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Review

Starch Utilization by Ruminants

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ABSTRACT

Starch comprises about 70–80% of the cereal grains, out of which 80 to 90% of the starch is degraded in the rumen. Differences among species in rumen starch degradation and its delivery to postrumen are mainly due to type and amount of carbohydrate consumed, rate and extent of digestion/fermentation, grain processing, particle size, density, and its passage rate. Steam flaking of sorghum (SFS) grains increased the total tract digestion of starch by 14%, ruminal digestion by 32%, and postruminal digestion by 33% than dry rolled sorghum (DRS). Higher ruminally degradable starch (RDS) corresponded to greater post ruminal digestibilites was because of greater digestibility potential of SFS or a lesser amount of starch exiting the rumen to challenge post ruminal amylolytic enzymes. Increased availability of ruminal starch decreases the ruminal pH, which may depress digestion of fibre, as starch increases the lag time before digestion can occur. Ruminal fibre digestion, acetate: propionate ratio, and milk fat percentages remained unchanged when the ratio of forage NDF to RDS in the diet was kept between 0.9–1.2. Diets containing more RDS in a proper balance with forage fibre (1: 1), resulted in higher yield of milk (+3.4 kg/d) and milk protein (+110 g/d) with no change in daily yield of milk fat. Quantity of starch passing into the abomasum (16 to 38%) increased with increasing starch intake which was digested in the posterior part of the rumen. Forage source due to its different buffering capacities, affects on chewing and rumination times, and on differential passage rates of feed particles and liquid through the ruminant digestive tract, also influences the ruminal degradability of starch. Starch digested in small intestine may be utilised more efficiently than ruminally digested starch because fermentation losses as methane and heat which account for about 20% of energy are avoided, and the end product of starch digestion i.e. glucose is more efficiently utilised than fermentation end products. Starch digestion in the large intestine and cecum, is not advantageous to the host, because the VFA and amino acids formed are not absorbed. Though more starch is digested postruminally as its intake is increased, efficiency of starch digestion suffers, due to the limited capacity of small intestine for starch digestion (1–2.2 kg/d). Low pancreatic amylase and inadequate isomaltose activities, short retention time, lower intestinal pH level due to high concentrate diet, saturation of the glucose active transport mechanism, and type of grain and its processing are the main factors which limit the starch digestion in ruminants. Thus during formulating diets not only the starch (concentrate) and forage contents of diet but also their ruminal and post ruminal digestion should be kept in mind. So that proper coupling of nutrients in the gastrointestinal tract especially in the rumen may take place that results in maximal animal production efficiency.

Key Words: Starch; Ruminants; Fibre; Glucose; Amylase

INTRODUCTION

Starch is the natural glucose storage polysaccharide of plants and major carbohydrate source for animals. Starch represents about 70 to 80% of most cereal grains and a large percentage of many roots and tubers. It is also a major component of many legumes such as peas, beans and lentils. The structure and composition of cereal and their interactions with proteins play a major role in the digestibility and feeding value of grains for livestock. The digestibility of starch is affected by a number of factors including its composition, physical form, protein starch interactions, the cellular integrity of the starch-containing units, and the physical form of feed or food material (Dreher *et al.*, 1984). Unique rumen behavioural patterns result in different proportions of starch escaping the rumen (Waldo, 1973; Owens *et al.*, 1986) resulting in a variable supply of starch for enzymatic digestion in the small intestine. In addition different fermentation patterns among different starches and plant cell wall components (Malenstein *et al.*, 1988) result in different nutrient profile available to the animal body. In general grain starches are more easily digested than root and tuber starches, while legume starches are intermediate in digestibility (Rooney & Pflugfelder, 1986).

The potential rate and extent of fermentation of different starches and other plant polysaccharides as influenced by feed intake, nature of the concentrates, grain processing etc., largely determine their fate in the digestive tract. Due to fermentation losses in the rumen, starch is thought to be utilised less efficiently by ruminants than by monogastrics (Tucker *et al.*, 1968). Undoubtedly, processing improves the efficiency of starch utilization by rumen microorganisms and (or) animal. Generally as rumen starch escape increases, postruminal starch digestion increases, which is used more efficiently for milk synthesis and body weight gain than that digested in the rumen.

Modern approaches of feed evaluation indicate that energy and protein are no longer sufficient nutrients for optimal feeding. New approaches that consider characterization of ruminal and post ruminal digestion of carbohydrates and protein are needed in ration formulation. Therefore, the objective of this paper is to review the ruminal and post-ruminal digestion of starch in ruminant as it affects the animal production efficiency.

Chemical structure of starch. Starch is a glucose composed of two major types of molecule amylose and amylopectin (Table I). Amylose is a linear polymer of α-1,4–linked D-glucose units. A branched amylose is also present in the starch molecule. The concentration of amylose in starch varies from 0 to 80%, depending upon the plant species and varieties of grain. Cereal starches normally contain 20 to 30% amylose. Starches waxy in nature contain little or no amylose. The enzyme, β-amylase, of malted barley completely degrades amylose to maltose. There are few α-1,3 linkages in amylose which are degraded by a specific plant enzyme called Z enzyme (Church, 1988).

Amylopectin is a much larger and branched polymer, which is the largest component of normal

Table I. Properties of starch compnents[a]

	Component	
	Amylose	**Amylopectin**
General Structure	Linear	Branched
Branch points	Name[b]	1 per 20 to 25 glucose units
Degree of polymerisation (DP)[c]	~1,000	~10,000-100,000
Iodine complex colour	Intense blue	Reddish-brown
Solution stability	Low	High

[a] Rooney and Pfugfelder (1986).

[b] Branched amylose may have 1 or 2 α–1, 3 branches per molecule.

[c] Number of glucose residues per molecule.

starches. It is insoluble in hot water and its branched polymer is composed of D-glucose with chains of α-1, 4-linked D-glucose connected by an α-1, 6 branch every 20 to 25 glucose residues (Maynard *et al.*, 1975). Amylopectin comprises 70 to 80% of most cereal starches and is the only starch in many of corn, sorghum, barley, rice and millet (Rooney & Pflugfelder, 1986). β-amylase does not completely degrade amylopectin, rather, it stops acting after approximately 50% of the amylopectin is converted to maltose. Only the amylose fraction of starch reacts with iodine to yield a blue colour.

The amylose and amylopectin molecules of the starch are held together by hydrogen bonding giving a highly organized structure to starch molecule. Starch granules are insoluble in cold water and swell reversibly. Starch granules are pseudocrystals that contain regions of organized crystalline form primarily (amylopectin) and also non-organized amorphous areas. The crystalline regions are quite resistant to water infiltration, whereas the water moves freely through the amorphous areas (French, 1973). The starches that are waxy in nature produce gel that has many applications in food and industrial purposes.

Ruminal starch digestion. Starch is the primary nutrient of ruminant diets that are used to promote high levels of production. Thus, optimal ruminal and postruminal starch utilization is fundamental to improving efficiency of production in animals. Generally starch is rapidly and in many cases entirely degraded in the rumen. Table II lists RDS contents of several ingredients determined by either in situ or in vivo methodologies but it is recognized that there are large differences among animals in this respect (Table III). ϕrskov *et al.* (1971) reported that when two sheep were given identical diets consisting of 93% of pelleted corn, more than 40% of starch escaped fermentation in sheep 1, whereas only 5% escaped fermentation in sheep 2 (Table III). There was less microbial protein produced in the rumen of sheep 2, as indicated by low diamino-pimelic acid content of abomasal nitrogen (N). These big differences between sheep are largely due to differences in ruminal outflow rates and to some extent due to differences in fermentation rates of starch.

Oliveira *et al.* (1995) found lower duodenal starch for SFS (Table IV) than dry rolled sorghum (DRS) reflecting greater ruminal disappearance with SFS. Digestion of starch in the rumen (81 vs. 62%), postruminal (83 vs. 62%) and in the total tract (97 vs. 85%) was highest for cows fed SFS than for DRS. It showed that steam flaking increased total tract digestion of starch by 14%, ruminal digestion by 32%, and postruminal digestion by 33%. Higher ruminally degradable starch corresponded to greater post ruminal digestibilites observed by Pooer *et al.* (1993) was perhaps because of greater digestibility potential of SFS (Theurer, 1986) or because of a lesser amount of starch exiting the rumen to challenge post ruminal amylolytic enzymes (Ownes *et al.*, 1986). For most of grains except corn and sorghum, about 90% or more of starch is normally fermented in the rumen.

Table II. Rumen degradable starch (% of total starch) values for various feedstuffs by *in vitro*, *in situ* and *in vivo* methods*

Feedstuffs	*in situ* and *in vitro*				*in vivo*			
	n[1]	X	SD	Range	N	X	SD	Range
Barley ground	3	89.9	6.2	83.2-97.0	4	87.9	4.6	84.2-93.0
Corn whole	-	-	-	-	5	62.6	9.9	58.975.0
Corn ground	5	58.4	5.1	53.1-67.0	11	76.4	12.1	51.4-93.0
Corn Gluten feed	3	80.6	0.8	79.7-81.3	-	-	-	-
Corn Gluten meal	1	86.5	-	-	-	-	-	-
Oats	2	94.3	6.6	89.6-99.0	2	84.0	11.1	76.1-91.8
Sorghum grain ground	2	54.2	4.4	51.0-57.3	9	67.3	17.5	42.0-91.0
Rice bran	3	71.3	3.3	67.5-73.5	-	-	-	-
Rice grains	1	68.0	-	-	-	-	-	-
Soybean meal (44%)	1	80.0	-	-	-	-	-	-
Wheat bran	1	88.2	-	-	-	-	-	-
Wheat grain	3	90.5	7.3	86.1-99.0	5	89.3	2.1	85.6-91.7
Wheat middling	2	88.8	0.8	88.2-89.4	-	-	-	-

*Adapted from Nocek and Tamminga, 1991.
[1] There may be more than one observation per cited reference.

A decreased ruminal pH, caused by increased availability of ruminal starch, may depress digestion of fibre (Hoover, 1986). Cellulolytic bacteria must adhere to fibre and develop colonies before structural polysaccharide degradation can occur (Costerton *et al.*, 1987). *In vitro* colonization increased with added starch but fibre digestion was decreased (Firkins *et al.*, 1991) and speculated due to an increased lag time. This may explain why higher levels of corn supplementation have a negative effect on fibre digestion.

Poore *et al.* (1993b) reported that ruminal fibre digestion, acetate: propionate ratio, and milk fat percentages decreased only when the ratio of forage NDF to RDS of the diet was below the critical limit of 0.9 and 1.0, and best results in terms of milk yield was obtained with ratio of 0.9–1.2 (Nocek & Russell, 1988). Poore *et al.* (1991) found that lactational response was adversely affected only when the ratio of forage NDF to RDS was less than 1.0. Diet containing more RDS in a proper balance with forage fibre (1.0), resulted in higher yield of milk (+3.4 kg/d) and milk protein (+110 g/d) with no change in daily yield of milk fat (Poore *et al.*, 1993b). So formulating energy supplements with low levels of corn and adding additional energy as fibrous feedstuffs such as soybean hulls (Sarwar *et al.*, 1991) may reduce the negative effects of starch on fibre digestion.

Post-ruminal starch digestion. Type and amount of carbohydrate source consumed, rate and extent of digestion, grain processing, particle size, density, and passage rate are the factors that influence the rumen starch degradability and its postruminal delivery. Klusmeyer *et al.* (1991) reported that ruminal and postruminal starch digestion was not affected by increasing the amount of concentrate in the diet, however, Nisa and Sarwar (1998) indicated that digestible energy of feeds are affected by level of intake because of the interaction between digestion and passage rate. Other reports (Karr *et al.*, 1966; Tucker *et al.*, 1968) indicated that a great proportion of dietary starch was digested post ruminally when starch was supplemented in the diet. Karr *et al.* (1966) reported that quantity of starch passing into the abomasum (16 to 38%) increased with increasing starch intake. Thus, postruminal starch digestion has a role in overall starch utilization when dietary intake of starch is increased. Tucker *et al.* (1968) conducted an experiment on sheep to measure ruminal and postruminal starch digestion with different levels of starch intake. With higher level of intakes, starch escaped rumen fermentation and was digested in

Table III. Differences between sheep given a pelleted diet in ruminal digestion of starch and consequences for post- ruminal digestion[a]

Item	Sheep 1	Sheep 2
Starch intake, g/d	942	778
Crude protein in faeces, %	59	27
Apparent nitrogen digestibility, %	47	72
Digestion in small intestine, g/d	324	21
Digestion in large intestine, g/d	57	
Excreted in faeces, g/d	21	
DAPA[b], g/16g abomasal nitrogen	3.56	4.95

[a] From ϕrskov *et al.* (1971).
[b] Diamino-pimelic acid.

posterior part of the rumen. Post-ruminal digestion in these sheep was highly efficient with over-all apparent digestion coefficients as high as 96%.

Table IV. Intake, ruminal, and total tract digestibility of starch and faecal pH in cows fed processed diets[1]

Item	Diets	
	Steam flaked sorghum	Dry rolled sorghum
Starch intake, g/d	6.63	6.76
Starch flow, kg/d		
Duodenal	1.25[b]	2.57[a]
Faecal	0.20[b]	0.96[a]
Digestibility %		
Ruminal	81.2[b]	61.5[a]
Entering intestines (duodenum)	82.7[b]	62.1[a]
Total tract	97.1[b]	85.0[a]
Faecal pH	6.30	6.14

[1] From Oliveira *et al.* (1995)
[a-b] Means followed by different superscript differed significantly ($P<0.05$)

Small Intestinal starch digestion. It has generally been assumed that in ruminants only small quantities of digestible carbohydrate escape fermentation in the rumen and, therefore, are available for absorption in the lower alimentary tract. Theurer (1986) related higher efficiency of body weight gain in beef cattle with greater ruminal and total tract digestion of starch, resulting in increased digestible energy in the total diet.

Starch digested in small intestine may be utilised more efficiently than ruminally digested starch

Table V. Capacity for digestion of different organs[a]

Rumen	Small intestine	Large intestine
No limitation per se	Limited capacity	Very limited and undesirable
Problems of maintenance of ruminal pH	Low amylase	Inadequate time
Problems of structure	Inadequate time in organ	Problems of scouring
Problems of high propionate	Inadequate maltase Limited absorption capacity of glucose	Problems of protein excretion

[a] From ϕrskov *et al.* (1971).

(Ownes *et al.*, 1986). They reported that, theoretically, starch digestion in the small intestine is 42% more efficient than starch digestion in the rumen. If starch that escapes rumen fermentation is digested in the small intestine to an extent exceeding 70% of that in the rumen, ruminal starch escape would be beneficial. Starch digested in small intestine is more efficient because firstly, the fermentation losses as methane and heat would be avoided which account for about 20% of energy (ϕrskov *et al.*, 1968), and secondly, the end product (glucose) is more efficiently utilized than fermentation end products such as propionic acid.

It is also observed that the starch that escaped rumen fermentation was not always fully digested in the small intestine due to limited capacity of small intestine for starch digestion, and passed terminal ileum to be subsequently fermented in the large intestine (ϕrskov *et al.*, 1969).

Work by Russell *et al.* (1981a) with steers fed high levels of corn, showed that more starch was digested in the small intestine of these animals, than fed lower level (0.415 vs. 0.224 kg), however, difference was not significant. In another study by Russell *et al.* (1981b), the amount of starch digested in the small intestine was highly related to the amount of starch escaping fermentation. As already mentioned, site and extent of starch digestion by ruminants varies with species, grain type and processing method. With more extensive grain processing, a smaller quantity of starch reaches the small intestine. Trials with growing animals indicate that starch in processed corn and sorghum grains is digested with 42% higher efficiency in the small intestine than in the rumen (Owens *et al.*, 1986). Efficiency of ruminal starch fermentation in cattle can be improved by proper processing of grain. Processing and grain source, both are important for maximal starch digestion and utilisation in ruminants.

Large intestinal starch digestion. Starch can also be fermented in the large intestine and gives end-products similar to ruminal fermentation, namely VAF (ϕrskov *et al.*, 1970). Reduction in digestion of starch in rumen resulted in less amount of energy available for ruminal microbes that might have decreased the supply of microbial protein available for the animal. When large quantities of digestible dietary carbohydrate escape ruminal fermentation and reach the cecum, where its digestion and fermentation leads to formation of VFA and synthesis of microbial protein from residual N in the digesta and urea N that is transferred to the large intestine from blood, is not advantageous to the host. The absorption of VFA is inefficient and microbial protein formed is not digested and excreted in the faeces, with a corresponding fall in urinary N

excretion, thus the apparent digestibility of dietary N decreases from 70 to 50% without influencing the amount of amino-N absorbed (ϕrskov, 1970). A change in the site of fermentation from the rumen to the cecum and large intestine is not likely to yield protein to the animal, since little or no absorption of amino acids from the large intestine has been demonstrated. Wheeler and Noller (1977) reported that less fermentative activity in the cecum and large intestine decreases endogenous N mobilization, resulting in greater N retention and higher apparent digestibility of crude protein. So it is suggested that dietary factors that cause changes in the site of fermentation from the rumen to the cecum will render microbial N less available to the host animal per unit of carbohydrate fermented and decrease the apparent digestibility of N. In the same study, the researchers examined the capacity of large intestine for starch fermentation in sheep by continuous infusion of starch into terminal ileum. Up to 100 g of starch was fermented daily in the cecum colon. The dry matter content and pH of the faeces decreased with increasing rate of cecal fermentation. Wheeler and Noller (1977) found a significant negative correlation between faecal pH and faecal starch content. The physiological constraints for starch digestion in different organs of the body are summarised in Table V.

Factors Affecting Starch Digestion in Ruminants. The relationship between starch escaping the rumen and intestinal digestion was evaluated to determine whether postruminal starch digestion was limiting. There was a positive relationship, indicating that, as ruminal escape starch increased, intestinal (small and large) digestion also increased (Ownes *et al.,* 1986). Although more starch is digested postruminally as its intake is increased, efficiency of starch digestion suffers. Starch digestion as a percentage of that entering the small intestine decreased as starch delivery increased. This relationship coincides with data demonstrating decreased energy digestibility associated with increased intake above maintenance (Conrad, 1966; Moe & Tyrrell, 1976). Based largely on these studies, the following factors suggested to be responsible for the incomplete digestion of starch in ruminant.

1. Low pancreatic amylase and inadequate isomaltose activities. Intestinal breakdown of starch to glucose requires enzymes capable of cleaving both α-1,4 and α-1,6 glucosidic linkages (amylose and amylopectin). An inadequate supply of pancreatic amylase (Karr *et. al.*, 1966; Little *et al.,* 1968) and its inability to breakdown α-1,6 glucosidic linkages (Siddons, 1968) have been suggested the factors limiting small intestinal starch digestion. Thus, at high levels of starch intake the small intestine unhydrolyzed starch increases because of limited supply of pancreatic amylase. Amylase is also secreted from the small intestinal mucosa but it is less active than pancreatic amylase. Isomaltase and maltase activities of the intestinal mucosa appears to be greatest in the mid-jejunum and ileum (Coombe and Siddons, 1973; Kreikemeier *et al.,* 1990), which results in less absorption of the end products.

In addition to total starch intake, percentage of starch in the diet also affects amylase production. Russell *et al.* (1981b) and Janes *et al.* (1985) reported that diet has little effect on small intestine disaccharidase activities, but that pancreatic α-amylase is greater in ruminants fed grain than in those fed forage. However, Kreikemeier *et al.* (1990) demonstrates that greater α-amylase activities associated with grain feeding are due to the increased energy intake. In fact, at equal energy intakes, hay fed steers had almost 75% greater pancreatic α-amylase activities than grain fed steers.

Carpenter, quoted by Van Soest (1982), stated a limit of 1 kg/d for starch digested in the small intestine. Herrera-Saldana *et al.* (1990) and Poore *et al.* (1993a) reported that average postruminal disappearance of starch (PDS) was 2.2 kg/d for dairy cows. Whereas Oliveira *et al.* (1995) reported the PDS value of 1.6 kg/d for dry rolled sorghum (Table IV) and suggested that the limit for starch digestion in the small intestine is greater than that suggested earlier (Van Soest, 1982); however, the amounts of starch digested in the small and large intestine were not determined separately. Mayes and Orskov (1974) attributed lower small intestinal starch digestion to limited pancreatic amylase secretion and short retention time of starch. However, infusion of amylase in steers did not increase starch digestion (Remillard and Johnson, 1984) suggesting that amylase activity may not limit intestinal starch digestion.

2. Intestinal pH level. The optimal pH for bovine pancreatic amylase activity is very important. Russell *et al.* (1981a) reported optimal pH for pancreatic amylase near neutrality (6.8). Decreases or increases in pH by 0.5 units result in 20% reduced amylase activity. Galyean *et al.* (1979) reported that a decrease in faecal pH with increased faecal starch content could result from increased large intestinal microbial fermentation of the starch that escapes digestion in the small intestine. Intestinal pH also depends on diet composition. The pH of digesta throughout small intestine is usually lower with concentrate that with

Table VI. Effect of various levels of abomasal corn starch infusion on small intestinal disappearance and net glucose absorption[1]

Item	Starch Infused, g/h				SE
	0	20	40	60	
DMI, kg	4.40	4.6	4.2	4.6	0.2
Arterial glucose, mM	4.09[a]	4.27[b]	4.38[d]	4.31[c]	.09
Net Portal glucose absorption, g/h	-1.55[d]	8.47[c]	11.38[b]	12.53[a]	2.21
Ileal Digesta					
pH	7.86[a]	7.78[b]	7.76[c]	7.72[d]	.03
DM, %	7.25[a]	8.08[b]	9.03[c]	9.82[d]	.35
Glucose, mM	-.03[d]	2.49[c]	4.37[b]	5.64[a]	0.75
Starch, %	-.36[d]	1.32[c]	7.69[b]	13.19[a]	.88
Acetate, mM	25.8	29.1	30.3	30.3	2.1
Total VFA, mM	26.3	29.8	30.6	60.8	2.0

[1]Kreikemeier *et al.*, (1991)

roughage diet (Russell *et al.*, 1981a). Therefore, digestion of starch in the small intestine is pH dependent besides amylase concentration.

3. Glucose absorption. It is known that glucose is readily absorbed from the small intestine, which limits the starch digestion. Kreikemeier *et al.* (1991) infused 0, 20, 40 or 60 g/h of cornstarch abomasally into steers (Table VI). As the concentration of infused starch increased, so did the amount of carbohydrate disappearing from the small intestine. A linear increase in net glucose appearance in portal drained viscera was associated with increased infusion of starch, but it was maximised at the 20 g/h infusion rate only. Because unpolymerized glucose was present at the ileum with starch infusion, the author concluded that starch hydrolysis exceeded the capacity for glucose absorption.

in vitro studies showed that hydrolysis of disaccharides begins to decline after 10 to15% of the substrate has been hydrolysed, suggesting end product (glucose) inhibition (Dahlqvist, 1964). Therefore the presence of free glucose in ileal fluid when starch was infused (Mayes & Orskov, 1974; Kreikemeier *et al.* 1991) might be interpreted that active transport of glucose across the small intestine was exceeded and the resultant accumulation of end product (glucose) reduced α-1,4 and α-1,6 hydrolysis by intestinal disaccharides.

Experiments indicated that increase in blood glucose level, an indicator of starch digestion in the small intestine should be used carefully. Because a large portion of small intestinal starch disappearance can not be accounted for, as glucose in the portal vein, as absorbed glucose is utilized for gut metabolism. Possible routes of digestion include microbial fermentation to VFA and small intestinal metabolism of glucose to lactate; however these routes are of minor importance (Kreikemeier *et al.*, 1991).

4. Type and form of grains. Physical and physiochemical grain processing methods viz. grinding, pelleting, cooking, steam flaking etc., greatly improves the digestibility of poorly digestible starches (Galyean *et al.*, 1981; Nocek, 1987; Zinn, 1990), as they disrupt the protein matrix in which starch granules are embedded. Starch with high amylose content is poor in digestibility both in raw and cooked forms, while many cereals are among the most digestible forms of all starches. Thus, digestibility of starch is generally inversely proportional to the amylose content. Interaction with proteins can reduce the susceptibility of both native and processed starch to enzyme hydrolysis as is the case with gelatinized starch in which indigestible starch-protein complexes are formed (Theurer, 1986). Antinutritional factors such as phytase, lectins, tannin and other enzyme inhibitors affect starch utilisation (Dreher *et al.*, 1984).

Many of the processing effects and species differences in starch digestibility can be explained by particle size reduction, increased particle density, increased particle passage rate, and starch exposure to enzymes are due to grain processing and mastication. Galyean *et al.* (1981) reported that rate of grain starch digestion in the rumen varies inversely with particle size of the grain. Furthermore, processing of corn either by high moisture grinding and ensiling or steam flaking result in more total in vivo starch digestibility than does dry rolling or treating high moisture shelled corn (Galyean *et al.*, 1976). Moe *et al.* (1973) found finely ground corn gave a higher total tract dry matter digestion (68.3%) than whole corn (59.1%) in 54.5% concentrate diets fed to cows. Younger cattle chew the feed more thoroughly than older, so they can utilise grains more efficiently than others. Starch granular structure as they are surrounded by a protective matrix, may also partially inhibit the small intestinal starch disappearance.

5. Forage source. Forage source could impact the responses of dairy cows to differences in ruminal degradability of starch because forage have different buffering capacities (Van Soest, 1982) and different effects on chewing and rumination times (Sudweeks *et al.*, 1981; Moore *et al.*, 1990) and on differential passage rates of feed particles and liquid through the ruminant digestive tract (Poore *et al.*, 1990, 1991). Cole *et al.*, (1976a) found that increasing the roughage level (7 to 14%) increases the rate of passage of corn grains through the gut, thus reducing total tract starch digestibility.

CONCLUSION

The main site of cereal grain starch digestion in rumen where about 95% of starch is digested out of the total digestive tract digestibility. Of the total starch digested by cattle, on an average 80% digestion occurs in the rumen, and the starch that escape rumen fermentation would be digested in the small intestine or fermented in large intestine. The capacity for digestion of raw starch in the small intestine is limited. This capacity is limited due to lack of enzymes involved in hydrolysis of oligosaccharides and also by rapid absorption of glucose. Starch fermented in the cecum leads to an increased N loss in the faeces. The low ruminal pH also affects fibre digestion and low pH in the small intestine reduce the absorption of starch.

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