Review paper
Pregledni znanstveni članek

MAIZE SILAGE GENOTYPE AND RUMINANT DIGESTION

Brigitte MICHALET DOREAU[a)] and Christelle PHILIPPEAU[a)]

[a)] INRA, Herbivore Research Unit, Center Clermont-Ferrand - Theix, F-63122 Saint-Genès Champanelle, France, Ph.D.

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ABSTRACT

Maize breeding objectives have for a long time been limited to agronomic criteria, but a high variability in nutritive value for ruminants is also observed among hybrids. Nowadays breeding takes into account the effect of chemical composition in the modification of maize nutritional value. The amount and composition of whole plant cell walls, especially their lignification, influences both digestibility and voluntary intake when maize is given as silage. Starch, the main constituent of grain, is degraded slowly in the rumen, and differences among genotypes exist. Among normal maize hybrids, the differences are mainly related to grain vitreousness.

Key words: animal nutrition / ruminants / feed / maize / hybrids / genetic variation / maize silage / digestibility.

GENOTIP KORUZNE SILAŽE IN PREBAVLJIVOST PRI PREŽVEKOVALCIH

IZVLEČEK

Čeprav že precej časa vemo, da je med posameznimi hibridi v hranilni vrednosti za prežvekovalce velika raznolikost, so pri žlahtnenju upoštevali le tiste lastnosti koruze, povezane z merili pridelovalcev. Sedaj pa pri vzgoji novih hibridov upoštevamo vpliv kemične sestave koruze na spreminjanje hranilne vrednosti. Količina in sestava spojin, ki sestavljajo celične stene v celi rastlini, predvsem lignifikacija, vplivata tako na prebavljivost kot tudi na zauživanje silirane koruze. Škrob kot osrednja sestavina zrnja se v vampu razkraja počasi, pri tem pa obstajajo med genotipi razlike. Med običajnimi koruznimi hibridi so razlike povezane predvsem s postekljenostjo zrnja.

Ključne besede: prehrana živali / prežvekovalci / krma / koruza / hibridi / genetska variabilnost / koruzna silaža / prebavljivost.

INTRODUCTION

Maize is widely used in ruminant nutrition mainly as grain, silage, and in some countries as high-moisture grain. In the European Community, the area devoted to maize crops is equally divided between grain and silage production, grain being more important in southern countries and silage in the northern ones. The main producer is France where areas for grain and silage production are equal, grain being primarily used for pig and poultry feeding.

The expected qualities of silage hybrids are clearly not identical to those of hybrids used in grain production. In addition to the classical agronomic qualities, yield, pest- and disease-resistance, root lodging and tolerance to climatic stresses, the main aim in silage maize breeding is to increase the net energy supplied by forage in cattle diet and the quality of animal products in relation to the nature of digestion products. The variation in net energy intake of a maize cultivar is related to the variations in the digestibility of the stover and in the ear content, but also to the variation in its ingestibility and to the digestive interactions between cell wall and starch fractions of the diet. The relative proportion of starch digested in the rumen and in the small intestine varies and has implications for the nature and amount of nutrients delivered to the ruminant in the form of volatile fatty acids (VFA) and glucose, the latter increasing when the proportion of intestinal digestion increases. These nutrients (VFAs and glucose) are used with different efficiencies for energy production (ATP synthesis) during catabolic reactions and for anabolic processes such as fat and protein synthesis, and would have an effect on products quality.

The influence of differences in maize genotypes on ruminant digestion is detailed in this paper. For each quality trait, differences among hybrids are given as well as research results obtained with mutant genotypes when they exist.

CELL WALL DIGESTION AND FEEDING VALUE OF MAIZE SILAGES

The feeding value of forage is related to its digestibility and intake, and determines the energy supplied by the forage in diets. A significant genetic variation has been found among normal maize hybrids. Many measurements were undertaken on a large genetic basis, significant differences were reported among normal maize hybrids in *in vitro* dry matter and/or cell wall digestibility (Roth *et al.,* 1970; Deinum and Bakker, 1981, Dhillon *et al*., 1990), as *in vivo* data (Andrieu and Demarquilly, 1974, Barrière *et al*., 1992). In 126 varieties, registered as very early to medium-early maize, OMD ranged between 65.2 to 73.5 %. Among these hybrids, 33 % had a OMD below or equal to 68 % and 40 % above or equal to 70 % (Barrière *et al*., 1992). The OMD of medium-early hybrids was on average 2.5 units less than the OMD of very early and early hybrids, but the whole range of OMD values was present in each class of hybrid maturity (Table 1). The effect of environment on in vivo data was high but the genotype x environment interactions were weak compared to the genotype effect (Barrière *et al.*, 1997).

Table 1. Variations in organic matter digestibility between different hybrids (from Barrière *et al*., 1992)

Earliness group	Number of hybrids	Organic matter digestibility (%)	
		Mean	Range of variation
Very early	14	72.0	70.1 – 74.2
Early	51	72.1	68.1 – 75.1
Medium-early	64	70.6	65.1 – 75.9
Semi-late	13	70.0	66.9 – 74.6
Late	23	69.2	63.9 – 76.1
Very late	10	66.6	65.0 – 69.9

The grain part of maize silage constitutes on average 37 % of the dry matter (DM) of the whole plant (Andrieu *et al*., 1993). Increasing the grain content of the plant should increase silage digestibility because the kernels are almost completely digestible in the digestive tract of ruminants. The same digestibility of maize silage could thus be achieved either by a high grain content and a low cell wall content with a low digestibility, or by a high digestibility of the stover with a high cell wall content. In fact, in a study with 99 maize samples, the correlation between OMD and starch content was weak compared to that between OMD and different cell wall constituents (Figure 1). Cell wall content depends firstly on the growth stage of the maizes, and decreases with maize age (Andrieu *et al*., 1993). To take into account this effect of growth stage, Barrière *et al.* (1992) compared 175 hybrids with the same maize silage DM content. Genetic variance for cell wall content was low, despite the large number of hybrids. On the other hand, the genetic variance for fibre digestibility was high, even if an important part of this variation was contributed by brown midrib (bm) hybrids. Genetic variation for OMD involving fibre effects was more related to fibre digestibility than to fibre content. Numerous *in vitro* studies have also proved that large genetic variations exist with regards to maize cell wall digestibility, either for the whole plant or for stover (Barrière *et al*., 1997). At maturity stage of silage, *in vitro* cell wall digestibility of maize stover was a stable genotypic trait, relevant to genotypic evaluations. The fact that these differences among hybrids have been reproducible over the years and with variation in the growth locations (Deinum, 1988) allows the selection of maize for silage on the basis of its digestibility.

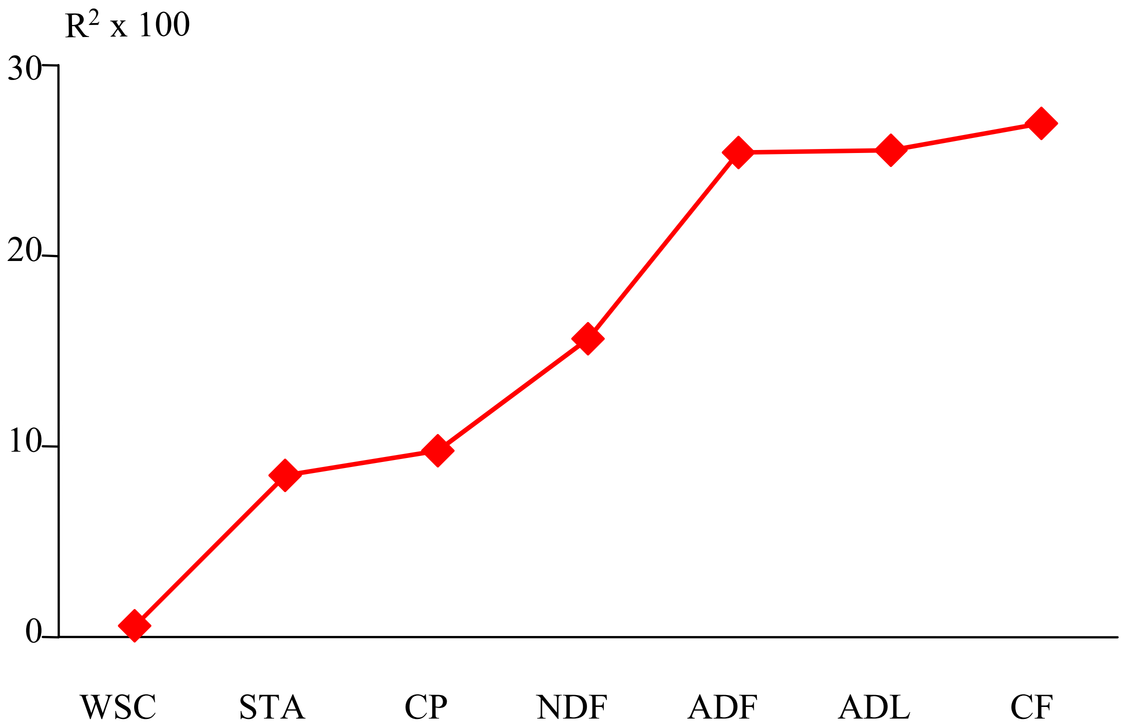

Figure 1. Corelations (R squared x 100) between OMD and the chemical composition of whole maize plants (N = 234) (from Dardenne *et al*, 1993). (WSC = water-soluble carbohydrates, STA = starch, CP = crude protein, NDF = neutral detergent fibre, ADF = acid detergent fibre, ADL = acid detergent lignin, CF = crude fibre)

An improvement in energy value of maize silage may be sought either from genetic variations demonstrated between normal genotypes or by using bm genes. Studies involving bm mutants, despite their lower agronomic values, showed that the bm hybrids had a higher digestibility (Barrière and Argillier, 1993). Among the 4 brown midrib genes (bm1, bm2, bm3, and bm4) described in maize, the bm3 gene, which allows an important decrease in lignin content, was the most efficient in improving maize digestibility (Lechtenberg *et al*., 1972), and was the most studied. Two recent reviews of Barrière and Argillier (1993) and Besle *et al*. (1994) took stock of the bm3 chemical composition, and particularly of lignification aspects. All the subsequent studies performed with normal and bm3 maize plants showed low contents of lignin in bm3 (Table 2). When investigated, this result proved to be true for each part of the plant, leaf blade, sheath and stem. As in other forages, lignin is the major limiting factor of cell wall digestibility. Lignin acts as a physical barrier that limits the penetration of enzymes in the cell walls, and thus limits the accessibility of cell wall components to enzymes. But variations in lignin content only partly explain the differences in cell wall digestibility among maize genotypes (Cone and Engels, 1993). This negative effect of lignins in cell wall degradation is in relation to their content, but their biochemical composition and the nature of the hydroxy-cinnamic, acids linked to lignins are also involved. Lignin consists mainly of syringyl and guaiacyl units, bound by linkages that define the condensation level of lignins. In comparison with normal plants, the bm3 mutants of maize had lower syringyl/guaiacyl molar ratio, so lignins of bm3 plants appeared as a more condensed polymer than the lignin of normal plants (Barrière and Argillier, 1993). These lignins link to the other cell wall components, mainly carbohydrates, by hydroxy-cinnamic acids in ether and ester bonds. Hartley and Jones (1978), studying the normal and bm3 inbred lines, observed in each of the vegetative organs a ratio of p-coumaric/ferulic acid inferior in bm3 plants compared to normal plants. Similarly, Cherney *et al.* (1989) reported a lower p-coumaric acid content in bm3 tissues compared to normal tissues of the fifth internode of the stem, whereas the ferulic acid content was similar for bm3 and normal internodes.

Table 2. *In situ* cell wall degradability in maize stovers with bm3 hybrids and their isogeneic normal (Tovar Gomez *et al.*, 1997)

	ADL (g kg^{-1} DM)	CV degradability (%)
Ex 223		
Normal	43	29
Bm3	12	36
Ex 234		
Normal	46	30
Bm3	19	34
Adonis		
Normal	48	30
Bm3	31	38

The intake of maize silage is considered to depend mainly on its DM content. In steers, voluntary intake of maize silage increases by 4 % when DM content of silage increases by 5 points (Demarquilly, 1994). Recently, for 15 maize silage hybrids with similar DM content, Andrieu *et al.* (1997) reported significant differences in daily voluntary intakes by dairy cows from 0,9 to 1,6 kg of DM. As in other forages, maize silage voluntary intake was partly linked to its digestibility. However this parameter cannot explain all the differences between hybrids. The range of voluntary intake among hybrids was not the same that the range of digestibility in the same plants (Barrière *et al.*, 1995). The measurement of *in situ* degradation kinetics in the rumen constitutes another approach to explain the variations in voluntary intake of maize silage. The concept that the ruminal capacity is involved in the control of feed intake, is widely known. A fill index was defined by Stensig *et al.* (1994) and was estimated from the cell wall in situ degradation rate (Faverdin *et al.*, 1995). *In situ* degradation kinetics of maize stovers varied considerably among maize hybrids. The degradation rate of stover cell walls was nearly doubled between extreme hybrids (Verbic *et al.,* 1995; Tovar Gomez *et al.*, 1997). However a relationship between DM or cell wall *in situ* degradation and voluntary maize intake is not available at this moment. Regarding breeding strategies, a similar improvement in the amount of energy intake by ruminants can be achieved either from an increase in the OMD (i.e. the energy value of maize silage), or from an increase in its intake. Both traits therefore should be a breeding objective for the improvement of maize silage. However, very few hybrids or genetic resources are currently known for a high intake by animals.

STARCH DIGESTION AND NUTRITIONAL IMPLICATIONS

For starch digestion, the nutritional objectives are to optimise the amount of starch degraded in the rumen in order to limit the disturbances of the microbial ecosystem, and to avoid an excess of by-pass starch that could lead to a reduction of total tract starch digestibility. This objective can be reached by controlling both starch intake and the ruminal starch degradation rate. Research progress in the manipulation of starch digestion by ruminants has been the topic of many reviews, of which the most recent are those of Nocek and Tamminga (1991), Sauvant *et al.* (1994) and Huntington (1997). Different approaches to control rate and extent of ruminal starch digestion of a cereal were considered including management of feed consumption, grain particle size, and cereal treatment (Poncet *et al.*, 1995). Most studies of maize starch digestion were carried out with maize grain. A maize silage approach is detailed in this paper.

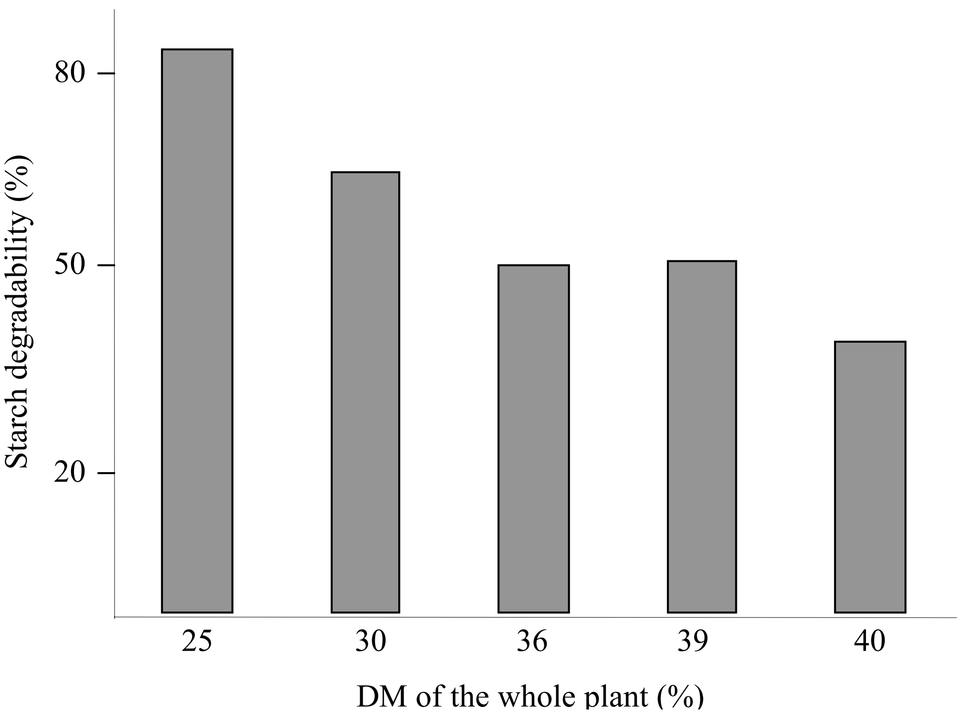

Figure 2. Influence of the maturity stage of the maize plant, expressed as DM content of the whole plant, on in sacco starch degradability (from Philippeau and Michalet Doreau, 1997).

The amount of maize starch degraded in the rumen depends on the proportion of grain in the whole plant and the degradation rate of this starch in the rumen. With maize silage, the percentage of grain in the whole plant increases with advancing maturity. A close relationship exists between starch and grain content in the whole plant (Figure 2). For the same maturity stage of maize silage or a given DM content of the whole plant, differences among hybrids are observed with respect to grain content (Aseltine, 1988; Russell *et al*., 1992) and starch content (Andrieu *et al*., 1993). The early-maturing hybrids had a higher grain-to-stover ratio than the late ones (Irlbeck *et al*., 1993). Genetic variance for grain content in silage is high, even when nested in groups of maturity. Heritability is also high, whether or not maturity is considered (Barrière *et al*., 1992).

Table 3. Effect of ensiling of maize on *in sacco* starch degradability (Philippeau and Michalet Doreau, 1998)

	Degradation characteristics				Effective degradability (%)
	Undegradable fraction (%)	Rapidly degradable fraction (%)	Slowly degradable fraction (%)	Degradation constant rate (h^{-1})	
Unensiled	0.0	22.3	77.6	0.069	66.9
Ensiled	0.2	34.0	65.6	0.078	72.8

Table 4. Effects of genotype on ruminal starch digestion of maize grain

Authors	Opatpatanakit *et al.* (1994)	Philippeau *et al.* (1999a)	Philippeau *et al.* (1999b)
Measurement	*In vitro*	*In sacco*	*In vivo*
Dent grain	140* (2)	61.9 (8)	60.8 (1)
Flint grain	129* (2)	46.2 (6)	34.8 (1)

* gas production (ml g^{-1} DM);
() number of studied varieties

Only a few experiments have been carried out on starch digestion of maize silage. At maturity of grain, effects of genetic variability on ruminal digestion of maize grain have prompted numerous studies of maize hybrids. The site and extent of starch digestion widely varies according to endosperm texture, dent or flint. The proportion of vitreous and floury endosperm that surrounds starch granules defines endosperm texture. Grains whose kernels have high proportions of vitreous endosperm (70 % at mean) are termed flint, and those with a low proportion of vitreous endosperm are termed dent. In addition to normal varieties, maizes of very low vitreousness have been obtained by the use of a specific mutant, the high-lysine variety. *In vitro* and *in situ* ruminal starch digestion is higher with dent than with flint maizes (Opatpatanakit *et al*., 1994, Philippeau *et al*., 1999a), and these results have been confirmed *in vivo* with steers (Philippeau *et al*., 1999b) (Table 3). Within each type of maize, the extent of variation in vitreousness and in *in situ* starch degradation is large. If *in situ* starch degradability averaged 61.9 and 46.2 % in dent and flint maizes, it varied from 55.1 to 77.6 % for dent hybrids and from 40.6 and 50.5 % for flint hybrids (Philippeau *et al.*, 1999a). These variations were due to a large difference in the vitreousness of grains, from 38.5 to 57.3 % for dent hybrids and from 66.8 and 79.1 % for flint hybrids.. At a structural level, starch granules in vitreous endosperm are surrounded by protein storage bodies and are embedded in a dense matrix of endosperm cells, whereas floury endosperm has little cellular structure and, hence, has the highest density of starch granules (Kotarski *et al.*, 1992). The differential association between starch and protein within each fraction of the endosperm is probably responsible for the variation of starch degradation at maturity of grain (McAllister *et al.*, 1990).

At a maturity suitable for ensiling, *in situ* ruminal starch degradability of maize is higher than that at maturity of grain (Figure 3), and the ensiling process involves an increasing of *in situ* starch degradability, averaging 6 percentage units (Table 4). The genetic variability in ruminal starch degradation is conserved. *In vitro* and *in situ* starch degradation of ensiled dent maize is always higher than that of flint (Table 5). In the same way, *in vitro* starch degradation of high-lysine hybrids is higher than that of normal ones (Beek and Dado, 1998). But all these data were obtained by *in situ* or *in vitro* techniques. At this moment, the effect of maize silage hybrid on starch ruminal digestion is not studied by *in vivo* measurements.

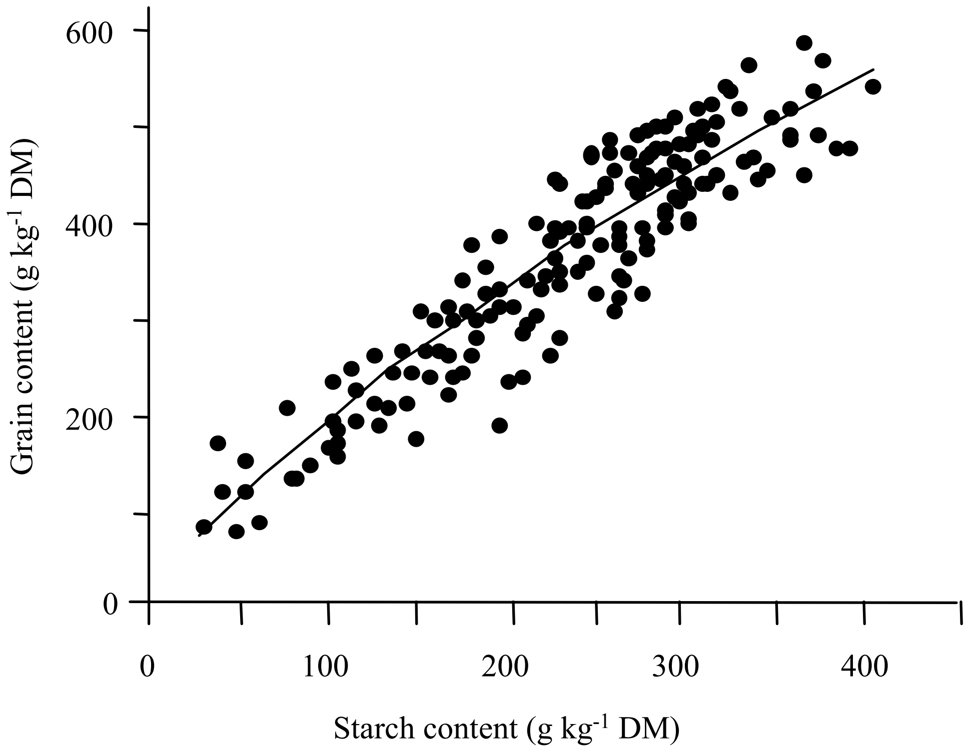

Figure 3. Relationship between starch and grain content in maize plant (Andrieu *et al.*, 1993).

In sacco technique has been extensively used to predict nitrogen degradability, but much less for kinetic measurements of carbohydrate degradation in the rumen. Nocek and Tamminga (1991) and Sauvant *et al.* (1994) proposed the use of the *in situ* technique to characterise starch degradability of cereals in the rumen. But in this relationship, the number of *in situ* and *in vivo* comparisons was low, and *in situ* degradability tended to underestimate the degradability of slowly degraded starches. This discrepancy could be the result of the failure of this technique to account for a reduction in the particle size of grains through mastication. The differences between cultivars in ruminal starch degradation rate depend on the starch accessibility to microorganisms. As an increase in cereal particle size involves a decrease of starch ruminal digestion, its effect is more important for slowly degradable cereals than for rapidly degradable ones (Huntington, 1997). So when cereals are coarsely cracked, *in situ* measurements give the same values as *in vivo* results (Philippeau *et al*., 1999b). In maize silages, grain is also coarsely cracked, and it is not possible to take account of this effect of particle size in the bag technique (Nozière and Michalet Doreau, 1999).

Table 5. Effect of genotype *in sacco* starch degradability of maize silage

	Whole plant DM content (%)	Maize	
		Dent	Flint
Verbič *et al.* (1997)	37	91.4	76.0
Philippeau and Michalet Doreau (1998)	30	78.6	67.0
Verbič *et al.* (1998)	–	91.5	74.3

CONCLUSION

Due to its high energy value maize is well adapted to feeding high-producing ruminants. An increase in nutritive value can be achieved by genetic modification. The improvement of silage fibre digestibility might allow an increase of both energy value and voluntary intake, and thus allow better utilisation of the whole plant as a forage. In the future, the improvement of whole feeding value should take into account voluntary intake by ruminants. The determination of high-intake hybrids and the prediction of intake have to be improved. An important research area concerns the effect of hybridization on starch utilisation. It is now established that ruminal starch digestion is related to starch accessibility. Factors of variation in starch ruminal degradation have been defined, but basic knowledge of the optimal starch degradation rate is not well known. The objective is thus to find a compromise in the rate of ruminal starch digestion which avoids risks of acidosis and yet maintains a high starch digestion in the total digestive tract. Moreover the consequences of a shift from propionate production in the rumen to glucose absorption in the small intestine on the efficiency of production and on the quality of milk and meat have not been established yet.

REFERENCES

Andrieu, J./ Demarquilly, C. Valeur alimentaire du maïs fourrage. II. Influence du stade de végétation, de la variété, du peuplement, de l’addition d’urée sur la digestibilité et l’ingestibilité des ensilages de maïs. Annales de Zootechnie 23(1974), 1-25.

Andrieu, J./ Demarquilly, C./ Dardenne, P./ Barrière, Y./ Lila, M./ Maupetit, P./ Rivière, F./ Femenias, N. Composition and nutritive value of whole maize plants fed fresh to sheep. I. Factors of variation. Annales de Zootechnie 42(1993), 221-249.

Andrieu, J./ Rouel, J./ Perry, C./ Bony, J. Influence de l’hybride sur l’ingestibilité chez la vache laitière des ensilages de maïs plantes entières. Rencontres Recherches Ruminants, 4(1997), 98.

Aseltine, M.S. Corn silage quality can vary depending on hybrid planted. Feedstuffs, January 25(1988), 13-15.

Barrière, Y./ Traineau, R./ Emile, J.C. Variation and covariation of silage maize digestibility estimated from digestion trials with sheep. Euphytica, 59(1992), 61-72.

Barrière, Y./ Argillier, O. Brown-midrib genes of maize: a review. Agronomie, 13(1993), 865-876.

Barrière, Y./ Emile, J.C./ Traineau, R./ Hebert, Y. Genetic variation in the feeding efficiency of maize genotypes evaluated from experiments with dairy cows. Plant Breeding, 114(1995), 144-148.

Barrière, Y./ Argillier, O./ Michalet Doreau, B./ Hebert, Y./ Guingo, E./ Giauffret, C./ Emile, J.C. Relevant traits, genetic variation and breeding strategies in early silage maize. Agronomie, 17(1997), 395-411.

Beek, S.D./ Dado, R.G.. Extent of digestion of high lysine corn or regular corn as grain or silage in lactating Holsteins. Journal of Animal Science, 76 (1998, suppl.1), 335 (abst.).

Besle, J.M./ Cornu, A./ Jouany, J.P. Roles of structural phenylpropanoids in forage cell wall digestion. Journal of the Science Food and Agriculture, 64(1994), 171-190.

Cherney, J.H./Anlicker, K.S./ Albrecht, K.A./ Wood, K.V. Soluble phenolic monomers in forage crops. Journal of Agricultural Food Chemistry, 37(1989), 345-350.

Cone, J.W./ Engels, F.M. The influence of ageing on cell wall composition and degradability of three maize genotypes. Animal Feed Science and Technology, 40(1993), 331-342.

Dardenne, P./ Andrieu, J./ Barrière, Y./ Biston, R./ Demarquilly, C./ Femenias, N./ Lila M./ Maupetit, P./ Rivière, F./ Ronsin, T. Composition and nutritive value of whole maize plants fed fresh to sheep. II Prediction of the in vivo organic matter digestibility. Annales de Zootechnie, 42(1993), 251-270.

Deinum, B./ Bakker, J.J. Genetic differences in digestibility of forage maize hybrids. Netherlands Journal of Agricultural Science, 29(1981), 92-98.

Deinum, B. Genetic and environmental variation in quality of forage maize in Europe. Netherlands Journal of Agricultural Science, 36(1988), 400-403.

Demarquilly, C. Facteurs de variation de la valeur nutritive du maïs ensilage. INRA Productions Animales, 7(1994), 151-167.

Dhillon, B.S./ Paul, E.Chr./ Zimmer, E./ Gurrath, P.A./ Klein, D./ Pollmer, W.G. Variation and covariation in stover digestibility traits in diallel crosses of maize. Crop Science, 30(1990), 931-936.

Faverdin, P., Baumont, R., Intgvartsen, K.L. Control and prediction of feed intake in ruminants. In: Recent Developments in the Nutrition of Herbivores (Eds.: Journet, M./ Grenet, E./ Farce, M.H./ Thériez, M./ Demarquilly, C.). 1995, pp. 95-120.

Hartley, R.D./ Jones, E.C. Phenolic components and degradability of the cell walls of the brown midrib mutant bm3 of *Zea mays*. Journal of the Science Food and Agriculture, 28(1978), 777-789.

Huntington, G.B. Starch utilization by ruminants : from basics to the bunk. Journal of Animal Science, 75(1997), 852-867.

Irlbeck, N.A./ Russell, J.R./ Hallauer, A.R./ Buxton, D.R. Nutritive value and ensiling characteristics of maize stover as influenced by hybrid maturity and generation, plant density and harvest date. Animal Feed Science and Technology, 41(1993), 51-64.

Kotarski, S.F./ Waniska, R.D./ Thurn, K.K. Starch hydrolysis by the ruminal microflora. Journal of Nutrition. 122(1992), 178-190.

Lechtenberg, V.L./ Muller, L.D./ Bauman, L.F./ Rhykerd, C.L./ Barnes, R.F. Laboratory and *in vivo* evaluation on inbred and F2 populations of brown-midrib mutants of *Zea mays* L. Agronomy Journal, 64(1972), 657-680.

McAllister, T.A./ Rode, L.M./ Major, D.J./ Cheng, K.J./ Buchanan-Smith, J.G. Effect of ruminal microbial colonization on cereal grain digestion. Canadian Journal of Animal Science, 70(1990), 571-579.

Nocek, J.E./ Tamminga, S. Site of digestion of starch in the gastrointestinal tract of dairy cows and its effect on milk yield and composition. Journal of Dairy Science, 74(1991), 3598-3629.

Nozière, P./ Michalet Doreau, B. In sacco methods. In: Farm Animal Metabolism and Nutrition: Critical reviews (Ed.: D'Mello, J.P.F.). 1999, in press.

Opatpatanakit, Y./ Kellaway, R.C./ Lean, I.J./ Annison, G./ Kirby, A. Microbial fermentation of cereal grains in vitro. Australian Journal of Agriculture Research 45(1994), 1247-1263.

Philippeau, C./ Michalet Doreau B. Influence of genotype and stage of maturity of maize on rate of ruminal starch degradation. Animal Feed Science and Technology, 68(1997), 25-35.

Philippeau, C./ Michalet Doreau, B. Influence of genotype and ensiling of corn grain on in situ degradation of starch in the rumen. Journal of Dairy Science, 81(1998), 2178-2184.

Philippeau, C./ Le Deschault de Monredon, F./ Michalet Doreau, B. Relationship between ruminal starch degradation and the physical characteristics of corn grain. Journal of Animal Science, 77(1999a), 238-243.

Philippeau, C./ Martin, C./ Michalet Doreau, B. Influence of grain source on ruminal characteristics and rate, site and extent of digestion in beef steers. Journal of Animal Science, (1999b), 1587-1596.

Poncet, C./ Michalet Doreau, B./ McAllister, T./ Rémond, D. Dietary compounds escaping rumen digestion. In: Recent Developments in the Nutrition of Herbivores (Eds.: Journet, M./ Grenet, E./ Farce, M.H./ Thériez, M./ Demarquilly, C.). 1995, 167-204.

Roth, L.S./ Marten, G.C./ Compton, W.A./ Stuthman, D.D. Genetic variation of quality traits in maize (*Zea mays L.*) forage. Crop Science, 10(1970), 365-367.

Russell, J.R./ Irlbeck, N.A./ Hallauer, A.R./ Buxton, D.R. Nutritive value and ensiling characteristics of maize herbage as influenced by agronomic factors. Animal Feed Science and Technology, 38(1992), 11-24.

Sauvant, D./ Chapoutot, P./ Archimède H. La digestion des amidons par les ruminants et ses conséquences. INRA Productions Animales, 7(1994), 115-124.

Stensig, T./ Weisbjerg, M.R./ Madsen, J./ Hvelplund, T. Estimation of voluntary feed intake from in sacco degradation and rate of passage of DM or DNF. Livestock Production Science, 39(1994), 49-52.

Tovar-Gomez, M.R./ Emile, J.C./ Michalet Doreau, B./ Barrière, Y. In situ degradation kinetics of maize hybrid stalks. Animal Feed Science and Technology, 68(1997), 77-88.

Verbič, J./ Stekar, J.M.A./ Resnik-Čepon, M. Rumen degradation characteristics and fibre composition of various morphological parts of different maize hybrids and possible consequences for breeding. Animal Feed Science and Technology, 54(1995), 133-148.

Verbič, J./ Babnik, D./ Žnidaršič-Pongrac, V./ Resnik, M. Ruminal starch digestion and microbial protein supply in sheep given maize silage made from dent (*Zea mays indentata*) or flint (*Zea mays indurata*) type hybrid. Proceeding 48th Annual Meeting of European Association of Animal Production (1997), 7 pp., Vienna, Austria.

Verbič, J./ Babnik, D./ Žnidaršič-Pongrac, V. The effect of maize grain type on digestibility of starch in the rumen of sheep. Research Reports, Biotechnical Faculty, University of Ljubljana, Zootechnica, 72(1998), 51-56.