42.45B
$k = 0.06$	47.08A	46.42A	40.76B

A, B, C in the same row, different at $P < 0.01$.
[a]Means of three cows and three replicates by incubation time in each cow.
[b]Degradability of slow degradable fraction (SDF) at 48 h of incubation.
[c]Rate of degradation of SDF calculated by regressing the LN of DM residue decay by incubation time.
[d]Non linear regression model by least square.
[e]Rate of dry matter degradation by NLIN.
[f]Effective degradability at different ruminal outflow rates.

Addition of calcium hydroxide to peels had some negative effect on ruminal degradation, depressing effective degradability. However, rates of degradation were not affected by the addition of calcium hydroxide to peels.

Progressive dry matter degradability in situ and effective degradability in the rumen were quite similar between orange peels' silage in the first experiment and orange peels in the second experiment.

3.3. Experiment 3

Silage made of sugar cane mixed with broiler litter (SC + BL) had the highest soluble fraction, as compared with silage made of orange peels mixed with broiler litter (OP + BL) and corn silage, which tended to be intermediate (Table 6). The summation of parameters constants $(a + b)$ of the NLIN were 99%, 67% and 74%, respectively for OP + BL, SC + BL and corn silages. This shows greater potential degradable dry matter for OP + BL and, again, an intermediate value for corn silage. Effective ruminal degradability (Ed), tended to be higher for OP + BL and intermediate for SC + BL.

4. Discussion

The potential ruminal degradable dry matter $(a + b)$ of citrus peels in all forms, whole dried, silage or mixed with broiler litter, was close to the unit. This suggests a high nutritive value feed for cattle, similar to that of processed cereal grains. Arieli et al. (1995) reported potential degradability values $(a + b)$ in dairy cows for dry matter of corn, sorghum and wheat averaging 93%, while Wanderley et al. (1996) reported values close to the unit for potentially degradable starch of dry rolled and steam flaked sorghum grain in dairy cows, which would be expected according to Theurer (1986) and Nocek and Tamminga (1986). Hadjipanayiotou and Louca (1976) concluded that citrus pulp appeared to compare favorably with barley as an energy source. This agrees with Deaville et al. (1994), although barley grain contains a high level of starch, whereas the by-products from the fruit processing have high levels of cell wall materials, as they pointed out. Moreover, Schaibly and Wing (1974), did not find effect, replacing 1/3, 2/3 and all of corn silage with citrus pulp in the diet, on disappearance of cellulose from nylon bags in the rumen of steers.

Calcium hydroxide addition inhibited yeasts and reduced losses in ensiling orange peels (Ashbell and Weinberg, 1988). This treatment was beneficial to lactic acid bacteria and allowed high levels of lactic acid in the silage. The addition of calcium hydroxide to fresh lemon peels in our study might affect the microbial population colonizing the incubated lemon peels, reducing the progressive dry matter degradation and the effective degradability in the rumen. However, the rate of degradation was not affected and potentially degradable dry matter $(a + b)$ summate near to unity in both treated and untreated lemon peels.

Aroeira et al. (1995), reported that the potential degradable dry matter $(a + b)$ of sugar cane averaged 63%, which somewhat agrees with the 67% average found for the silage made with sugar cane mixed with broiler litter in our study. The slightly higher potential degradable DM (67 vs. 63%) was due to the complementary effect of the mixture with broiler litter. The combination of broiler litter with moist by-products has proved beneficial for ensiling these by-products (Ashbell et al., 1995). Each component in the mixtures retains its original fermentation characteristics. In our study, the combination of either OP or SC with BL was complementary for ensiling. Broiler litter contributed to increase dry matter, nitrogen and minerals, while OP and SC contributed mainly as sources of soluble non structural carbohydrates, such as sugars.

In situ degradable dry matter fractions may serve as a quality nutritive index (Arieli et al., 1995). It can also be used to predict voluntary feed intakes (Khazaal et al., 1995). The parameters determined in the present studies, suggested high nutritive value for OP fresh or in preserved forms, including when mixed with BL as silage for cattle. High voluntary feed intakes of citrus peels in different forms can be predicted for ruminants. No differences were found between pelleted and nonpelleted citrus pulp as a replacement for corn in steers' diet (Pinzon and Wing, 1975) and dairy diet (Wing, 1974). This shows that pelleting does not affect citrus pulp or peels as on other concentrate feedstuffs.

Tables from the NRC - National Research Council (1989), show 74% total digestible nutrients (TDN) for corn silage, 77% for dried citrus, 78% for citrus pulp silage and 78% for either fresh whole or dehy orange pulp. This shows higher energy values for citrus pulp than corn silage, assuming that 1 kg of TDN has 4409 Mcal of digestible energy.

No data on kinetics of ruminal digestion of citrus peel were found in the literature to compare our results.

Based on the milk production of the cows in the experiments, an outflow rate of 0.05 (ARC - Agricultural Research Council, 1984), was used to calculate average Ed values. Estimated Ed, ranged from 52 to 58% for citrus peel, 50% for OP + BL, 48% for SC + BL and 43% for corn silage.

5. Conclusion

Thus, based on this background, it can be concluded that citrus peels can be used as an energetic feedstuff replacing cereal grain or silage in diet for cattle (Wanderley et al., 1994). The limitation would be only by economic consideration (Wing, 1974).

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