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The Effect of Processing on Physical Quality and Chemical Quality of pelleted feeds for Ruminants

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Abstract

This study carried out to examine the effect of feed processing on physical quality of feedstuff and on rumen degradation rate of dry matter, protein and starch. Each of three feedstuffs, barley, maize, and soybean meal were used to make 16 different pellets under different process, separately. First, barley was ground with 2mm and 6mm in Hammer mill. Barley mills from 2mm grinding were extruded in both 3mm and 6 mm die size. Pellets from both 3mm and 6mm die size were made 4 different feeds under low or high RPM and with/without cooling. Except for extruder die size difference (6mm or 9 mm) applied for feed mills from 6mm grinding, all the other steps used in processing for 6mm were same as it was in 2mm barley mills. The same procedure used for barley ware applied on maize and soybean meal to make pellets.

Afterwards, physical quality tests regarding to bulk density, durability and hardness were done for all feeds. And 4 feeds from each feedstuff were selected for In-Sacco tests.

It is pleasant to increase availability of feeds by improving physical quality of pellets applying proper processing techniques.

Kaywords: feedstuff, feed processing, physical quality, degradation rate, passage rate, digestion rate.

Introduction

In ruminants, the alimentary tract can be divided into the forestomach (rumen, reticulum and omasum), the real stomach (abomasum), the small intestine and the large intestine (Sjaastad et al., 2016). In the forestomach and the large intestine, microorganisms digest and ferment the nutrients in the feedstuff, whereas in the stomach and the small intestine feed nutrients are degraded by the animal's enzymatic system. Protein, and carbohydrates in form of fiber, starch and sugars, are quantitatively the main nutrients in ruminant diets. Digestion and metabolism of protein and carbohydrates is a multi-step complex process. In ruminants, the interaction between microorganisms and digestion properties of these nutrients in the rumen is largely affecting overall feed digestion and utilization will be the main topic discussed in this thesis.

With respect to protein, the rumen microflora will degrade parts of it into amino acids and ammonia. The microflora utilizes ammonia and amino acids together with energy from digestion of carbohydrates, to produce microbial protein. When the microbes and the rumen un-degraded dietary protein enter the small intestine, they will be digested and thereby supply the ruminant animal with amino acids that can be used for maintenance and production of meat and milk. Excess ammonia will be absorbed through the rumen wall and excreted as urea in urine, or recycled to the rumen with saliva. With respect to the carbohydrates used for energy by the microbes, they will be converted into volatile fatty acids that are absorbed through the rumen wall and utilized as energy by the ruminant animal.

To what extent protein and carbohydrates are digested by the microbes in the rumen is however, mainly determined by the balance between rate of rumen digestion and rate of rumen passage. Both rate of digestion and rate of passage is influenced by several aspects. The physical quality of pelleted feeds is such aspects. For example, particle density regulates rate of passage of feedstuff from the rumen, although the role of density is not clear (Ehle 1984);(Martz and Belyea 1986). Moreover, the particle size of ingredients determines the available surface area for microorganisms' attack and their multiplication and thus rate of digestion (Stokes, Goetsch et al. 1988); (Dehority and Orpin 1997), but particle size also influences the rate of passage in the digestive tract ((Balch 1950). In that respect, a pelleted feed where particle density and particle surface area allow for an optimized balance between the rate of digestion and rate of passage in the rumen should increase nutrient utilization in ruminants. In the present experiment, the extruder technology and knowledge from the salmon feed production were used to produce pelleted feed for ruminants with different densities and particle disintegration rates. The effect of processing was assessed by evaluating pelleting characteristics of barley, maize and soybean meal extruded at various conditions. The pelleting characteristics evaluated were bulk density, durability, hardness, and water stability. In addition to the physical characteristics, the effects of processing on rumen disintegration of some selected feedstuff were investigated using the in-Sacco method. The hypothesis was that extruder processing can be used to manipulate the density and rate of disintegration of ruminant feed, and thus improve nutrient utilization in ruminants.

Literature Review

Raw Materials

The 2018 world cereal production was 2601.2 million tonnes, a forecast drop of 2.4 percent, or 64.5 million tonnes compared to 2017. The decline in production was predominantly weather reduced maize and barley outputs due to unfavorable conditions worldwide. (http://www.fao.org/3/CA2320EN/ca2320en.pdf) (http://www.fao.org/3/CA1487EN/ca1487en.pdf).

The global oilseed production stagnated in 2017/18, but is forecast to reach a new record in 2018/19 thanks to the expected increase in yield and cultivation area in a number of countries (http://www.fao.org/3/CA2320EN/ca2320en.pdf).

In this experiment barley, maize and soybean meal were chosen as raw materials. A comparison of chemical components in them are listed in Table 1.

Table 1. Chemical components in barley, maize and soybean meal

Main analysis	Barley	Maize	Soybean Meal (dehull)
Dry matter (% as fed)	87.1	86.3	88.1
Crude protein (% DM)	11.8	9.4	53.5
Crude fibre (% DM)	5.2	2.5	4.9
NDF (% DM)	21.7	12.2	11.0
Ash (% DM)	2.6	1.4	7.2
Starch (polarimetry) (% DM)	59.7	73.4	-
Total sugars (% DM)	2.8	2.1	10.6

https://www.feedipedia.org/

Barley

Barley (*Hordeum vulgare*), one of the world's first cultivated grains, was domesticated 10,000 years ago by early primitive humans (Zohary and Hopf. 2000).The 141.7 million tones produced in 2018, accounted for 5.5% of world cereals production. The 2018 production was a 3.5 mill tones drop from 2017, and a further drop is forecasted for 2018/19 (http://www.fao.org/3/CA2320EN/ca2320en.pdf).

Barley (Hordeum sativum) is a commonly used grain in animal diets. It is characterized by a thick fibrous coat, or hull surrounding the kernel, high amount of non-starch polysaccharides (NSPs) and simply-arranged starch granules.

Maize

Maize accounted for 41.09 % of all cereal production worldwide in 2018, and in total 1068.9 million tonnes were produced. This was a decline of 23.8 million tones from 2017 ("ProdSTAT". *FAOSTAT*. Archived from the original on 9 February 2012. Retrieved 26 December 2006) (http://www.fao.org/3/CA2320EN/ca2320en.pdf). In contrast to Europe where draught reduced maize production, beneficial weather conditions increased yields in China (Mainland), Ukraine and USA. The production is anticipated to increase in 2018/2019 thanks to expected increase in demands for feed and industrial production (http://www.fao.org/3/CA1487EN/ca1487en.pdf).

Tract of Ruminants

The alimentary tract of ruminants can be divided into stomach, small intestine and large intestine. The stomach consist of rumen, reticulum, omasum and abomasum, of which the three first are known as the forestomach and the last one (abomasum) is the real stomach.

The rumen is the largest compartment and the content could basically be divided into three phases: liquid phases in the bottom, gas phase sitting up above, and the fiber rafts in the middle floating on the rumen liquid. Large objects in the raft, such as undigested feed will be conveyed back to mouth for masticating, or rumination, which is the origin of the name ruminants. After the rumen, the digested feed particles enters the reticulum where the feed particles enters into omasum through the omasal orifice. The internal wall of omasum consists of leaves, aiding digestion and adsorption of water before the feed material finally are passing into abomasum. The abomasum is considered as the true stomach of ruminants, where digestive acids and enzymes are secreted for further digestion of feeds.

In the rumen and large intestine, billions of micro-organisms digest or ferment feedstuff into smaller molecules, whereas in the small intestine, it is the enzymatic system of the animal that further digest feedstuffs. Despite the variety in their digestion mechanisms of these compartments, the processes of mixing and passage of the three parts are different as well. The rumen operates as an imperfectly stirred, continuousflow reactor, whereas the small intestine acts like a plugged-flow reactor (Levenspiel 1972); (Penry and Jumars 1987). However, digestion of nutrients in ruminants is a multi-step complex process, which involves a large amount of nutrients and digestion processes. Carbohydrates in form of sugar, starch and fiber, and protein, are the main nutrients digested in the rumen, and volatile fatty acids (mainly acetic, propionic and butyric acid) (VFA) and microbial protein are the main products. VFA's are absorbed from the rumen and constitute the major energy supply to the animal, whereas microbial protein and rumen undigested dietary protein digested constitute the main supply of metabolizable protein when absorbed as amino acids in the small intestine.

The unique digestive and metabolic mechanisms of feedstuff in ruminants is of great importance which could provide possibilities to control milk and meat production. The amount and extent of digestion of nutrients in the rumen and the small intestine can be manipulated by choice of feed ingredient, or processing. The main factors to manipulate are rate of rumen degradation (kd) and rate of rumen passage (kp), and choices can be made depending on ingredient source and type of machines for feed manufacturing available (Levenspiel 1972); (Penry and Jumars 1987).

Feed processing

In farm industry, pelleted feeds have become a popular and even an initial part of animal feeding because the combination of different originated raw ingredients in processing could complement each other on nutritional scarcity, which somehow fits with what farmers demand. Pelleted diets, both feedstuffs (ingredients) and compound feeds, are produced by means of physical, thermal and/or chemical treatments in feed manufacturing, in which, feedstuffs are pure ingredients of plant or animal origin that can be used as nourishment for animals either in a natural state or after processing; whereas, compound feeds can be defined as a mixture of different ingredients (or feedstuff) used as a complete or partial feed for animals. Compound feeds may also include premixes that are composed of micro-ingredients such as vitamins, minerals, chemical preservatives, fermentation products and other essential ingredients.

Animal diets are normally produced in process of grinding- weighing- mixing-pelleting (extrusion; expansion)-cooling-drying- cooling.

Grinding

Parallel to the increased demand for animal products, grinding was the first technology emerged to process cereals and other ingredients into feed. Grinding reduce particle size of ingredients that result in more surface area for particles in-between interaction during processing and its its interaction with other chemicals or microorganisms while digestion (Church 1991); (Yang, Beauchemin et al. 2001). Tait and Beames found that fineness of grinding is correlated to type and moisture content of materials, as well as screen size and flow rate of mills, which were also proven by some other researchers *(Tait and Beames 1988)*; (Michalet-Doreau and Cerneau 1991). While hammer mill and roller mill are the most commonly used mills in feed industry (Figure 1).

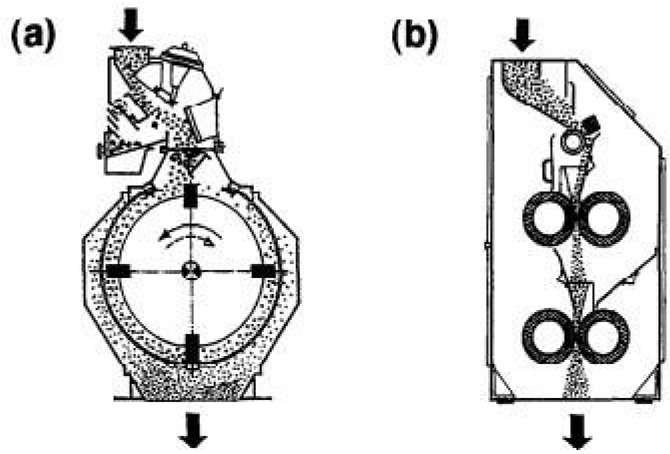


Figure 1. (a) Hammer mill. (b) Roller mill.*(Audet 1995).*

In contrast to others, hammer mill is used more in feed industry owns to its flexibility of grinding large variety of products ((Behnke 1996). Whereas, Roller mill is especially used for whole grains (Behnke 1996).

The Physical Quality of Pellets

The physical quality of pellets is affected by ingredients selection, choice of equipment as well as equipment processing conditions (Thomas and Van der Poel 1996). Raw material composition and equipment used to make feeds affect pellet quality due to properties of different raw materials on thermal and physical treatments from different equipment and its variable conditions such as temperature, moisture content, residense time. Addition of heat and water/steam within conditioning and extruding machine will change component's structure like protein and starch and thus, affect binding properties of pellets (Thomas and van der Poel, 1996). Or some other application of processing equipment such as drying and the cooling machine could also have an impact on physical quality of pellets. Drying and cooling are used to decrease moisture and latent heat content, which will give an optimal condition to store pellets for a sufficient time (Thomas, Van Zuilichem et al. 1997);(Brooker, Bakker-Arkema et al. 1992).

On the other hand, recrystallization of soluble components and viscosity increase of some other compositions will occur during the process drying and cooling, thus, maintaining the structural integrity of pellets (Thomas, Van Zuilichem et al. 1997). Functional property of composition of raw materials, at the same time, is affecting pellet quality, such as starch and protein. In the presence of thermal (heat, steam) and mechanical treatment, starch could get to its desired properties like swelling and recrystallization (Thomas, Van Vliet et al. 1998). And the change in the structure of amylose and amylopectin are known as the important mechanism that gives pellets binding properties (Schwartz and Zelinskie 1978). In general, factors resulting in a wide variety of pellet physical qualities are specific properties of raw materials and mechanical or thermal treatments of the processing system.

The influence of pellets' physical quality in In-Sacco tests

Protein contents of diet will be degraded into amino acids and ammonia by microflora in rumen liquid. Of which, ammonia will be absorbed through rumen wall. Whereas, those fermented amino acids will be synthesized into essential amino acids for maintenance, or growth of ruminants and of microflora. Carbohydrate or energy sources will be integrated into volatile fatty acids that are directly absorbed through rumen wall and utilized as the energy source of ruminants.

The degree of pellets disintegration in rumen acidic environment affect utilization of feeds in ruminants. Well-degradation of feed would guarantee the utilization of nutrients by cattle, whereas, over degradation might cause waste of feeds and animals cannot utilize it efficiently. Thus, ruminants need more pellets to meet their nutrient and energy requirement of maintenance and growth, thus higher costs of feeding in the farming industry.

However, pellets' physical and chemical quality has huge impacts on the disintegration of pellets in the rumen. When eating diets with ideal physical and chemical quality, animals could digest and absorb more required nutrients in small and large intestine due to more overflow of feeds from stomach. For example, perfectly processed barley increases un-degraded starch and protein flowing into small intestine which offers positive effect on absorption of glucose and productivity of animals. Therefore, a proper process for pellets is urgent to increase utilization and decrease risks from the waste of pellets and costs on feeding. Pelleted feeds are widely used in fish feeds mono-gastric feed and in ruminant feeds due to their and passage rate of pellets in the rumen.

Materials and methods

Feed formulation and processing

Three feedstuff rations composed of only one or two ingredients in each of them were applied to make extruded pellets, given great opportunities to estimate functions of raw ingredients more easily and accurately without interference from other materials (table 2).

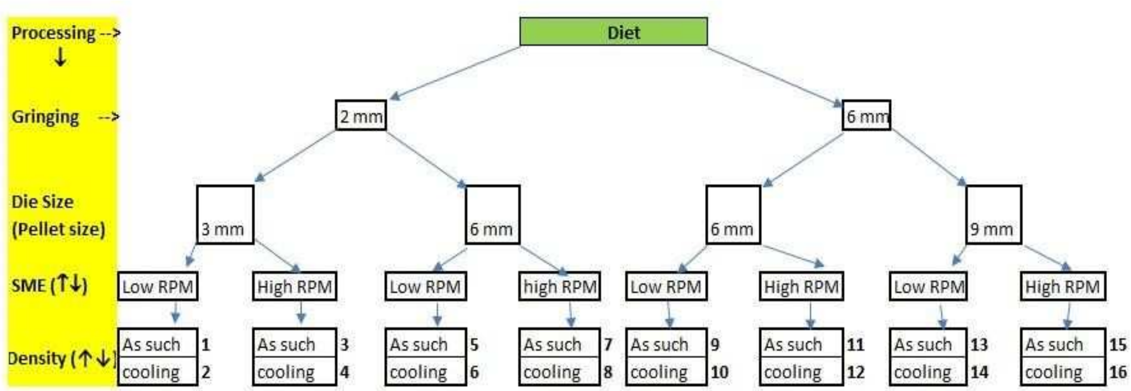
Table 2. Ingredients in pelleted rations

Ration	Barley (%)	Maize (%)	Soybean meal (%)
1	100	---	---
2	---	100	---
3	---	10	90

The primary purpose of 100% barley and maize in ration 1 and 2 respectively was to evaluate the effect of various processing parameters on the physical quality of pellets and its contribution in In-Sacco test. Whereas, ration 3 included 10% maize in addition to 90% soybean meal. The added maize content acted as a glue to provide proper binding property in pellets.

Feed production was conducted at FôrTek, NMBU in 2017. All 3 rations were through the same production line: grinding→ conditioning→ extruding → cooling, to make 16 different pelleted feeds from each (table3). And the barley group is chosen to illustrate the whole process of making pellets down below.

Table 3. "Flow" diagram for processing of extruded feed



Grinding, Conditioning and Extrusion

Barley was ground in a hammer mill (Hammer mill, MünchEdelstahl, Wuppertal, Germany licensed by Bliss, USA, 18 kW, 3000 RPM) where two sieve sizes (2 mm and 6 mm) were used, divided ground barley into two groups. All ground barley was conveyed into conditioner under the same condition of 80-85 ^{O}C of temperature + 25%- 30% of moisture.

Afterward, a twin-screw extruder (Bühler BCTG 62, 5 sections, 72 kW DC, Bühler, Switzerland) was used to produce pellets. Both of 2 mm and 6 mm ground barley were extruded through high and low SME combined with two extruders die size (3 mm or 6 mm), producing 8 different pelleted barley feeds.

Pellets from extruder were sent for drying immediately via mobilized dryers (4 levels) for about 40 minutes and then half from each of those 8 different types of feeds were cooled before storage and half were not cooled, made 8 different barley pellets into 16 at the end.

The same feed manufacturing process was used indiscriminately for Formulation 2 and 3. In this case, 48 different pellets were produced in total for further analysis.

Physical Quality Tests

Physical quality tests and water stability test was done for all 48 types of pellets.

Bulk Density

After drying (or cooling if it is applied), A 1liter capacity of container was fulfilled with pellets and measured the mass of it to calculate Bulk density (3 times for each type of diets) by the formula:

Bulk density = mass of pellets used to fulfill 1 liter of container/ 1 liter.

Moisture Content

The moisture content of the sample was determined by IR moisture analyzer. Ground Barley was kept in the tared aluminum plate and run for analysis whereas for pellet samples were ground with mortar and pestle prior to analysis. Three readings were analyzed for each sample.

Pellet Durability Index

Pellets durability index (PDI) were tested using a Holmen pellet durability tester (Holmen NHP200 pellet durability tester, UK) (Fig1). It uses the pneumatic system to measure the surface attrition on the pellets that is moved around in a closed circuit by high air velocity for given time intervals (Øverland, Romarheim et al. 2007).

A sample of 100 g pellets was put into the machine, and the machine, then, removed fines by sieving pellets in 0.5 mm sieve, weighed the sample, tested pellets, weighed remaining samples and calculated pellets durability index (PDI) at the end which was displayed on the LCD screen.

The following formula was used to estimate PDI:

$$PDI(\%) = \frac{weight\ of\ pellets\ (g)\ after\ Holmen(60s\ 30s)\ Sieve(30s)\ (from\ 1^{st}\ sieve)}{weight\ of\ pellets\ (g)\ before\ Holmen(\sim 100g)} \times 100$$

Figure 1. Holmen NHP200 Pellet Durability Tester, UK

Pellet Diameter & Length and Hardness

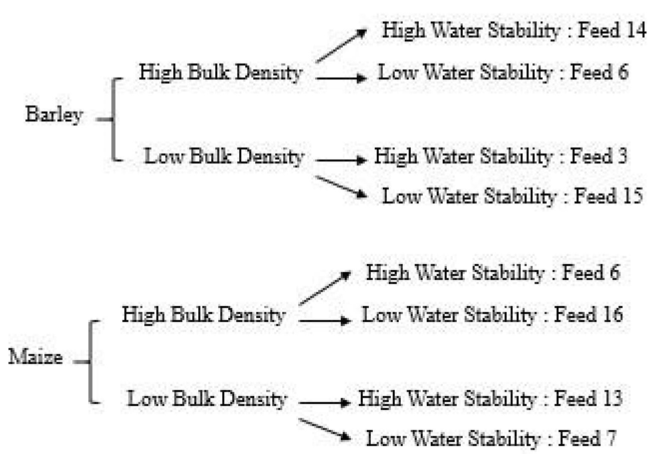
Random 30 pellets from each type of pellets were chosen for diameter and length tests using an electronic caliper (Fig2). Afterward, 30 pellets were selected based on the mean diameter of each diet for hardness test. In hardness test, a hardness tester machine, Tinius Olsen Texture Analyzer H5KT, (Fig3) was used. Samples were horizontally placed one by one between two plates that were approaching each other and the force used to break pellets were read at a very first time.

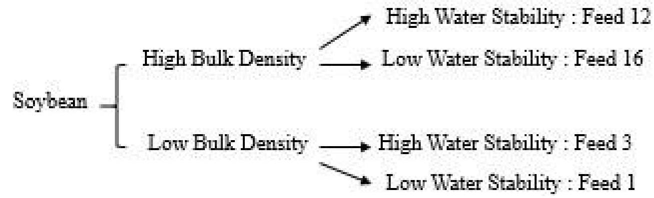
Figure 2. Electronic Caliper

Figure 3. Tinius Olsen Texture Analyzer H5KT

In-Sacco Test

By finishing all physical quality tests, there were 4 different pellets from each feed formulation (12 feeds in total) selected for in situ starch and N disappearance, based on low& high bulk density with low& high water-stability index.





The reason for why bulk density and water stability index were the criteria for selecting feed is because first, the bulk density of pellets is widely related to passage rate of it in the rumen. And water stability test is seen as a similar test with In-Sacco test. Enhance, it was the most apparent to carry out the effect of bulk density on passage rate of pellets in the rumen along with different rumen digestion rate of pellets by choosing the diet with highest and lowest bulk density & water stability index.

It is a purpose that this report is trying to figure out the influence of bulk density on the passage rate of pellets in the rumen. It is also aimed to find out how different data those two tests would bring regarding digestion rate.

After selection of pellets, Dacron bags (10 cm * 20 cm; pore size, 51±2 μm) with two grams of each feed sample, without grinding, were placed into rumen liquid zone and token out after 4h, 8h, 24h, and 48h.

Weibull Analysis

Weibull analysis is published by W. Weibull. (Hoddeson, Brown et al. 1997);(Aarseth and Prestløkken 2003). Weibull distribution can be described well by linear regression from the probability plot, and Weibull parameters (σ_0 and m) ((Wu, Li et al. 2001).

The Weibull modulus (m) represents the variability or dispersion in materials strength, where a small m value means low homogeneity, or large scatter of pellets Thus, pellets with higher Weibull modulus (m) is always desired (homogenous products), in the context of feed manufacturing and prediction of damage while handling and transportation of pellets (Sonnergaard 2002).

Whereas, the scale parameter σ_0 expresses the stress level (texture analyzer) that pellets can sustain before achieving any fracture. In other words, pellets with higher physical quality shows large scale parameters values (σ_0) (Sonnergaard 2002).

Results

Physical qualities of all 4 extruded feeds (14 barley, 16 maize and 16 SBM feeds) in terms of hardness, durability, and bulk density are shown. And results from InSacco tests in the rumen were illustrated.

Raw data of physical qualities were analysed by Minitab 16 with Turkey analysis. In addition, Weibull analysis were done on hardness. Moreover, Statistics Analysis System (SAS) was applied to analyse In-Sacco tests raw data.

Bulk density

Bulk density of pelleted barley, maize and soybean meal is given in Figure 1, 2 and 3, respectively. Pellets chosen for In-Sacco tests are marked in red.

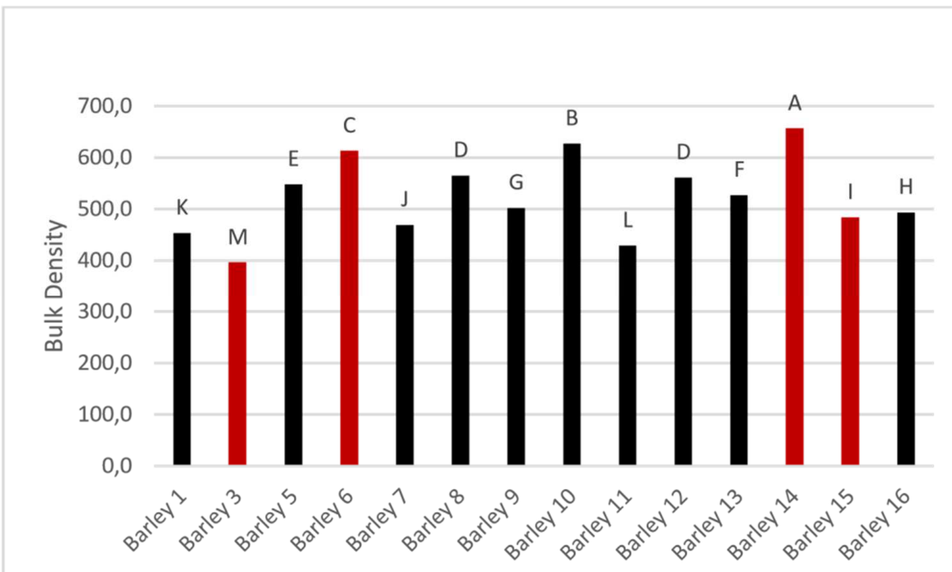


Figure 2. Comparison of bulk density among 16 different barley pellets. All bars with different letters indicate significant difference ($p<0.05$).

All pelleted barley is significantly different from each other on bulk density except there is no significant difference between barley 8 and 12. The range was from 395h/l (barley 3) to 656g/l (barley 14).

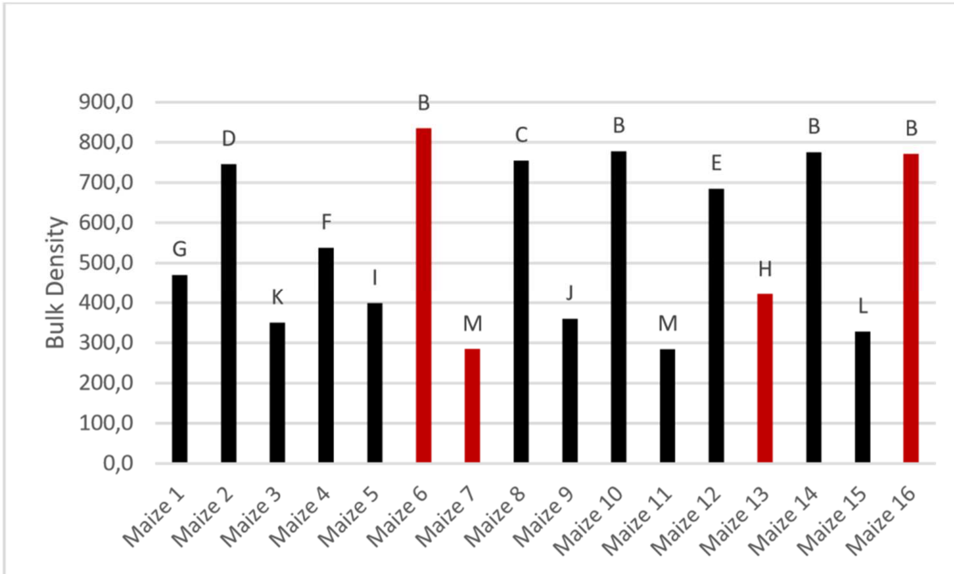


Figure 3. Comparison of bulk density among 16 different maize pellets. All bars with different letters indicate significant difference ($p<0.05$).

Bulk density of maize 6, 10, 14 and 16 have no in-between significant difference (group A). Same result is detected between maize 7 and 11 (group B). However, bulk density of feeds in group A and B are significantly different between groups, but also, they are different from that of feeds that are not included in two groups. Moreover, all non-included pelleted maize in group A and B is significantly different from each other on bulk density. Bulk density range of 16 pelleted maize is from 284g/l (maize 7) to 835g/l (maize 6).

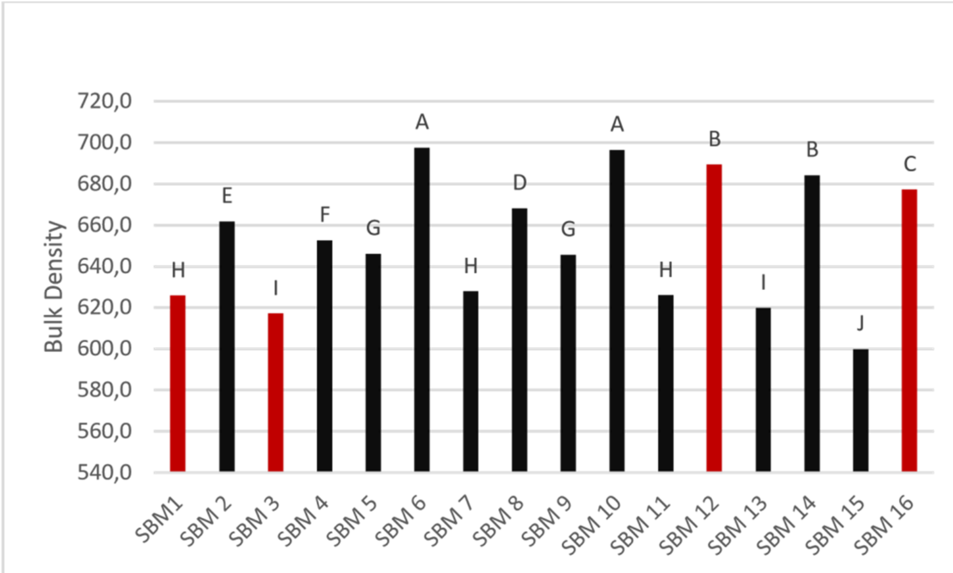


Figure 4. Comparison of bulk density among 16 different soybean meal pellets. All bars with different letters indicate significant difference ($p<0.05$).

There are significant differences on bulk density among feeds from different groups, but no differences for feeds from the same group: soybean meal 6, 1 and 10 (group A); 12 and 1 (group B); 5 and 9 (Group C); 1, 7 and 11 (group D); 3 and 13 (group E) on bulk density. All other soybean meal pellets are significantly different. The range is from 599.8g/l (SBM 15) to 697.6g/l (SBM 6).

Durability

Durability indexes of pelleted barley, maize and soybean meal (SBM) are given in Figure 4, 5 and 6, respectively. To explain results clear, 16 feeds from three ingredients are divided into different groups based on letters they marked. There are no differences between feeds in the same groups, but feeds from different groups are significantly different on Durability. Pellets chosen for In-Sacco tests are marked in orange.

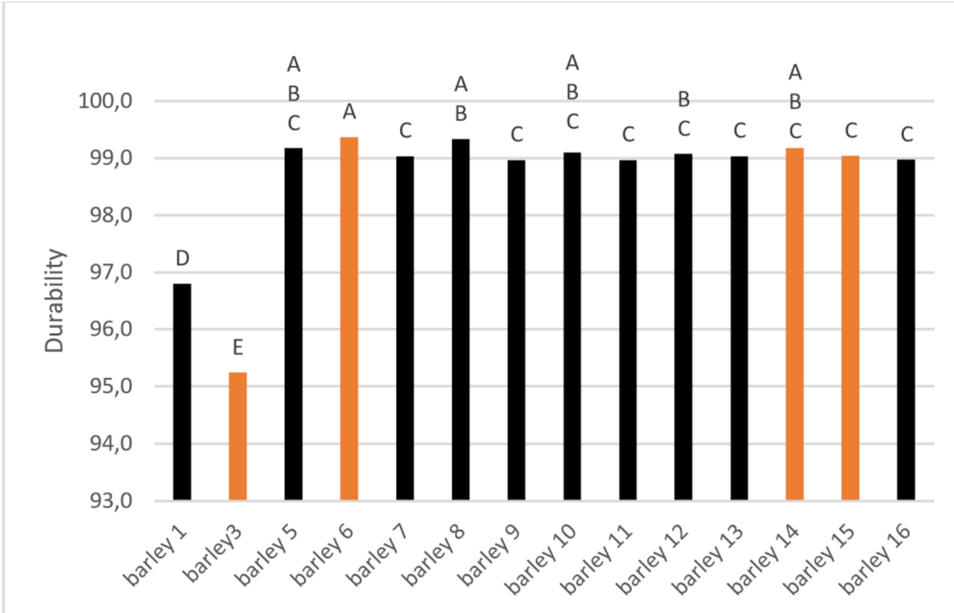


Figure 5. Comparison of durability among 16 different barley pellets. All bars with different letters indicate significant difference ($p<0.05$).

Group A: barley 5, barley 6, barley 8, barley 10, and barley 14.

Group B: barley 5, barley 8, barley 10, barley 12 and barley 14.

Group C: barley 5, barley 7, barley 9, barley 10, barley 11, barley 12, barley 13, barley 14, barley 15 and barley 16.

Group D: barley 1.

Group E: barley 3.

The durability index range of barley feeds is from 95.2 (barley 3) to 99.3 (barley 8).

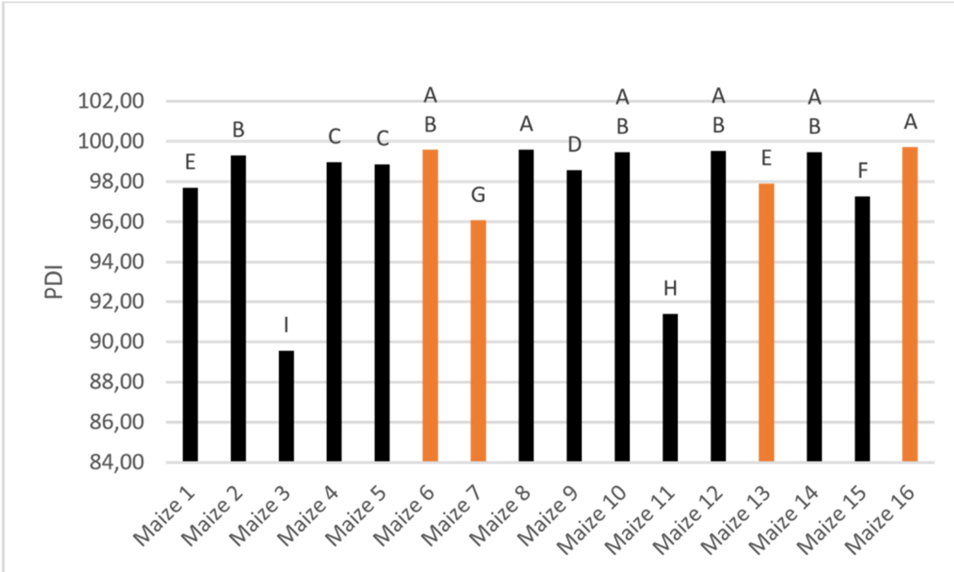


Figure 6. Comparison of durability among 16 different maize pellets. All bars with different letters indicate significant difference ($p<0.05$).

Group A: maize 6, maize 8, maize 10, maize 12, maize 14 and maize 16.

Group B: maize 2, maize 6, maize 10, maize 12, and maize 14.

Group C: maize 4, and maize 5.

Group D: maize 9.

Group E: maize 1, and maize 13.

Group F: maize 15.

Group G: maize 7.

Group H: Maize 11.

Group I: maize 3.

The durability index range of maize feeds is from 89.6 (maize 5) to 99.7 (maize 16).

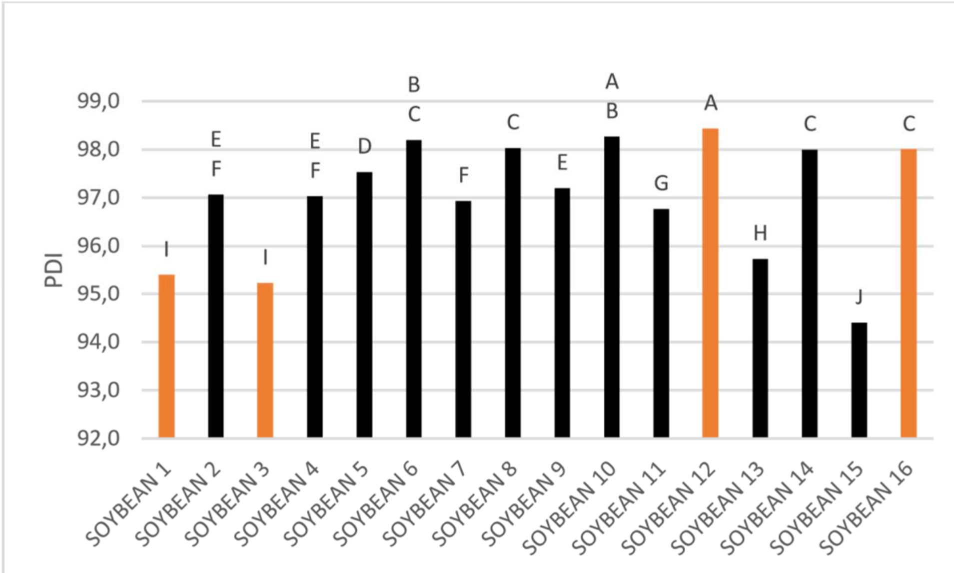


Figure 7. Comparison of durability among 16 different soybean meal pellets. All bars with different letters indicate significant difference ($p<0.05$).

Group A: SBM 10 and SBM 12.

Group B: SBM 6 and SBM 10.

Group C: SBM 6, SBM 8, SBM 14 and SBM 16.

Group D: SBM 5.

Group E: SBM 2, SBM 4 and SBM 9.

Group F: SBM 2, SBM 4, and SBM 7.

Group G: SBM 11.

Group H: SBM 13.

Group I: SBM 1 and SBM 3.

Group J: SBM 15.

The durability index range of SBM feeds is from 94.4 (SBM 15) to 98.4 (SBM 12).

Hardness

Weibull analysis results on hardness of barley, maize and soybean meal are given in table 4, 5, 6, and the accumulated Weibull probability plots of 12 feeds selected for In-Sacco tests are illustrated in figure 8, 9, 10, respectively.

Table 4. Parameters from Weibull Analysis of 14 different barley pellets. The Weibull modulus m is the slope of accumulated distributions, and the scale parameter σ_0 is calculated from the Y-intercept. For the failure stress of barley 1; m = 7.469 and σ_0 = exp ((30.052)/ 7.47) = 55.87 MPa; R^2, coefficient of determination

Feed	Function	m	b	σ0 (MPa)	R2
barley 1	y = 7.469x - 30.052	7.47	30.05	55.87	0.93
barley 3	y = 6.4207x - 24.303	6.42	24.30	44.04	0.91
barley 5	y = 12.04x - 60.177	12.04	60.18	148.13	0.96
barley 6	y = 15.314x - 79.795	15.31	79.80	183.20	0.91
barley 7	y = 13.379x - 64.737	13.38	64.74	126.31	0.97
barley 8	y = 13.667x - 69.447	13.67	69.45	160.99	0.95
barley 9	y = 11.643x - 53.034	11.64	53.03	95.11	0.96
barley 10	y = 13.168x - 73.419	13.17	73.42	263.90	0.84
barley 11	y = 9.9712x - 46.9	9.97	46.90	110.34	0.98
barley 12	y = 12.868x - 71.802	12.87	71.80	265.04	0.79
barley 13	y = 12.206x - 58.794	12.21	58.79	123.57	0.95
barley 14	y = 12.919x - 72.13	12.92	72.13	265.93	0.78
barley 15	y = 11.553x - 53.505	11.55	53.51	102.64	0.99
barley 16	y = 9.9825x - 49.595	9.98	49.60	143.77	0.82

The range of Weibull modulus m of barley feeds is from 6.42 (barley 3) to 15.31 (barley 6). And the range of scale parameter σ_0 is from 44.04 (barley 3) to 265.93 (barley 14).

Table 5. Parameters from Weibull Analysis of 14 different maize pellets. The Weibull modulus m is the slope of accumulated distributions, and the scale parameter σ_0 is calculated from the Y-intercept; R^2, coefficient of determination

Feed	Function	m	b	σ0	R2
maize 1	y = 5.8432x - 25.904	5.84	25.90	84.20	0.99
maize 2	y = 12.83x - 70.354	12.83	70.35	240.70	0.98
maize 3	y = 4.6928x - 17.871	4.69	17.87	45.07	0.97
maize 4	y = 4.5026x - 21.824	4.50	21.82	127.35	0.89
maize 5	y = 5.257x - 25.065	5.26	25.07	117.68	0.95
maize 6	y = 145.48x - 813.62	145.48	813.62	268.45	0.96
maize 7	y = 5.3714x - 26.136	5.37	26.14	129.77	0.96
maize 8	y = 3.3964x - 17.513	3.40	17.51	173.53	0.91
maize 9	y = 5.2752x - 26.791	5.28	26.79	160.56	0.96
maize 10	y = 231.98x - 1297.6	231.98	1297.60	268.70	0.87
maize 11	y = 7.0882x - 31.783	7.09	31.78	88.58	0.95
maize 12	y = 5.3821x - 27.843	5.38	27.84	176.49	0.94
maize 13	y = 7.7921x - 36.073	7.79	36.07	102.46	0.95
maize 14	y = 20.046x - 111.61	20.05	111.61	261.83	0.91
maize 15	y = 3.9038x - 18.231	3.90	18.23	106.70	0.94
maize 16	y = 5.8526x - 31.105	5.85	31.11	203.31	0.90

The range of Weibull modulus m of maize feeds is from 3.40 (maize 8) to 231.98 (maize 10). And the range of scale parameter σ_0 is from 45.07 (maize 3) to 268.70 (maize 10).

Table 6. Parameters from Weibull Analysis of 14 different SBM pellets. The Weibull modulus m is the slope of accumulated distributions, and the scale parameter σ_0 is calculated from the Y-intercept; R^2, coefficient of determination

Feed	Function	m	b	σ0	R2
SBM 1	y = 5.1061x - 18.087	5.11	18.09	34.54	0.91
SBM 2	y = 3.6579x - 13.478	3.66	13.47	39.74	0.92
SBM 3	y = 5.4733x - 21.006	5.47	21.01	46.43	0.90
SBM 4	y = 5.8798x - 21.191	5.88	21.19	36.75	0.91
SBM 5	y = 7.6152x - 31.812	7.62	31.81	65.20	0.87
SBM 6	y = 3.9227x - 16.325	3.92	16.33	64.18	0.96
SBM 7	y = 6.3406x - 28.525	6.34	28.53	89.91	0.90
SBM 8	y = 4.546x - 21.159	4.55	21.16	105.05	0.96
SBM 9	y = 4.7507x - 20.195	4.75	20.20	70.17	0.92
SBM 10	y = 4.4834x - 20.129	4.48	20.13	89.09	0.97
SBM 11	y = 6.7217x - 28.769	6.72	28.77	72.24	0.82
SBM 12	y = 2.9783x - 13.572	2.98	13.57	95.29	0.93
SBM 13	y = 5.7661x - 25.005	5.77	25.01	76.44	0.95
SBM 14	y = 4.8221x - 21.202	4.82	21.20	81.19	0.95
SBM 15	y = 6.297x - 29.341	6.30	29.34	105.59	0.88
SBM 16	y = 4.3155x - 19.466	4.32	19.47	90.99	0.93

The range of Weibull modulus m of SBM feeds is from 2.98 (SBM 12) to 7.62 (SBM 5). And the range of scale parameter σ_0 is from 34.54 (SBM 1) to 105.59 (SBM 15).

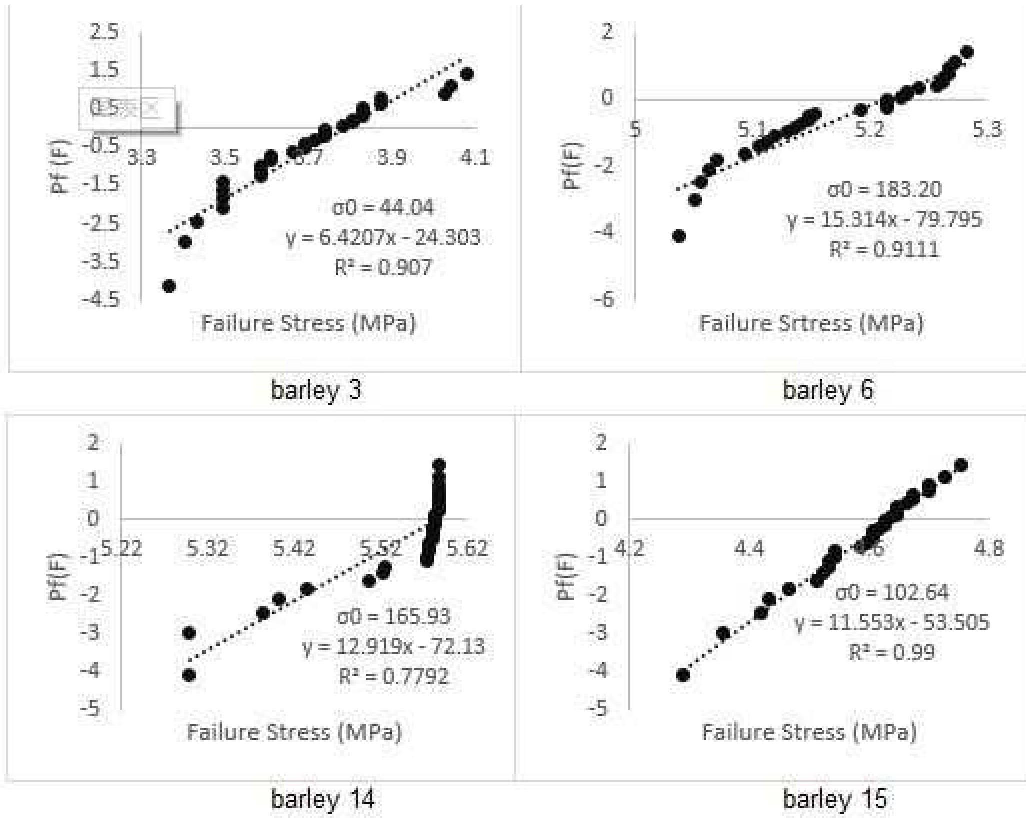


Figure 8. Accumulated Weibull probability plots for the stress at failure, in MPa. (barley 3 6 14 15, respectively); the weibull modulus m is the slope of the accumulated distributions and the scale parameter σ_0 is calculated from the Y-intercept; for the failure stress of barley 3; m = 6.4207 and $\sigma_0 = \exp((24.303)/6.4207) = 44.04$ MPa; R^2, coefficient of determination

Among 4 barley feeds selected for In-Sacco tests, the lowest Weibull modulus m and scale parameter σ_0 were tested on barley 3 (6.42; 44.04MPa), followed by barley15 (11.553; 102.64 MPa), barley 14 (12.919; 165.93 MPa) and barley 6 (15.314; 183.20 MPa).

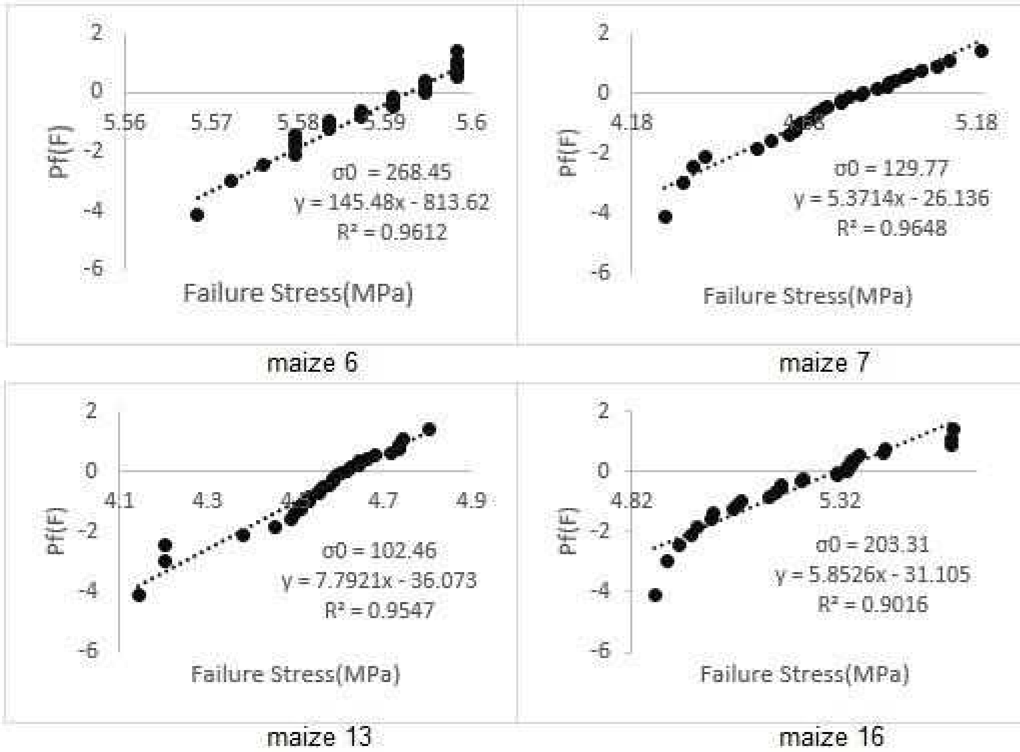


Figure 9. Accumulated Weibull probability plots for the stress at failure, in MPa. (Maize 6 7 13 16, respectively); the weibull modulus m is the slope of the accumulated distributions and the scale parameter σ_0 is calculated from the Y-intercept; R^2, coefficient of determination

Among 4 maize feeds selected for In-Sacco tests, the lowest Weibull modulus m is 5.3714 (maize 7), followed by 5.8526 (maize 16), 7.7921 (maize 13) and 145.48 (maize 6). And lowest scale parameter σ_0 is 102.46MPa (maize 13), followed by 129.77MPa (maize 7), 203.31MPa (maize 16), and 268.45MPa (maize 6).

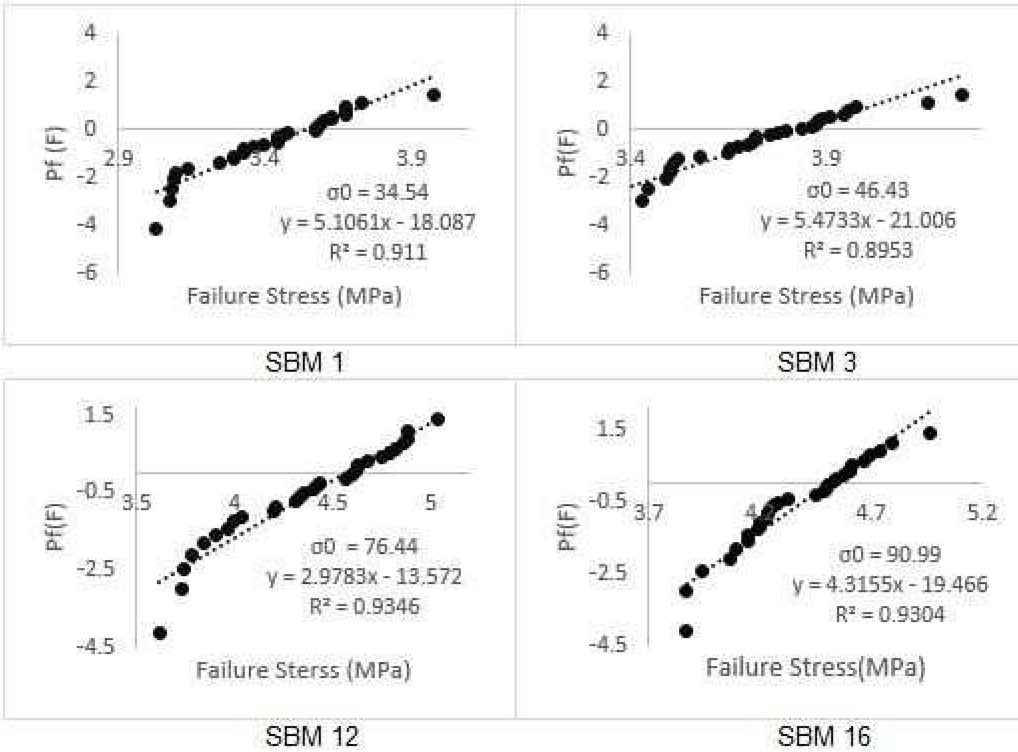


Figure 10. Accumulated Weibull probability plots for the stress at failure, in MPa. (SMB
1 3 12 16, respectively); the weibull modulus m is the slope of the accumulated distributions and the scale parameter σ0 is calculated from the Y-intercept; R^2, coefficient of determination

Among 4 SBM feeds selected for In-Sacco tests, the lowest Weibull modulus m is 2.9783 (SBM 12), followed by 4.3155 (SBM 16), 5.1061 (SBM 1) and 5.4733 (SBM 3). And lowest scale parameter σ_0 is 34.54MPa (SBM1), followed by 46.43MPa (SBM 3), 76.44MPa (SBM 12), and 90.99MPa (SBM 16).

In-Sacco tests

In-Sacco tests degradation rate of feed samples are illustrated in figure 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22.

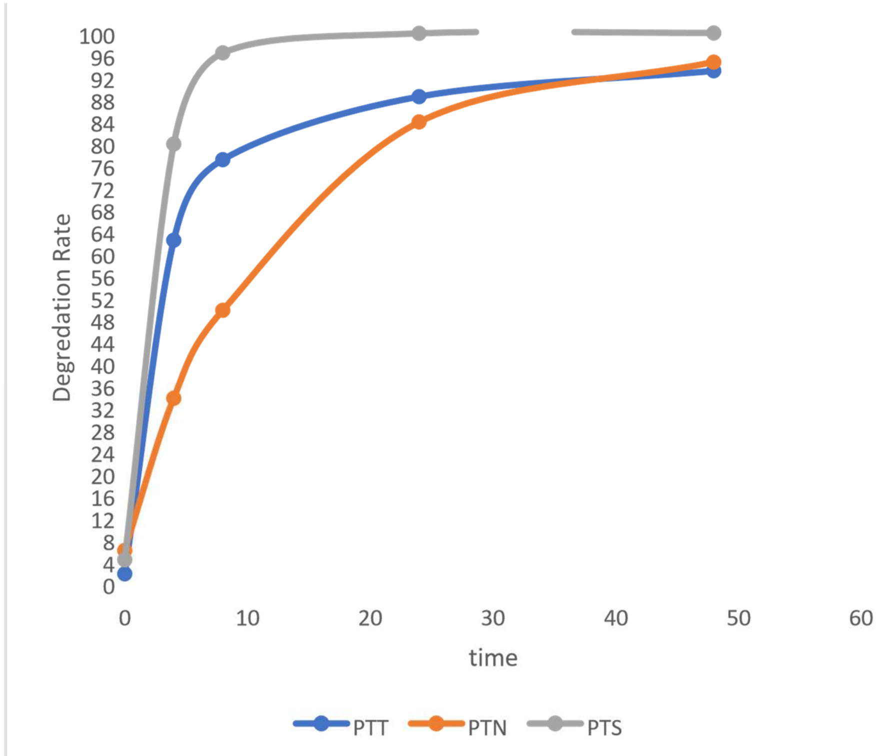


Figure 11. Degradation rate of barley 3 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate; PTS means starch degradation rate.

PTT of barley 3 increased rapid to 76.84% after 8 hours in rumen and then rise steadily to 94.58% at 48 hours. Comparing to a relative steady increase of PTN, PTS reach sharply to 96.24% after 8 hours in rumen and kept the high degradation rate.

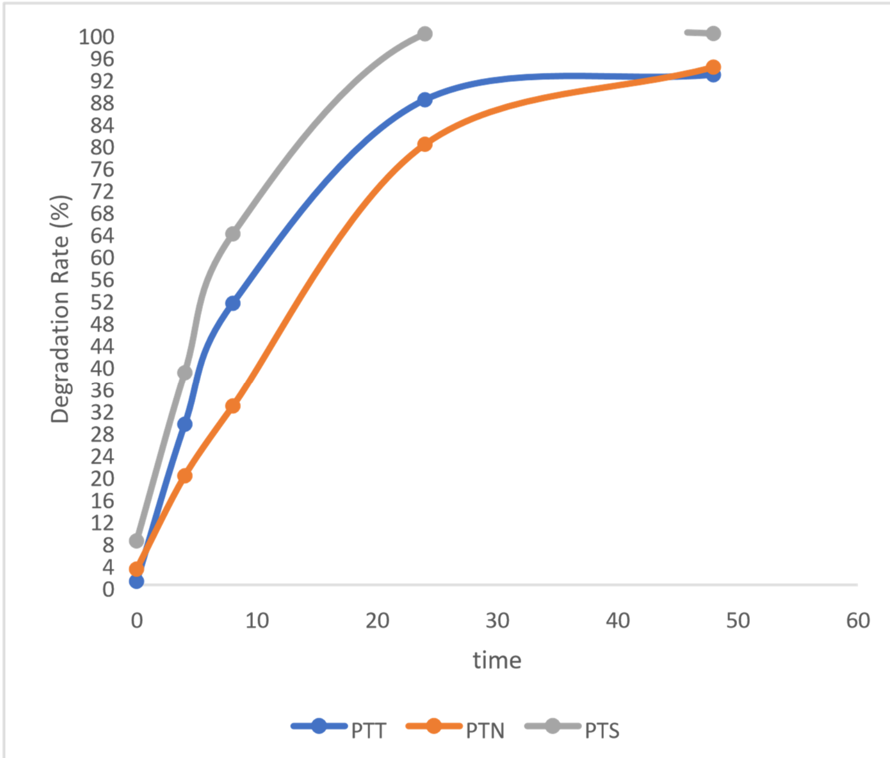


Figure 12. Degradation rate of barley 6 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate; PTS means starch degradation rate.

PTT, and PTS of barley 6 were fast and reach their highest percent at 24 hours in rumen (88%, and 99.8%, respectively) and remained their highest degradation rate. Whereas, PTN of barley 6 steadily increased to 93.77% at 48 hours after a speedy rise to 80% at 24 hours.

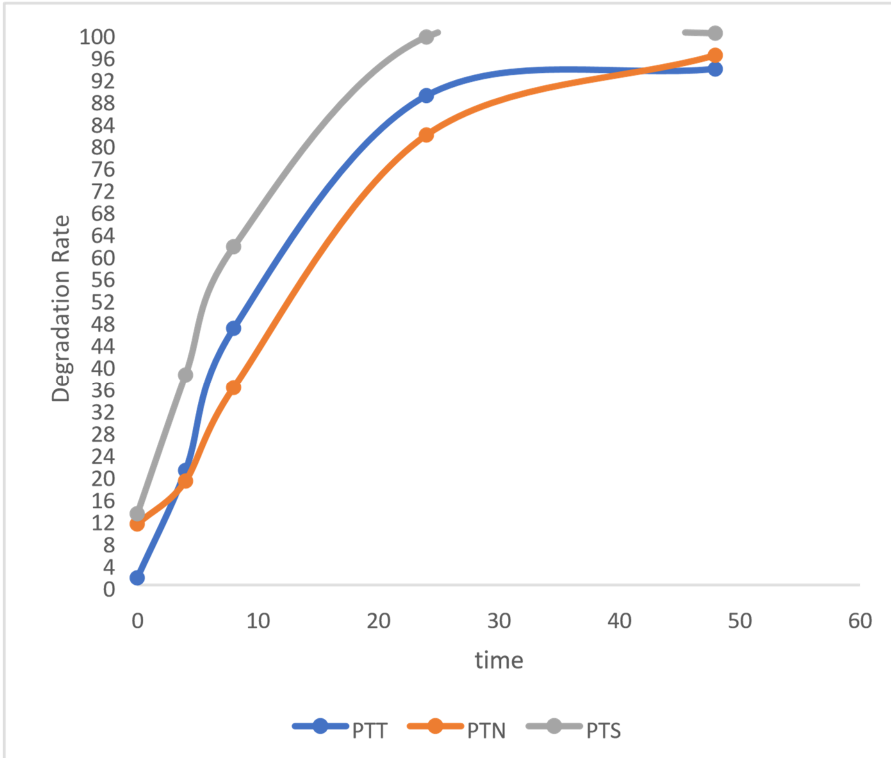


Figure 13. Degradation rate of barley 14 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate; PTS means starch degradation rate.

PTT, and PTS of barley 14 had fast reach their highest percent at 24 hours in rumen (89.6%, and 99.2%, respectively) and remained their highest degradation rate. Whereas, PTN of barley 6 had a relatively steady increase to 95.90% at 48 hours.

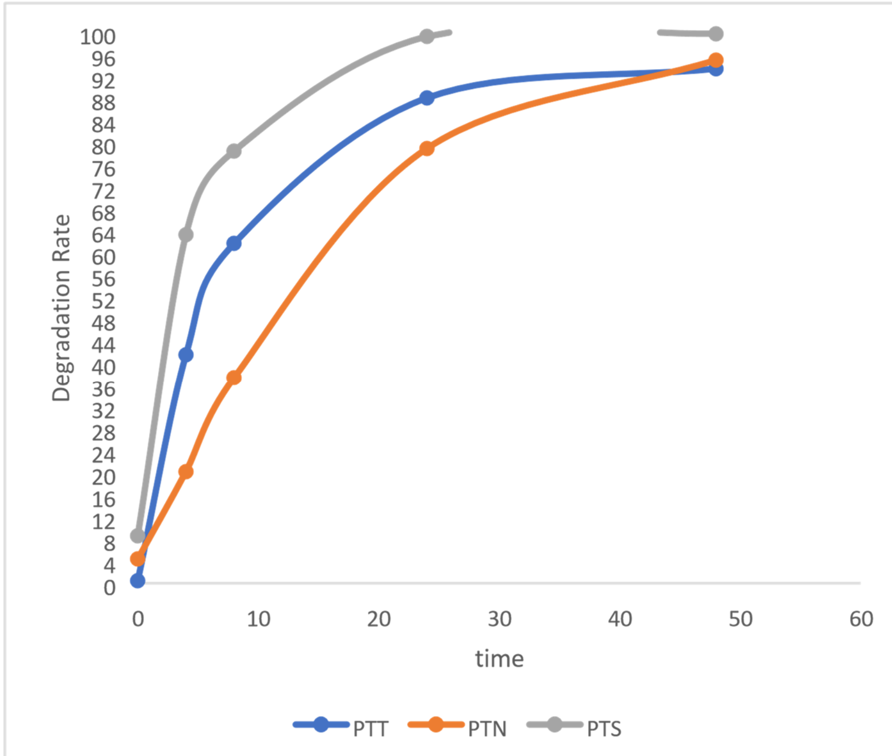


Figure 14. Degradation rate of barley 15 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate; PTS means starch degradation rate.

PTT, and PTS of barley 15 were swift and reach their highest percent at 24 hours in rumen (88.2%, and 99.3%, respectively) and then, remained the highest degradation rate. Whereas, PTN of barley 6 was relatively slow (78.99% at 24 hour) and increased to 95.04 at 48 hour.

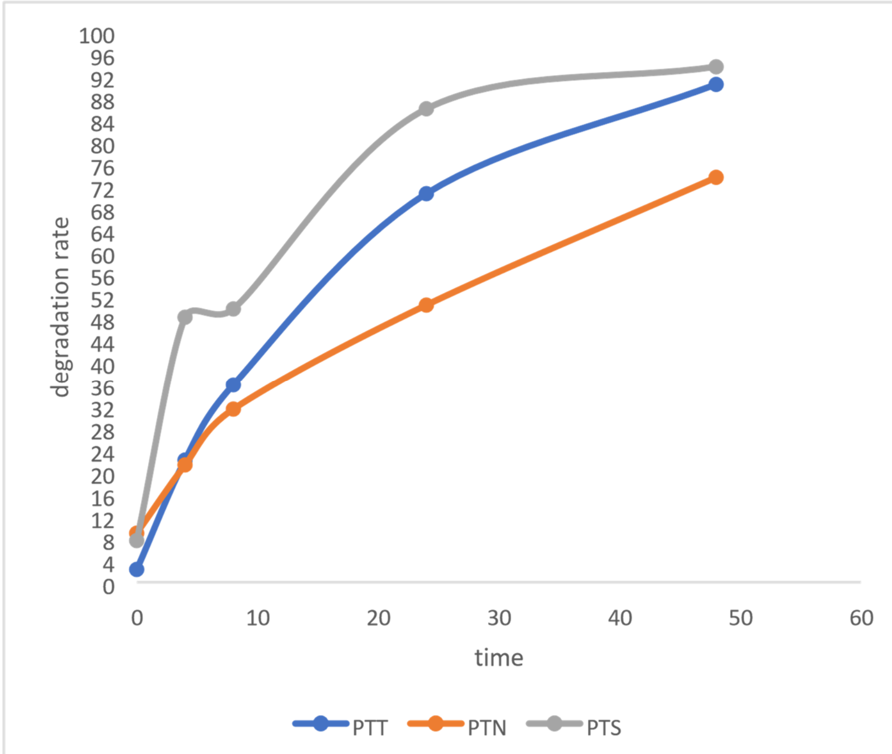


Figure 15. Degradation rate of maize 6 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate; PTS means starch degradation rate.

PTT of maize 6 had a slow increase and reach its highest point, 90.46% at 48hour. PTS of maize 6 was fast in the first 4 hours (from 7.58% to 48.17%), and rise relatively slow to the top, 93.65 by 48-hour after having a stop from 4 to 8 hours. Whereas, PTN of it was even slower and the highest degradation rate (73.55% at 48hour) is not high.

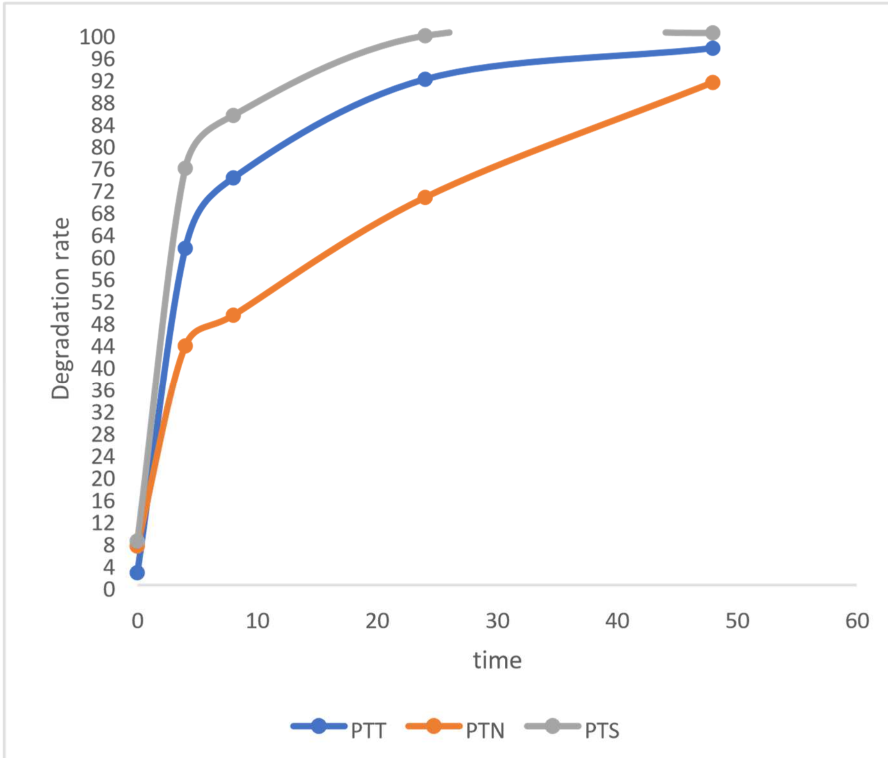


Figure 16. Degradation rate of maize 7 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate; PTS means starch degradation rate.

PTT, and PTS of maize 7 were fast in the first 5 - 6 hours (reach to 68% and 80.04 respectively), and then steadily increased to their highest point at 24 hours (97.21%, and 99.96%). Furthermore, PTN also had a sharp increase in the first 4 hours (reach to 43.30) and then steadily reach the highest point, 91.02%, at 48-hour.

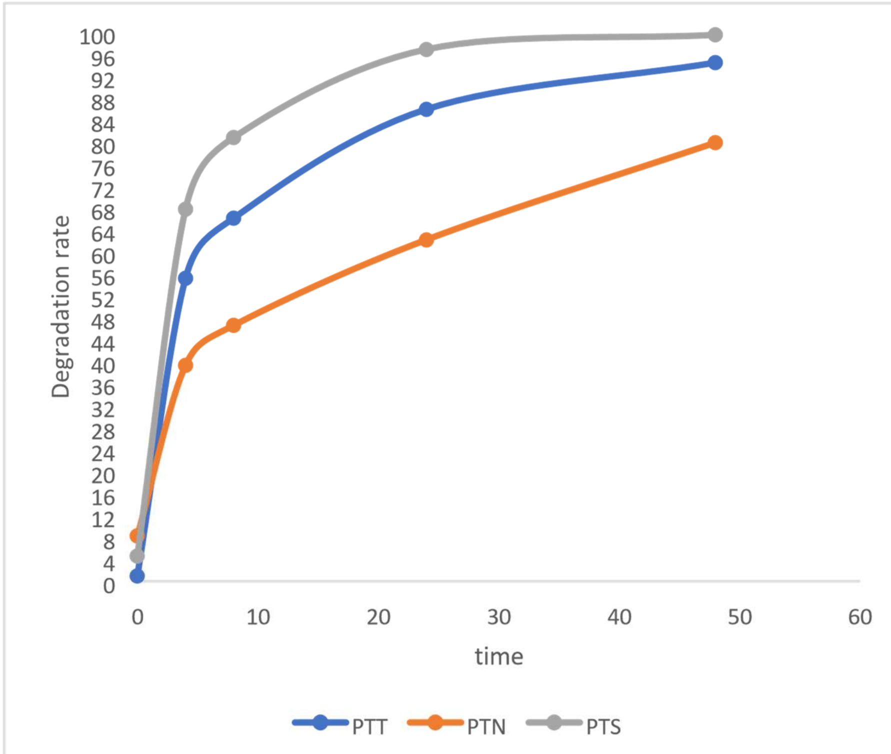


Figure 17. Degradation rate of maize 13 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate; PTS means starch degradation rate.

As respect to maize 13, happy increase detected in the first 4 hours for PTT, PTN and PTS (55.19%, 39.32, and 67.81%). Afterwards, all of them had a firm increase to their high point (94.53%, 79.94%, and 99.61%) until 48-hour.

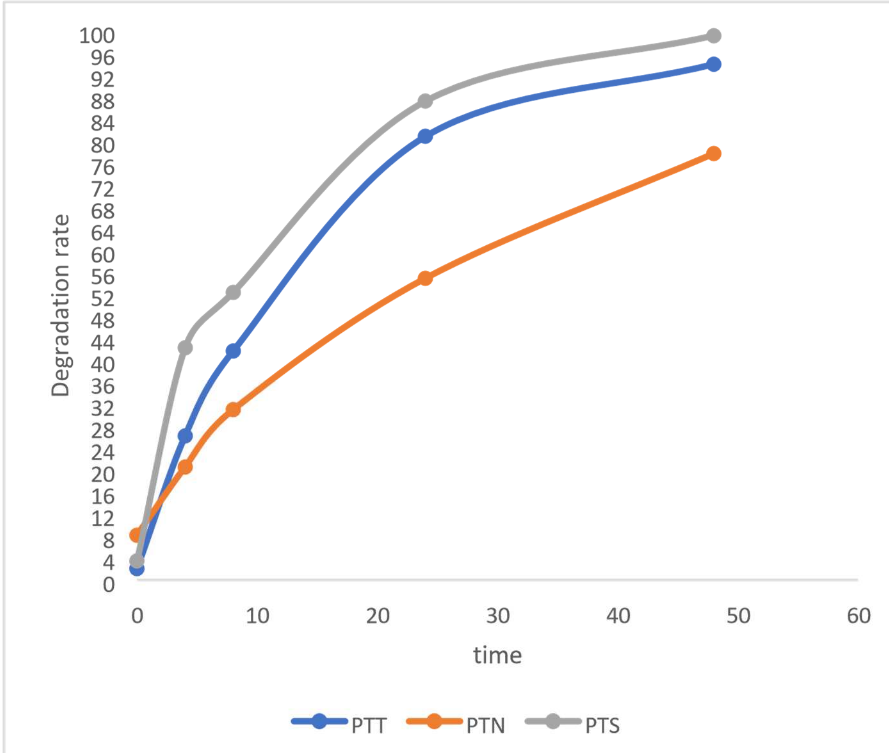


Figure 18. Degradation rate of maize 16 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate; PTS means starch degradation rate.

PTT, and PTS increase of maize 16 were relatively fast (80.87%, 87.29%) in the first 24 hours, and then slowly reach their highest point (94.04%, 99.24%) in the last 24 hours. Whereas, PTN of maize 16 was relatively even till the highest amount (77.74%) at 48-hour.

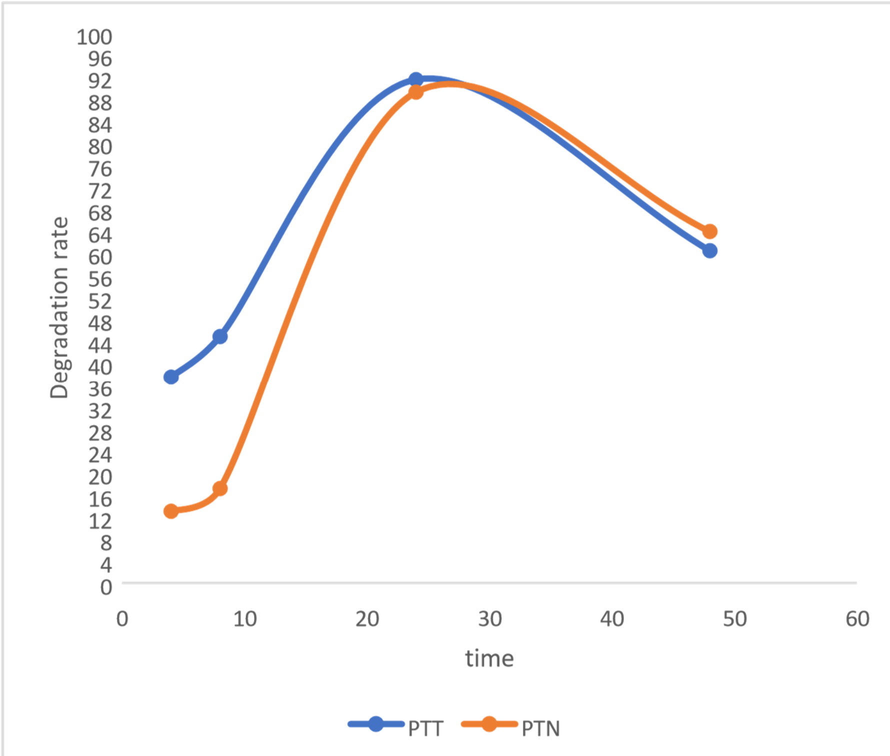


Figure 19. Degradation rate of SBM 1 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate. PTT, and PTN of SBM 1 were sharp in the first 24 hours till get the top (91.50% and 89.20%). Then, both PTT and PTN decreased to 60.42% and 63.90% at 48–hour, respectively.

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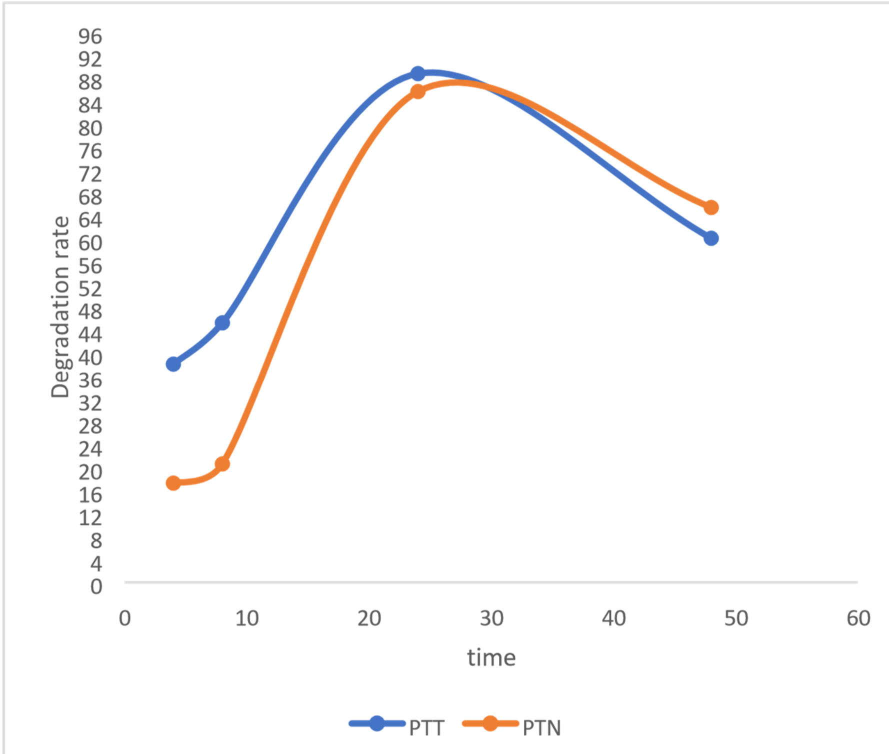

Figure 20. Degradation rate of SBM 3 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate.

PTT, and PTN of SBM 3 were fast in the first 24 hours till get the top (88.77% and 85.65%). Then, both PTT and PTN decreased to 60.08% and 65.46% at 48-hours.

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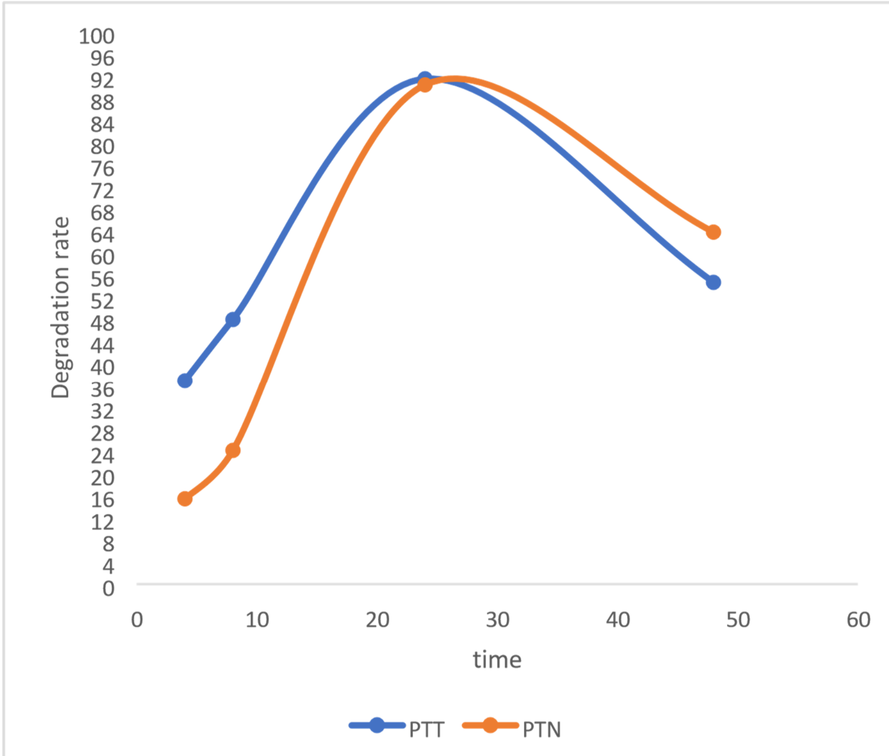

Figure 21. Degradation rate of SBM 12 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate.

PTT, and PTN of SBM 1 were sharp in the first 24 hours till get the top (91.51% and 90.44%). Then, both PTT and PTN decreased to 54.68% and 63.75% at 48-hours.

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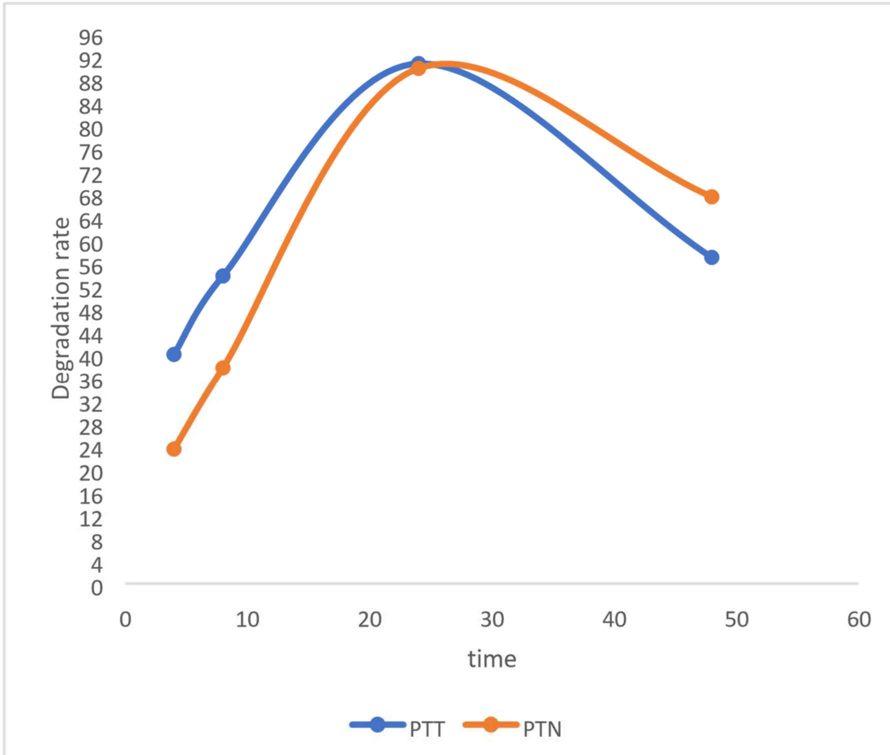

Figure 22. Degradation rate of SBM 16 in rumen; PTT means dry matter degradation rate; PTN means nitrogen degradation rate.

PTT, and PTN of SBM 1 were sharp in the first 24 hours till get the top (90.73% and 89.90%). Then, both PTT and PTN decreased to 56.94% and 67.50% at 48-hour, respectively.

Discussion

Barley 3 which has the lowest Weibull parameters (Figure 8) possess the most fast PTT, PTN and PTS among 4 barley feeds selected for In-Sacco tests, followed by barley 15 with second low Weibull parameters (Figure 11 and 14). And PTT, PTN and PTS of barley 6 were the slowest one (Figure 12), thanks to its high Weibull parameters (Figure 8).

In contrast with extrusion condition of maize 6 (low RPM + cooling), maize 7 was extruded with high RPM without cooling (Table 3). Maize 7 had fast PTT, PTN and PTS, comparing to an overall slow PTT, PTN and PTS of maize 6 within 48 hours' In-Sacco tests (Figure 15 and 16), which may because of a lower physical quality of maize 7 illustrated in PDI and Weibull parameters (Figure 6 and 9). And the highest amount of the three degradability at 48-hour for maize 7 were all higher than those of maize 6 (Figure 15, 16). In general, low RPM with cooling produced pellets with better quality than thigh RPM without cooling. Cooling could promote binding properties of pellets.

PTT, PTN and PTS of maize 16 were faster than that of maize 13 (Figure 17, 18), which might because cooled pellets got higher binding characteristic than pellets without cooling (Table 3) (better physical quality) (Figure 6 and 9), and hence, resistant more in rumen liquids.

According to the Table 3, there were only one difference between these two diets that low RPM was applied in the process of making SBM1, while high RPM was applied in SBM 3. The highest PTT and PTN of soybean meal 1 were higher than that of soybean meal 3 (Figure 19 and 20). means higher RPM reduced PTT and PTN of soybean meal. Increased extruder die size also decrease total amount of PTT and PTN of soybean meal which were detected between soybean meal 12 and 16 (Figure 21 and 22).

Conclusion

Pellets with higher Weibull parameters are more likely to possess slower degradation rate in rumen. In addition, cooled pellets own better binding properties, thus, lower degradation rate. And more research are required to assess the effect of processing on physical and chemical quality of pelleted feeds for ruminants.

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