KRMIVA

EFFECT OF HYDROTHERMAL PROCESSING ON THE FEED QUALITY, THE RUMINAL DEGRADATION OF GRAINS AND THE MILK COMPOSITION IN HIGH PRODUCING DAIRY COWS

DJELOVANJE HIDROTERMALNE OBRADE NA KAKVOĆU KRMIVA, RUMINALNO RASTVARANJE ZRNJA I SASTAV MLIJEKA U VISOKOPROIZVODNIH MLIJEČNIH KRAVA

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Scientific review - Pregledno znanstveni članak
UDC:636.2. i 636.085.6.62.
Received - Primljeno 31. may - svibanj, 2002

SUMMARY

Starch is the major energy component of cereal grains. Proportions of starch fermented in the rumen can be predicted satisfactorily for a variety of grains and processing methods. In practice, since the mid-1980's high temperature, short time conditioning (HTST) has been described as a wet (hydro-) thermal process of a wide range of machines capable of feed pasteurisation and as an effective means to kill pathogenic micro organisms. In the feed manufacturing industry the processes spread firstly in monogastric animal nutrition but more recently also in ruminant nutrition. Wet (hydro-) thermal process causes gelatinization of grain starch, denaturization of protein, bonding of lipids, inactivation of anti-nutritional factors, pasteurisation of processed material. Based on the literature data using wet (hydro-) thermal processing, effectively controls Salmonella in feed, increase of the percentage of bypass protein, increases ruminal starch degradability of cereal grains, affects the site of digestion of the starch and of the protein, simultaneously improving intestinal rate of degradation, increase of the total digestibility of grain starch, feed structure corresponding to the needs of the animals as well as to the TMR feeding systems, increase of the milk yield and improve the pellet quality if the feed is to be pelleted. Economical by we have to note that hydrothermal treatments are approximately 2-3 times more expensive than dry rolling.

INTRODUCTION

Processing cereal grains has become important in the feed industry since it increases energy availability from cereals by improving ruminal and total tract digestibility (Reynolds et al, 1996). Particle size reduction (Thomas et al, 1988., Cerneau and Michalet – Doreau 1991), starch gelatinization, retrogradation and dextrination which improve accessibility of enzymes to the starch granules, may shift the site of digestion of protein and starch from the rumen to the small intestine

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(Hale 1973., Ørskov 1976., Theurer 1986., Owens et al, 1986) and so result in an improved supply of amino acids and glucose to animal metabolism (Nocek and Tamminga, 1991). Elevated glucose absorption represents a mechanism by which increased postruminal starch digestion might increase milk, and milk component yield (Sutton, 1985., Mac Rae et al, 1988, McGuire et al, 1995.). Increased net energy density of cereals is also beneficial because high yielding dairy cows are frequently unable to consume sufficient net energy during early lactation to meet their requirements. Increased digestion of feed protein and starch in the small intestine results in less nitrogen and carbohydrate loss to the environment because a high flow of starch to the large intestine stimulates microbial growth and causes a net N influx to the large intestine thereby increasing N in faeces.

Research into the effects of chemical treatment such as NaOH, formaldehyde, ammoniation, (Miron et al, 1997, Maine and Doherty, 1996, Robinson and Kennelly, 1988, Fluharty and Loerch, 1989, Oke et al. 1991, McAllister, 1992, Theurer 1986) and physical processing (i.e. breaking, cracking, grinding, rolling) of dried grains on utilisation of the starch in cereal grains has been studied extensively. However the studies have hardly focused on the effects of hydrothermal processes on cereal starch. Therefore this study is an attempt to throw light on this issue in order to develop an understanding of the effects of these processes on ruminal starch degradation and fermentation.

STARCH IN CEREAL GRAIN AND ITS IMPORTANCE IN DAIRY DIETS

Carbohydrates represent the most important source of energy for dairy cows. They may be classified on the basis of their nutritional importance for dairy cows: this involves distinguishing between fibrous and non-fibrous carbohydrates. Fibrous carbohydrates are only slowly digested by cows, while non-fibrous carbohydrates such as sugars, starch and pectin are rapidly fermented and digested. Carbohydrates are quantitatively the most important substrates for rumen fermentation and intestinal digestion hereby providing dairy cows with substantial quantities of metabolites to support milk component synthesis. The supply of nutrients from the polysaccharides, in starch and cell wall constituents, depends on enzymatic hydrolysis to release their component monosaccharides. Starch is composed of two major molecules: amylose and amylopectin. Amylose is a linear polymer of α 1-4 D-glucose units while amylopectin is a branched polymer with linear chains of D-glucose that has a branch point every 20 to 25 glucose units (French, 1973). Ruminants digest starch in the small intestine by the activity of endogenous enzymes. Starch in degraded in to glucose which is after absorption, used metabolically. In contrast, the hydrolysis of structural polysaccharides in dependent on the enzymes of the microbes in the digestive tract, primarily in the fore- stomachs. Ruminal degradation of these carbohydrates depends on other nutrients, such as amino acids and nitrogen, to meet microbial nutrient requirements. In ruminants, part of the starch is hydrolysed by microbial enzymes and after further degradation, becomes available as microbial fermentation products such as microbial protein and volatile fatty acids. The amount of starch escaping rumen fermentation intact depends on its rate of degradation and the rate of passage out of the rumen (Nocek and Tamminga, 1991.). Starch passing to the small intestine is digested, and absorbed as glucose to a varying degree. However, higher resistance to microbial enzymatic degradation in the rumen is related to a lower intestinal digestion. In cattle given whole grains fermentation may occur in the large intestine and starch be voided in faeces. High quantities of starch entering the small intestine may exceed the capacity of the small intestine to digest it. Nevertheless, since enzymatic digestion of non-structural carbohydrates in the small intestine yields 11 to 30 % more net energy than when it is fermented in the rumen (Leng, 1981.), it may be worthwhile to accept some faecal loss of starch to increase the amount digested in the small intestine, vs. that fermented in the rumen. Ruminal degradation of starch varies from 39 to 94 % depending on grain source, differences in processing method and other factors (Nocek and Tamminga, 1991). Rapidly degraded sources of starch are wheat, barley, and oats while resistant sources are corn, milo, rice, sorghum, and starches in legume seeds, such as peas and beans. Starch digestion by ruminants has been reviewed and discussed (Sutton 1979., Theurer 1986.; De Visser et al, 1993., Hale 1973., Ørskov 1976., 1986., Owens et al., 1986., Campling, 1991., Nocek and Tamminga 1991., Mills et al., 1999), and all emphasise the importance of the site of starch digestion, as well as the influence of the nature of feed starch and technological processing, on the NE values of the feedstuffs.

DIFFERENCES BETWEEN DIFFERENT GRAIN STARCHES

Generally the starch content of cereal grains varies (Table 1). This difference in starch values is the primary reason why barley, wheat or oats have a lower energy content than corn or sorghum (Hunt, 1996.). However, barley starch is degraded rapidly and almost completely in the rumen whereas a substantial proportion of corn starch often escapes rumen fermentation (Waldo, 1973.). Within the endosperm, starch granules are surrounded by a protein matrix (Rooney et al., 1986.) which must be digested to allow amylolytic digestion of starch granules. McAllister et al. (1993.) suggested that variation in the protein-starch matrix could be a factor responsible for differences in ruminal digestion of cereals. In corn, a highly crystalline amylopectin matrix (French, 1973.) can be found and the protein matrix surrounding the starch granules is strong (Rooney and Pflugfelder, 1986.) and extremely resistant to invasion. Rumen fungi appear to be the only ruminal microorganisms capable of penetrating this structure (McAllister et al., 1990.). The protein matrix in barley is readily digested by a variety of proteolytic bacterial enzymes and digestion in the rumen generally proceeds rapidly (McAllister et al., 1990.) resulting in the production of large quantities of glucogenic precursor the, propionic acid, as well as the lipogenic precursor, the acetic acid.

Starch granules of corn and milo are reported to be similar in size, shape and composition, although the protein surrounding the starch granules differs in amount and composition (Wall and Paulis, 1978.; Rooney et al., 1980.). Wheat starch is more available to ruminal microorganisms (Aimone and Wagner, 1977.) because it has a less dense starch structure, a higher amylose content and a higher reducing-sugar content than does corn or milo (Banks and Greenwood, 1975.). Readily degradable prolamines (gliadins) in the native wheat are the cause of the relatively high degradability of cereal crude protein in the rumen (68 %) whereas zein in corn, protein rich in disulphide bonds, gives rise to only 50 % degradation (Sommer, et al., 1994.). There are important differences between grains in in situ parameters characterising the rumen degradation of starch (Table 2). The water soluble fraction (W), which is assumed to be instantaneously and completely available is very high in oats, and more than 60 % in wheat and barley, therefore the starch of the grains degradation in the rumen is faster than that of corn, milo or sorghum.

Table 1. Starch content and physico-chemical characteristics of starch granules for a range of cereal grains
Tablica 1. Sadržaj škroba i fizikalno – kemijske značajke zrnaca škroba za niz zrnja žitarica

Grain - Zrno	Starch % DM* Škrob % ST	Granule size (mm)** Veličina zrnca	Amylose - Amiloza %**	Gelatinization range °C** Raspon želatiniranja
Barley - Ječam	55 – 74	20	22	59 – 64
Corn - Kukuruz	65 – 76	15	26	62 – 72
Sorghum - Sirak	68 – 80	20	26	68 – 75
Wheat - Pšenica	68 – 82	25	26	62 – 75
Oats - Zob	42 – 69	25	27	-
Milo - Proso	68 – 78	25	-	-

* Waldo, 1973.; Herrera-Saldana et al., 1990.; Nocek and Tamminga, 1991.; Huntingtnog, 1994., Prestlokken, 1998.
** Pomeranz, 1984., Kent and Evers, 1994.

Table 2. In situ mean degradability characteristics for different starch sources in lactating dairy cows
Tablica 2. In situ značajke prosječne razgradljivosti za razne izvore škroba mliječnih krava u laktaciji

	W %	D %	Kd %/h	ESD % (only insoluble starch escape) Nestajanje/hlapljenje samo netopivog škroba
Barley** - Ječam	62	37	23	92
Corn** - Kukuruz	25	75	5	58
Sorghum* - Sirak	32	68	3.5	61
Wheat* - Pšenica	68	32	18	93
Oats* - Zob	96	4	19	98
Milo* - Proso	32	68	3.5	61

W: water soluble fraction - u vodi topiva frakcija
D: insoluble, potentially degradable fraction - netopiva, potencijalno razgradljiva frakcija
kd: the fractional rate of degradation of D - djelomični stupanj razgradnje od D
ESD: effective starch degradability in the rumen - efektivna razgradljivost škroba u buragu
* Nocek and Tamminga, 1991.,
** Philippeau et al., 1992., Cerneau et al., 1991., Herrera-Saldana et al., 1990., Tamminga, 1989., Nocek and Tamminga, 1991.

HEAT TREATMENTS

It is clear that chemical composition and physical structure of starch are primary factors influencing the ruminal degradability of starch. Other factors that can influence the extent of rumen degradation are pH, microbial population, feeding frequency through an effect on synchronisation, and physical form of the concentrates if the cereal grains are processed. Processing is generally associated with an increased efficiency of nutrient utilization as it disrupts the protein matrix and allows starch to be more accessible to enzymatic digestion. However, processing may lead to formation of indigestible starch-protein complexes (Thorne et al., 1983.) due to the Maillard reaction. Heat treatments tend to increase both the soluble starch fraction and the rate of digestion of the potentially digestible starch fraction, resulting in improvements of the efficiency of nutrient utilisation in the gastrointestinal tract. Chemical treatment of grains has been shown to enhance or retard ruminal degradation of starch, depending on the chemical and the concentration used.

Generally, heat treatment involves the gelatinization of starch, denaturization of protein, binding of lipids, inactivation of antinutritional factors, and it affects the site of digestion of the starch and protein (Focant, 1992.).

Heat treatments can broadly be divided in thermal and nonthermal processes. Nonthermal processes do not involve the addition of external heat, such as roller and hammermill grinding. Thermal processes can be further divided into dry (i. e. roasting, popping, micronizing) and wet (i. e. autoclaving, steam-flaking, steam pelleting, expanding, extruding, toasting) processes.

In practice, many heating techniques and processing systems are applied to cereal grains (Table 3). For each of the hydrothermal processes the efficiency of heat treatment on the nutritional value of cereals depends on the combination of particle size (if ground), processing temperature, heating time initial moisture content and the amount of water added during the heat process. Since the mid-1980's high temperature, short time conditioning (HTST) has been described as a process of a wide range of machines capable of feed pasteurisation and as an effective means to kill pathogenic micro organisms. In the feed manufacturing industry these processes are applied firstly in monogastric animal nutrition but more recently also in ruminant nutrition.

Table 3. **Potential methods for thermal treatments and decisive variables (after van der Poel, 1990. and van Zuilichem, 1993.)**

Tablica 3. **Moguće metode termalnog tretiranja i određene varijable / prema . . .**

Process *	Temperature (°C)	Time - Vrijeme (sec)	Heating source Izvor grijanja
HTST			
Extrusion - Ekstruzija	80 – 200	30 – 150	Steam - Para
Expander - Ekspandiranje	80 – 140	5 – 15	Steam - Para
Micronizing - Mikroniziranje	80 – 130	40 – 60	Gas - Plin
Steam Plosion - Parna plozija	140 – 210	20 – 45	Steam/gas - Para/plin
Pressurised Toasting - Tostiranje pod tlakom	100 – 140	60 – 300	Steam - Para
Roasting - Prženje	90 – 190	10 – 120	Gas/elect. - Plin/struja
Infrared radiation - Infracrveno zračenje	80 – 130	40 – 60	Natural gas - Prirodni plin
MTMT			
Autoclaving - Autoklasiranje	110 – 130	600 – 1000	Steam - Para
LTLT			
Conventional toasting - Konvencionalno tostiranje	90 – 105	1800 – 2700	Steam - Para
LTMT			
Flaking - Ljuštenje	90 – 95	600 – 1200	Steam - Para
Pelleting (long conditioning) - Peletiranje (dugo kondicioniranje)	60 – 95	70 – 250	Steam - Para
LTST			
Pelleting (short conditioning) Peletiranje kratko – kondicioniranje	60 – 90	25 – 35	Steam - Para

* H/M/LT = high/medium/low temperature, S/M/LT = short/medium/long time

* H/M/LT = visoka/srednja/niska temperatura, S/M/LT = kratko/srednje/dugo vrijeme

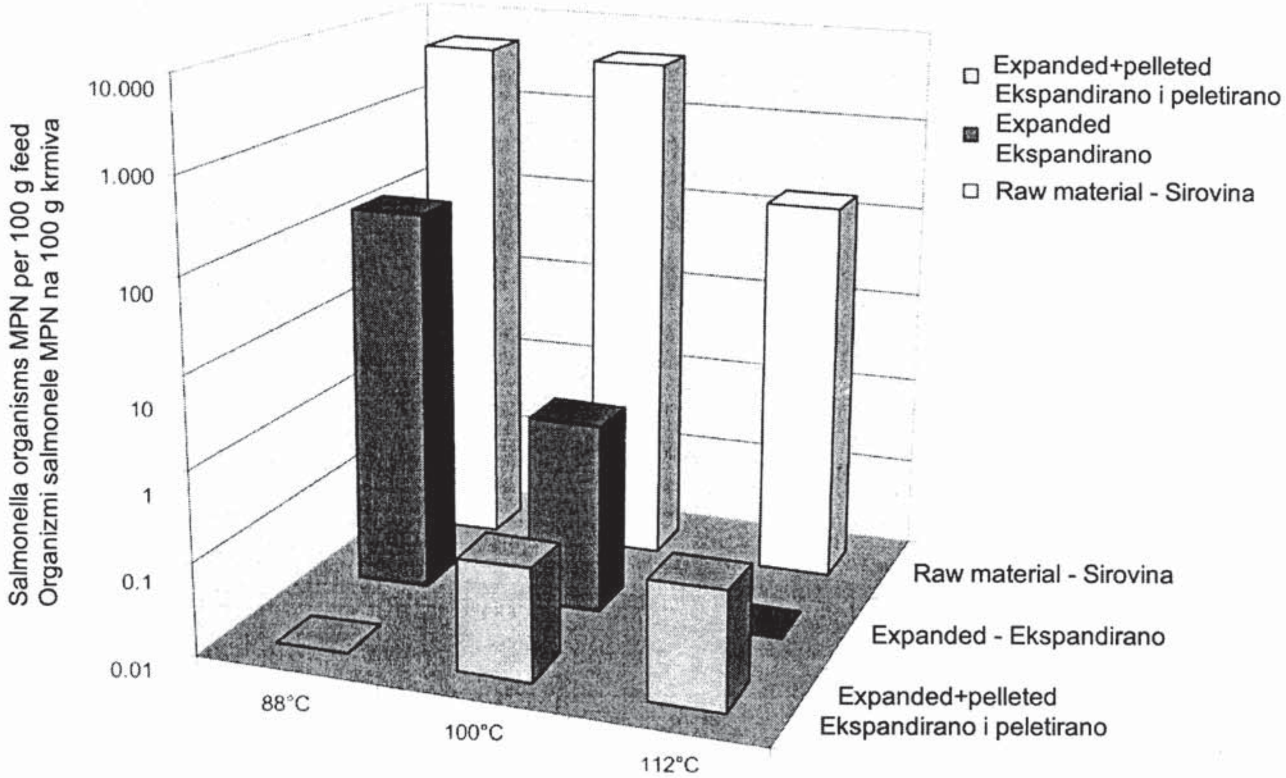
EFFECT OF WET (HYDRO-) THERMAL TREATMENT ON REDUCTION OF SALMONELLA

The hygienic quality of feeds is very important. Hygienic quality involves the control of microbiological contamination of feeds based on levels of enterobacteria and Salmonella (Israelsen, 1996., Sreenivas, 1998., McCapes et al., 1989.). There are over 2,300 types of salmonella, many of which are shared by humans and animals. In cattle, salmonella causes diarrhea, decreased milk production, abortions and sometimes death. Some salmonella, such as Salmonella dublin, affect primarily calves while others like Salmonella typhimurium attack adult animals. To completely get rid of enterobacteriaceae such as salmonella and other potentially pathogenic bacteria in feed is extremely difficult.

Conventional steam pelleting reduces salmonella contamination of feed with a varying degree of success. Salmonella reduction by pelleting is influenced by a low moisture content and by the temperature of the pellets, although changes in retention time have little effect. Expanding, pressure conditioning or HTST conditioning are techniques which offer the possibility of reducing salmonella more efficiently than pelleting alone because higher temperatures and moisture contents can be achieved. In several recent experiments with the expander treatment the salmonella content has been estimated indirectly by using other enterobacteria that are less pathogenic than salmonella and simpler in measuring quantitavely (Heidenreich and Lowe, 1994., Konig, 1995.). Naturally infected feed is more resistant to heat treatment than artificially infected material

Figure 1. **Number of salmonella in untreated, expanded and expanded + pelleted feed at low, medium and high expander die temperatures (Sreenivas 1998.)**

Slika 1. **Broj salmonela u netretiranom, ekspandiranom i ekspandiranom + peletiranom krmivu na niskoj, srednjoj i visokoj temperaturi ekspandera**



(Konig, 1995.). The reason may be that heat resistance increases with the age of bacteria cell. A typical level of salmonella in infected raw material is around 1 bacteria per 100 g, if this typical level is reduced 100000 times by expanding and pelleting, only 1 bacteria will remain per 10 tons of feed (Israelsen et al, 1996.). Very few salmonella has been detected in feed that is expanded and pelleted. Salmonella bacteria are typically reduced to about 0.001 % of the level in the raw material. In feed that was not pelleted, no salmonella has been found at die temperatures of 112°C. A similar level of contamination could be found at low die temperatures of 88°C, due to lover steam conditions (Figure 1). The reason for this pattern of increased contamination may be the shorter retention period during which the feed is held at the processing temperature. When processing with the expander alone, a somewhat higher temperature is required to reduce salmonella than when expansion is combined with pelleting.

STEAM PELLETING

Pelleting was defined by Falk (1985.) as the agglomeration of small particles into larger pellets by means of a mechanical process using a combination of moisture, heat, and pressure. When the product is mixed and after a low pressure steam addition of 2 to 5 bars, it is conveyed into a rotating die. This die contains hundreds of holes through which the product passes, pushed by rotating rolls situated inside the die. The production parameters of this process have been extensively explained in the literature (Putier, 1993.). Heating and moisture added during conditioning activate the natural binding in many ingredients primarily between starch and protein. The heating and moisture addition act on the particle surface to gelatinise the starch. This gelatinised starch then becomes the liquid bridge between particles that actually form the pellet or agglomerate. It is not clear whether the agglomeration of feed particles that occurs during pelleting will negate the benefits of reducing particle size although pelleting generally reduces the resistance of starch to ruminal degradation by about 15 % (Tamminga and Goelema, 1995.).

EXPANDING (EXPANDER PELLETING)

Expander processing is used in the animal compound feed industry (Veenendaal 1990., Pipa and Frank 1989.). There are a number of types of pressurised screw-type conditioners called expanders or, by their full name, annular gap expanders, but the principles of construction and operation are the same. These pressurised high-temperature-short time (HTST) conditioners were designed to be positioned behind the mixer and in front of the pelleter. Steam conditioned meal is fed into a compression screw into which more steam is injected, and the mass is then subjected to increasing pressure and shear action and then forced through a variable exit gap. The compressed product after reduction in particle size, is fed into a standard pelleting press. Most expanders work under 25 to 40 bars of pressure and temperatures between 90 to 130 °C, with treatment times between 5 and 20 seconds. The temperature/time patterns of these prepelleting processes differ. The temperature of 80 °C can be reached in the conditioner and this is increased, and peaks during pelleting, due to frictional heat in the die. The total time of approximately 15 min shows how long it takes for the pellets to be brought back to the ambient temperature cooling. The maximum temperature reached is increased by double pelleting, but the total time to return to ambient temperature will be much the same. In order to improve liquid absorption, and achieve a better elimination of bacteria, some feed mills may hold the meal at higher temperatures (i.e. above 130 °C) for several minutes. Because of the longer time at higher temperature and high moisture levels (i.e. 20 do 35 %) involved, the loss or destruction of heat sensitive nutrients such as vitamins, amino acids and enzymes will be increased (Pickford, 1992.).

Because of the heat and pressure involved in expander conditioning, control of undesirable microbes is relatively easily obtained. Several studies have shown substantial decreases in all forms of bacteria and fungi present in typical feed ingredients. Israelsen (1996.) reported that expanding, in combination with pelleting, was an effective means of reducing the content of Salmonella in a compound feed containing severely infected ingredients with high moisture content of 14 to 15 % before steam addition. In the study of Prestlokken et al., (1999.), the expander treatment reduced ruminal degradation of protein to a much higher extent than it reduced the degradation of dry matter (DM). This means that the treatment had a specific effect on the ruminal degradation of protein. Nielsen (1999.) showed that expander processing reduced the effective protein degradability of raw materials by an average 8 % unit. These effects may lead to differences in mild production and composition in the animals fed the processed feeds.

Pressure Toasting (atmospheric and pressurized steaming), autoclaving and steam flaking

Autoclaving for 30 min at 120 °C is mainly used for legume seeds (Aguilera et al., 1992.). Steam flaking, which is a combination of toasting for 15 to 30 min under 100 to 105 °C followed by flaking the heated grains is the technique used for corn and sorghum. It has been concluded by several authors (Hale, 1973., Ørskov, 1976., Theurer, 1986., Nocek and Tamminga, 1991.) that steam flaking increases the amount of starch fermented in the rumen and its intestinal digestibility (Owens et al., 1986.). Toasting can be carried out at atmospheric pressure or in pressurised vessels such as an autoclave. In the latter case there is a positive correlation between steam pressure and temperature in the autoclave (Van der Poel et al., 1990.). Processing times can be varied, although during autoclaving very short treatment times are difficult to achieve because pressure has to be built up after closing the autoclave. Steam heating at 100 °C, a process generally termed toasting, is commonly applied as a heat treatment for legumes and some oilseeds. In the oil extraction industry it is normally used in conventional vertical, so called cascade-type, toasters. A laboratory scale toaster for batch type or continuous steaming was developed at the Wageningen Agricultural University (Van der Poel, 1990.) and this pressurised toaster permits use of short processing times. to be able to control processing time and temperature, special equipment with higher precision was developed (Van der Poel et al., 1990.), enabling control of processing temperatures and time. Toasting is generally applied to inactive antinutritional factors in legume seeds, but toasting may also result in a shift of the degradation of starch in the rumen to digestion in the small intestine.

Effect of wet (hydro-) thermal treatment on carbohydrate and protein synchronization

Rumen microorganisms require protein and carbohydrates to synthesise microbial protein and VFA. The concept of carbohydrate fractionation also applies to protein. The goal should be to balance carbohydrate and protein availability, such that one or the other is not limiting at any time. Thermal processing of grains facilitates the achievement of an optimal ruminal balance in the availability of energy and protein for microbial synthesis. Tamminga et al., (1990.) reported that when degradation of carbohydrates and proteins is synchronized and takes place in a ratio of approximately 5:1, microbial protein synthesis will occur most efficiently and with minimal N losses from the rumen. For example, if a diet has high levels of soluble protein (fresh grass), adequate quantities of readily fermentable carbohydrates (starch) should be included in the diet to avoid ammonia loss. For an optimal synchronisation of energy supply and microbial growth, supplements should have a rate of carbohydrate fermentation close to that of fresh grass crude protein (Van Vuuren et al., 1993.). Gains meet the requirement of a low protein and high carbohydrate content, but their rate of degradation may not always match with that of fresh grass. A variety of feed processing methods can be applied to alter the degradation characteristics of grains and make them more effective as a supplement to fresh grass.

Thus, to optimise rumen fermentation, degradative behaviour of the rumen should be controlled. Manipulation through processing is a useful tool for optimising lactating dairy cow production. Another tool is to shift the site of digestion of protein and starch from the rumen to the small intestine.

Effect of wet (hydro-) thermal treatment on ruminal and intestinal starch digestion

Studies of effects of processing on starch degradability were mainly set up to increase rumen degradability of corn and sorghum (e.g. Theurer 1986., Owens 1986.). Heat treatment, like extrusion, increased (Walhain et al., 1992., Focant en al., 1990.), while pressure toasting (Goelema, 1998.) reduced the in situ degradability of legume seed starch in ruminants. Steam flaking of cereals results in an increased digestibility of the starch in ruminants, and also of DM because starch is its major component (Theurer, 1986.). In sorghum, steam flaking has been found to increase ruminal starch digestion, compared with ground (McNeill et al., 1971.), dry rolled or ground (Hinman and Johnson, 1974.) and whole or rolled (Aguirre et al., 1984.) grain. Consistent increases in ruminal starch digestion have also been observed in steam-flaked corn compared with whole (Lee et al., 1982.), ground Beever et al. (1970) or dry rolled corn (Galyean et al., 1976., Zinn et al., 1990.). Zinn (1993.) reported increased ruminal starch digestion with steam rolled barley compared to dry rolled barley. Cone et al. (1989.) showed that steam rolling of barley decreased the nylon bag degradation of DM and starch compared with dry rolling. In contrast, Malcolm and Kiesling (1993.) reported that steam flaking barley tended to increase rumen DM degradation in sacco. These experiments have generally shown that steam flaking increases the amount of starch fermented in the rumen and increases the intestinal digestibility of starch that escapes the rumen. Pressure toasting has been shown to reduce rumen availability and in situ rumen degradability of legume seeds protein (Goelema, 1998., Aguilera et al., 1992., Sommer et al., 1994., Singh et al., 1995.) and starch (Goelema, 1998.) by reducing the size of the water soluble fraction and the fractional rate of its degradation. Goelema (1998.) reported a concomitant shift of protein digestion from the rumen to the intestines. There are no studies on the effect of pressure toasting on cereal grains. Expander treatments may improve the energy values for ruminants (Nielsen, 1994.; Prestlokken, 1994.) by increasing the size of the water soluble fraction and fractional rate of starch degradation, although effects on degradability of protein and starch are not always (Arieli et al., 1995.; Goelema et al., 1996.). Arieli (1995.) reported a decreased in situ rumen starch degradability of several cereals, while Goelema (1998.) showed increased starch degradability after expander treatment with legumes, due to a higher washable fraction and rate of degradation of starch. In steam treatment the steaming time plays an important role. Zinn (1990.) showed that altering steaming time during processing of corn grain could affect rumen digestibility of starch. Steam treatment of milo for either 10 or 20 min appeared to reduce rate of starch disappearance in sacco compared with either no treatment or only a 2 min treatment (Thomas et al., 1988.) as shown in Table 4.

Table 4. Disappearance of starch from dacron bags (in situ) (Thomas et al., 1988.)

Tablica 4. Nestanak škroba iz vreća od dacrona (in situ) (Thomas i sur., 1988.)

Starch source Izvor škroba	120 °C autoclaving (min) Autoklariranje 120 °C			
	0	2	10	20
Corn grain Zrno kukuruza	75.0	77.6	75.5	72.3
Milo grain Zrno prosa	74.5	75.7	73.2	66.1

Effect of wet (hydro-) thermal treatment on rumen fermentation and DMI

During wet (hydro-) thermal treatments, particle size reduction increases the surface of grains and therefore facilitates microbial enzymatic digestion. Particle size reduction results in increased rate of starch digestion in the rumen. This is reflected in the experiment of Joy et al. (1997.). These researchers measured higher total VFA production and increased percentage of propionate when fed steam flaked corn instead of dry rolled corn. On the other hand, particle size reduction caused a depression in rumen pH close to higher VFA concentrations (De Visser et al., 1992.). The lower rumen pH can reduce the activity of cellulolytic bacteria resulting in a lower rate of degradation for NDF (Cameron et al., 1991., Gasa et al., 1991.). A depression in NDF digestion may also occur because of the addition of flaked corn starch (Hoover, 1986.). In early lactation cows, feeding steam rolled barley compared to ground corn increased ruminal digestion of starch, decreased DM intake and NDF digestibility in the rumen and total digestive tract (Overton et al., 1995., McCarthy et al., 1989.). In other studies (Poore et al., 1993., Chen et al., 1994.) steam processing of corn starch increased rumen fiber digestion and DM intake. It seems that the intake response to starch supplementation of dairy cows rations is effected by the method of feeding employed, the level and degradability of dietary protein, the type of forage and the type and amount of starch fed (Rejnolds et al., 1997.). The effects of thermal processing on total DMI seem inconsistent. Chen et al. (1994.) reported an elevated intake with steam flaked sorghum compared with dry rolled sorghum but with the same treatment Oliviera et al., (1993.) showed decreased DMI and Simas et al., (1997.) found no effect. Sinas et al. (1997) suggested that the animal factors (stage of lactation, body score) or environmental factors could influence the DMI response.

Effect of wet (hydro-) thermal treatment on milk production

The potential to change milk components through ration formulation depends upon the component (Bequette et al., 1998.; Kennelley et al., 1999.; Sutton, 1989.).

An example of how starch fermentability can affect milk yield and components is illustrated in a series of experiments on steam-flaking corn or sorghum grain (Theurer et al. 1999.). Compared to dry-rolling, steam-flaking corn or sorghum increased starch digestion in the rumen and intestines (Table 5). Because carbohydrate fermentability is the main determinant of growth of ruminal bacteria (Chalupa and Sniffen, 1996.), steam-flaking corn increased the flow of microbial protein to the small intestine. An increased mammary intake of amino acids on cows fed steam-flaked grains was associated with an increased yield of milk protein. Milk fat yield was not increased by feeding steam-flaked grains but neither were mammary intakes of the milk fat precursors acetate and butyrate. Steam-flaking increased mammary intake of glucose that was accompanied by an increased milk yield. Kronfeld (1i76.) estimated that 1 kg of milk is produced for every 72 g of glucose intake. Data in Table 6 show that mammary intake of glucose was increased 117 g/d when cows were fed steam-flaked corn or sorghum versus steam-rolled corn or dry rolled sorghum. This equates to 1.6 kg/d of milk, Milk yield of cows fed steam-flaked corn was 2.2 kg/d greater than of cows fed steam-rolled corn. When cows were fed steam-flaked grains, protein yield increased more than milk yield so concentration of protein in milk increased (Table 7). On the other hand, feeding steam-flaked grains did not increase fat yield so concentration of fat in milk decreased.

Table 5. **Effect of steam-flaking versus dry-rolling corn on starch digestion and microbial protein flow to the small intestine (Theurer et al., 1999.)**

Tablica 5. **Djelovanje parnog ljuštenja zrnja prema suhom valjanju kukuruza na probavljanje škroba i tok bjelančevina mikroba u tanko crijevo (Theurer i sur., 1999.)**

Measurement - Mjerenje	Processing - Obrada		
	Dry-rolled - Suho valjanje	Steam-flaked - Parno ljuštenje	P<
Starch digestibility - Probavljivost škroba			
Ruminal (% intake) - Buragova (% unosa)	35	52	0.03
Intestinal (% entry) - Crijevna (% unosa)	61	93	0.05
Microbial protein (kg/d) - Mikrobska bjelančevina	1.04	1.23	0.08

Table 6. **Effect of steam-flaking (SF) corn or sorghum versus steam-rolling (SR) corn or dry-rolling (DR)sorghum on mammary uptake of substrates (Theurer et al., 1999.)**

Tablica 6. **Djelovanje parnog ljuštenja (SF) kukuruza ili sirka prema parnom valjanju (SR) kukuruza na unošenje substrata sisanjem (Theurer i sur., 1999.)**

Net mammary intake - Neto unos sisanjem	Processing Obrada		P<
	SR corn and DR sorghum SR kukuruz i DR sirak	SF corn and SF sorghum SF kukuruz i SF sirak	
Amino acid - Amino kiselina N (g/d)	61	84	0.01
Glucose - Glukoza (g/d)	1609	1726	0.16
L-Lactate - L. laktat (g/d)	68	94	0.19
Acetate - Acetat (mol/d)	11	12	0.58
Propionate - Propionat (mol/d)	.21	.27	0.09
n-Butyrate - n-Butirat (mol/d)	.05	.05	0.91
B-Hydroxybutyrate - B-Hidorksibutirat (mol/d)	2.20	2.70	0.03

Table 7. **Effect of steam-flaking (SF) versus steam-rolling (SR) corn on milk yield and composition (Theurer et al., 1999)**

Tablica 7. **Djelovanje parnog ljuštenja (SF) prema parnom valjanju (SR) kukuruza na prinos i sastav mlijeka (Theurer i sur., 1999.)**

	Processing Obrada			
Measurement - Mjerenje	SR corn - SR Kukuruz	SF corn - SF Kukuruz	Response - Reakcija	P<
Milk - Mlijeko (kg/d)	35.80	38	+2.20	0.02
Protein - Bjelančevina (kg/d)	1.07	1.16	+0.09	0.01
Protein - Bjelančevina (%)	2.99	3.06	+0.07	0.11
Fat - Masnoća (kg/d)	1.12	1.13	+0.01	0.44
Fat - Masnoća (%)	3.11	2.98	-0.13	0.02

Table 8. **Effect of steam-flaking on milk yield and composition (Huber et al., 1994)**

Tablica 8. **Djelovanje parnog ljuštenja na proizvodnju i sastav mlijeka (Huber i sur., 1994.)**

Measurement - Mjerenje	Processing - Obrada	
	Grinded sorghum - Mljeveni sirak	Steam flaked sorghum Parno valjani sirak
Ruminal degradation - Buračana razgradnja (%)	51	76
Bypass starch (kg, estimated value) Bypass škrob (kg, procijenjena vrijednost)	3.3	1.5
DMI (kg/nap)	26.3	25.3
Milk production - Proizvodnja mlijeka (kg/nap)	35.0	37.4
Milk protein - Mliječna bjelančevina (%)	2.9	3.0
Milk fat - Mliječna masnoća (%)	3.24	3.1

The energetic efficiency of starch utilisation is the highest if not more that 1,5 kg starch per day enters the small intestine (Flachowsky and Lebzien, 1997). Results of 11 feeding experiments (In Table 8. dataset based on 424 Holstein-Friesian cows, 10 kg/day sorghum intake) confirm this recommendation. Huber et al. (1994) stated that an elevated amount of bypass starch resulted in a decreased milk yield. In the case of a higher starch flow to the duodenum starch should be treated to increase ruminal degradation. Under practical conditions the digestion of starch is mainly related to the physical characteristics of starch and not to animal factors (Van Vuuren et al., 1997).

CONCLUSIONS

Wet (hydro-) thermal processing causes gelatinization of grain starch, denaturization of protein, bonding of lipids, inactivation of anti-nutritional factor, pasteurisation of processed material. Using wet (hydro-) thermal processing, a technique which effectively controls Salmonella in feed, increases ruminal starch degradability of cereals, affects the site of degradation. Steam processing and flaking grains render the starch fraction more available to rumen microorganisms and enzyme attack. Starch degraded in the rumen supports synthesis of microbial protein and VFA but rapid or excess degradation may induce ruminal acidosis, increased secretion of insulin and decreased fat in milk. Conversely too much undegraded starch exiting the rumen may exceed the digestive or absorptive capacity of the small intestine or both. Steam processing may not proportionally improve barley and wheat as much as it does sorghum grain since barley has most of its starch digested in the rumen even without steam processing. Therefore, processing methods developed for corn and sorghum corn and sorghum cannot be applied directly to barley. In the corn endosperm, starch is tightly packed within a protein matrix. The objective of corn processing is the release of starch from the matrix so that digestion is increased. Since barley is encased in a hull, the objective of processing barley is breaking the hull so that starch can be digested. Barley starch is more fermentable than corn starch. Since steam processing grains increases ruminal fermentation of starch, application of steam processing methods to barley may excessively increase ruminal fermentation of starch to cause low ruminal pH, acidosis and metabolic problems. On the other hand, under-processing can lead to reduced ruminal and intestinal digestibility. Economical by we have to note that hydrothermal treatments are approximately 2-3 times more expensive than dry rolling.

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SAŽETAK

Škrob je glavni energetski sastojak zrnja žitarica. Omjeri škroba fermentirani u rumenu mogu se dobro predvidjeti za niz žitarica i metoda obrade. U praksi od sredine 1980. visoka temperatura, kratkotrajno kondicioniranje (HRST) opisuje se kao mokro (hidro) termalni postupak čitavog niza strojeva koji mogu pasterizirati krmiva te kao uspješno sredstvo za uništavanje patogenih mikroorganizama. U industriji krmiva obrada se najprije odnosi na hranidbu monogastričnih životinja a u zadnje vrijeme također i na hranidbu preživača. Mokra (hidro) termalna obrada potiče želatiniranje škroba zrnja, denaturizaciju bjelančevina, vezanje lipida, onesposobljavanje antinutritivnih čimbenika i pasteriziranje obrađenih materijala. Prema podacima iz literature primjena mokre (hidro) termalne obrade djelotvorno suzbija salmonelu u krmivu, povećava postotak bypass bjelančevina, povećava razgradivost zrnja žitarica buragovog škroba (škroba u buragu), djeluje na mjesto probave škroba i bjelančevina, te istodobno poboljšava stopu razgradnje u crijevima i povećava ukupnu probavljivost škroba zrnja te strukturu krmiva prema potrebama životinja kao i TMR sustava hranidbe, povećava proizvodnju mlijeka i poboljšava kakvoću peleta ako se krmivo peletira. Što se tiče ekonomičnosti, mora se priznati da je hidrotermalno tretiranje otprilike 2 do 3 puta skuplje od suhog valjanja.