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Quality Assessment of Feed Wheat in Ruminant Diets

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Abstract

With adverse growing and harvesting conditions as well as the fluctuation of grain pricing, there have increased supplies of feed wheat used as livestock feed. However, the majority of wheat has been used as feed for poultry and swine, and ruminant producers have been reluctant to use large quantities of wheat because feeding wheat increases the risk of rumen acidosis due to rapid wheat starch digestion in the rumen. To avoid this problem, animal producers often believe that they must limit the amount of wheat in the diet to 50% or less. This chapter summarizes some research findings published in peer reviewed and extension articles on the use of feed wheat in ruminant diets. Substantial variation in physical and chemical composition exists among wheat samples, which are mainly influenced by type of wheat, variety and environmental conditions. Feed values of wheat are largely influenced by its physical properties and nutrient content; however, grain processing as well as its interaction with the physical characteristics is a critical consideration to optimize wheat utilization in ruminant diets. Wheat grain can be fed to animals at higher than typically used in the current livestock industry if proper bunk management and processing are employed.

Keywords: wheat grain, kernel hardness, nutrient content, starch digestion, ruminants, rumen acidosis, digestibility, grain quality

1. Introduction

Wheat is not used traditionally as a feed grain because its milling properties make it desirable for use in breads, pastas and noodles; the milling of wheat produces flour for human use and appreciable quantities of by-products for animal feeds. However, recently, there have been significantly increased supplies of feed wheat used as livestock feed, in particularly in ruminant feeding. The livestock industry is interested in increasing wheat portion in animal

rations because of competitively priced wheat compared with other feed grains. Wheat is high in starch and protein, and low in fiber [1]. Similar to other cereal grains, feed wheat is primarily used a source of energy in the form of carbohydrates. Available energy expressed as either digestible energy or metabolizable energy per unit of dry matter is similar to corn, but higher than other major grains [2]. The majority of wheat has traditionally been used as feed for poultry and swine because the use of large quantities of feed wheat in ruminant rations has a number of concerns and problems. The primary problem appears that wheat starch is highly fermentable and its rate of digestion in the rumen is greater than that of corn and barley grains that increase the risk of rumen acidosis in animals fed high-grain diet [1, 3]. Furthermore, the physical characteristics and nutrient content of wheat can vary considerably due to different types of wheat: soft, hard and durum, and the growing conditions [4]. Therefore, nutrient contents of wheat, variety and growing conditions need to be considered when quality of feed wheat is assessed. In addition, kernel processing is another key factor affecting wheat quality. Whole wheat kernels are poorly digested due to the resistance of the seed coat to attack by rumen microbial or host enzymes. Therefore, wheat grains require processing to break seed coat. The digestibility of wheat can be increased from about 60% if fed whole to over 90% if properly processed. However, attention to processing is crucial for best results when feeding wheat since over processing can result in digestive upset and several factors (kernel hardness and uniformity, and processing methods) can significantly affect the processing results. Finally, level of deoxynivalenol in wheat grain may affect feed value. The deoxynivalenol, commonly referred to as vomitoxin, is a mycotoxin that may be produced in wheat and barley grain infected by Fusarium head blight or scab [5]. Ruminants are generally considered to have more tolerance to Fusarium toxins such as deoxynivalenol than poultry and swine because of the detoxifying potential of rumen microbes. However, little information is available on the effects of deoxynivalenol level in wheat on performance and health of ruminant animals. The levels of deoxynivalenol vary with type of wheat and the tolerance to deoxynivalenol also differs depending on type of animals (dairy versus beef cattle) or production levels [5]. The present review will be focusing on assessing physical and chemical characteristics of wheat, kernel processing and levels of deoxynivalenol related to feeding value for ruminant animals based on the published results.

2. Physical and chemical characteristics of feed wheat

Wheat quality is a complex term, and it depends upon the end-use. For feed wheat, the quality should be associated primarily to energy level and protein content as well as its digestibility in the digestive tract of animals. The feed wheat quality can be assessed with its nutrient content such as content of starch or protein, and physical characteristics like thousand kernel weight, test weight, and kernel hardness which are easily measured and commonly used by commercial feedlots and feed mills to assess the quality of wheat as animal feed. Wheat cultivars can be classified by planting season (Winter and Spring), hardness of the grain (soft and hard), and color (red and white). Winter wheats are winter hardy, so they are planted in the fall. In the spring they resume maturation and are harvested early in the summer. Spring wheats are planted in the spring and harvested late in

the summer. Soft wheat varieties have starchy kernels and less gluten which mill easier than the hard wheats, whereas hard wheats have higher protein and gluten levels than the soft wheat with the hardest wheat is durum.

2.1. Physical characteristics

Test weight, also referred to as volume weight or bulk density, is one of the criteria used to assess the quality and grade of cereal grains. Test weight is a measure of density and it is measured volume of grain expressed as kilograms per hectoliter (kg/hL; **Table 1**). The test weight is easily measured and commonly used by feed mills to assess the quality (energy value) of grain as animal feed. Heavy kernel typically has larger plumper kernels with greater starch and lower fiber concentrations than light weight grain, but there is no consistent relationship between test weight of grain and animal growth performance [6]. The test weight is influenced by genetics, agronomic management and environment conditions. Each kernel is composed of the bran (seed coat), the germ, and the endosperm. The endosperm is primarily comprised of carbohydrates (starch) with protein woven among the starch granules. Starch weighs more than protein, thus the tighter the starch molecules are woven within a kernel, the greater the test weight. The test weight in itself is not a good indicator of feeding value to ruminants. Generally, cattle fed wheat with test weights greater than 70 kg/hL will have similar feed efficiency. However, usually only wheat with low test weight (<70 kg/hL) will be used as feed, and its energy values will be lower and feed efficiency is poorer. Wheat with low test weight may be more difficult to properly process compared to wheat with higher test weight. In general, kernel size is more variable with low test weight grains, making processing more difficult. When the roller is set properly for larger kernels, many small kernels will pass through the rollers unprocessed. When set properly for smaller kernels, many larger kernels will be processed too finely.

Kernel hardness, defined as the resistance of the kernel to fracture, is a critical factor affecting grain processing and product quality for feed wheat. The wheat industry has applied this trait for decades to differentiate grain quality and market classes. Hard wheat kernels require more force to fracture than do soft wheat grains, which is caused by differences in the endosperm starch-protein matrix [7]. Kernel hardness can be measured as a hardness index using a Single Kernel Characterization System [8], milling energy using a Comparamill [9] or by particle size analysis [10]. The particle size analysis is the measurement of particle size after feed processing, and is a commonly used method to evaluate end-use quality [11]. Soft wheat fractures easily with small particle size and limited starch damage, while hard wheat produces larger particles with increased starch damage. Kernel hardness is closely related to

Item	Mean	STD	Min	Max
1000 Kernel weight, g	36.4	2.9	32.7	39.1
Test weight, kg/hL	81.6	2.4	78.1	84.3
Kernel hardness	18.4	12.3	0	35.5

Table 1. Variation with variety of physical characteristics of wheat; kernel hardness was estimated by particle size index, lower number indicates harder kernel.

the wheat process affecting the starch damage, particle size and process quality. The grain hardness is therefore one of the important distinguishing factors in the wheat evaluation for grain quality and plays an important role with regard to the suitability of processing. Kernel hardness is measured on a scale from 0 to 35 with durum variety being the hardest (0) and soft white spring the softest (35) (**Table 1**). The increased kernel hardness is generally associated with a decrease in the rate of starch digestion, likely because the protein protects starch granules from microbial digestion. Kernel hardness could be a particularly important property as hard kernels may be more susceptible to shattering and generating the fine particles that are often associated with rumen acidosis [12] and bloat in ruminants fed high-grain diet [13]. It has been found that ruminant performance is significantly influenced by particle size of the feed consumed, and a negative relationship between feed particle size and rumen dry matter digestibility of grains was reported [14].

2.2. Kernel structure and chemical composition

The major structures of the wheat kernel include the pericarp (seed coat), the endosperm and the germ. The pericarp covers and protects the endosperm, which is composed of starch granules embedded in a protein matrix (about 80% of dry weight). Starch granules in the endosperm vary in size, shape and molecular structure depending on the variety and the environmental conditions of cultivation. All starches are made up of two types of glucose polymers: amylose and amylopectin. Amylose is a linear polymer with α-(1,4) glycosidic linkages and amylopectin is a branched polymer with both α-(1,4) and α-(1,6) linkages. Cereal starches are typically composed of approximately 25% amylose and 75% amylopectin. Starch digestibility in the digestive tract of animals can vary with relative proportion of amylose and amylopectin starch since the digestion of amylose is slower due to lesser accessibility of digestive enzyme compared with amylopectin.

Corn and barley are two mostly used feed grains worldwide in livestock animal rations. Wheat is in general higher in protein (15.4%) than corn (9.7%) and barley (12.9%) and has starch content intermediate (70%) between corn (76%) and barley (58%) as well as lower in fiber than barley (**Table 2**). As a result, wheat has a total digestible nutrient and net energy for gain content that is comparable to corn but higher than that of barley grain [2]. However, owing to the number of different types of wheat, soft, hard and durum, the nutrient content of wheat can vary considerably. For example, on a dry matter basis, the starch content of wheat can range from 62 to 75%, protein from 9 to 19% and neutral detergent fiber from 10 to 18% (**Table 3**). This variation was most pronounced in protein content which presumably reflects the interaction between proteins and starch granules in the endosperm of wheat [15]. The high protein content of wheat may offer advantages in meeting the protein requirements of growing animals, whereas the low fiber content may contribute to its increased propensity to cause rumen acidosis. Because it exist substantial variation in the chemical composition of wheat, there is an interest in developing predictive tools to relate chemical composition to nutritional quality and animal performance [16]. Seifried et al. [17] observed negative correlation of protein content of wheat with ruminal protein degradability (r = −0.51; $P < 0.05$) and negative or positive correlation with some amino acid content. Furthermore, new developments and research in near infrared reflectance spectroscopy may allow accurate and rapid assessment of feed quality characteristics related to utilization and animal performance [18].

Item	Wheat	Barley	Corn	Oats
Organic matter	98.0	97.8	98.5	97.7
Crude protein	15.4	12.9	9.7	12.8
Neutral detergent fiber	13.3	20.5	9.3	24.0
Acid detergent fiber	3.2	6.8	3.3	16.5
Starch	70.3	58.3	75.7	58.1

**Table 2.** Nutrient contents (% of dry matter) of cereal grains.

Item	Mean	STD	Min	Max
Organic matter, %	98.5	0.15	97.1	98.7
Crude protein, %	12.6	2.9	9.3	19.1
Neutral detergent fiber, %	13.3	1.8	8.6	17.9
Acid detergent fiber, %	3.6	0.3	3.3	5.2
Ether extract, %	1.7	0.2	1.2	3.2
Starch, %	69.1	4.7	62.5	75.6

Table 3. Variation with variety of chemical and physical characteristics of wheat.

3. Biological characteristics

Biological characteristics are here referred to as their digestion characteristics in the digestive tract, especially in the rumen. The quality of feed wheat is not only depending on its physical and chemical characteristics, but also depending on its biological characteristics, i.e., its rate of digestion in the rumen and potential digestibility in the total digestive tract. Among cereal grains, wheat has the most rapid rate of starch digestion in the rumen (**Figure 1**), with a rate that is almost twice that of barley and almost four times that of corn, if the grains are processed similarly. Rapid starch digestion in the rumen increases the production rate of fermentation acids, primarily the volatile fatty acids and if these accumulate, subclinical or clinical ruminal acidosis can occur. However, as with other cereal grains, whole wheat kernels are poorly digested owing to the resistance of the seed coat to attack by rumen microorganisms. Low fiber levels and a rapid rate of starch digestion make wheat more difficult to feed than most other cereal grains. The digestion rates of wheat starch vary with both inherent of kernel nature and the kernel processing including processing method used and extent of processing.

The rates of wheat digestion in the rumen are commonly measured either using in vitro or in situ technique [19]. In vitro methodologies that simulate animal digestive tract conditions become vital in developing feed additive products and screening large number of feed samples at the same time. Batch culture is the one most commonly used in vitro techniques in evaluating grain digestion in the rumen [20]. The grains that are tested in batch culture need to be ground or rolled and incubated in fermentation media containing buffer and
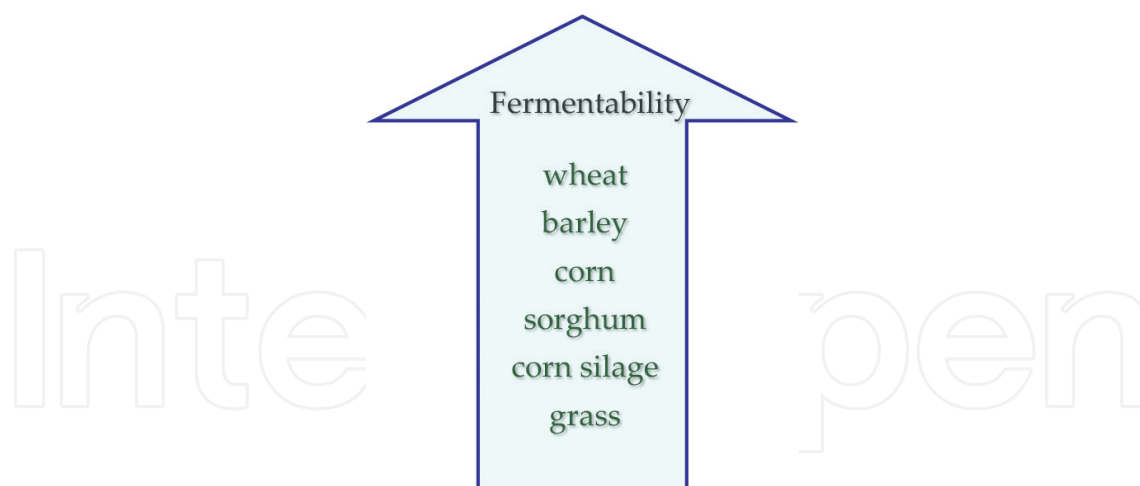
Figure 1. Rumen fermentability of feeds that are commonly fed to ruminants, the highest is wheat grain and lowest is straw.

rumen inoculum at 39°C under anaerobic condition over a period of up to 48 h of incubation. The data that are generated can be used to determine the kinetic parameters of fermentation including the rate and extent of the grain digestion. The in situ techniques have been extensively used for measuring rumen digestion of feeds as well. The dynamic interactions within the rumen are difficult to simulate in vitro, and thus the in situ techniques study digestion within the rumen itself and reduce the need for ruminal simulation. Current nutrition models need for quantitative information on rates and extents of feed digestion in the rumen. The in situ rumen digestion kinetics of grains are measured by filling processed grain in bags and incubated in the rumen via rumen cannula for a period of series times, thus rumen cannulated animals are required.

The rates of wheat dry matter or starch digestion in the rumen varied with type of wheat. McAllister and Sultana [19] measured in situ rumen digestion kinetics of three different wheats (i.e., soft, hard and very hard) with same degree of processing (**Table 4**). These authors found that the rates of dry matter digestion were lowest for durum (4.1%/h) and highest for soft wheat. The digestion rates of wheat in the rumen appeared to be associated with kernel hardness because the kernel hardness can reflect to relative affinity between protein and starch in the endosperm [15]. It suggests that the nature of endosperm protein may influence rumen digestion of wheat. However, Lanzas et al. [21] reported the variation in the fermentation kinetics among wheat samples from various sources, did not attribute to any chemical parameters. Whereas, the study by Lanzas et al. [21] focused mainly on the impact of kernel processing that may confound with chemical effects on the fermentation dynamics of wheat. In fact, it was reported that protein content of wheat was most highly correlated with the rate of wheat digestion ($r^2 = -0.77$) in the study by McAllister and Sultana [19]. It suggests protein characteristics as a factor that influences the digestive properties of wheat in the rumen. This phenomenon could be explained by the nature of wheat protein. Wheat grain has two major proteins, puroindolines A and B that are associated with the fibrillin protein complex on the surface of wheat starch granules which may have a central role in determining the digestion rate of wheat starch [22].

	Kinetics parameters			
Item	a	b	c	ED, %
Dry matter				
Durum	0.123a	0.756	0.041	43.0b
Red spring	0.121a	0.736	0.044	43.2b
Soft red winter	0.097b	0.720	0.062	46.3a
Protein				
Durum	0.081a	0.857	0.035	39.7
Red spring	0.027b	0.837	0.051	41.2
Soft red winter	0.008c	0.868	0.053	41.5
Starch				
Durum	0.173b	0.783	0.039b	48.2b
Red spring	0.243a	0.738	0.043b	55.1a
Soft red winter	0.104c	0.744	0.060a	47.6b

Kinetics of nutrient digestions were estimated using the model: $y = a + b(1 − e^{−c(t−lag)})$, a = soluble fraction; b = slowly digestible fraction; c = fractional digestion rate constant at which b is digested; lag = lag time (h), and t = time of incubation (h). Effective degradability (ED) = $a + bc/(c + k)$, where k is the ruminal flow rate assuming 0.06/h. a,b,c means within a column and within a nutrient, with different letters differ ($P ≤ 0.05$).

Table 4. Variation with variety of in situ rumen digestion kinetics of wheat.

Rumen digestion kinetics of wheat grain also varies with wheat genotypes. Seifried et al. [17] measured in situ rumen digestion kinetics of over 20 wheat samples varying with genotypes and found considerable variation in digestion kinetics of dry matter, protein and starch among wheat genotypes. The digestion kinetics parameters include soluble fraction which is immediately digestible, potential digestible fraction and rate of digestion. The soluble fraction ranged from 21 to 40% for dry matter, 11 to 22% for protein and 25 to 49% for starch; the potential digestible fraction varied between 53 to 71% for dry matter, 51 to 74% for starch and 75 to 89% for protein; and the digestion rate ranged from 29 to 54%/h for dry matter, from 18 to 27%/h for protein and from 38 to 99%/h for starch [17]. The differences in digestion kinetics among genotypes were explained by the variation in the endosperm characteristics [22]. Therefore, these authors concluded that selection of wheat grains with slower digested wheat can be used to shift starch digestion from the rumen to the small intestine. The potential to shift more starch digestion from the rumen to the small intestine by developing lower ruminal digested wheat will be beneficial to reduce risks of rumen acidosis and improve energy efficiency, in particularly for ruminants fed high-grain rations. It is known better energy efficiency with starch digested in the small intestine than in the rumen [23, 24]. However, although improving wheat as a feed grain by selection of slower rate of digestion in the rumen is a wise consideration for wheat breeder, it may be challenging as all types of wheat (soft, hard and durum) examined in the study of McAllister and Sultana [19] exhibited rapid digestion rates than that of corn.

4. Processing wheat

Processing of cereal grains either by grinding, rolling, tempering (i.e., addition of water prior to rolling), steam-rolling (i.e., exposure to steam prior to rolling) or steam flaking (i.e., longer duration of exposure and higher grain temperature) breaks down barriers such as the hull, pericarp and protein matrix and allows microbes access to the starch harbored within endosperm. Furthermore, these processes reduce the particle size of the grain, increasing the surface area available for microbial attachment that these actions increase the rate and extent of starch digestion [25]. Although wheat has the most rapid rate of starch digestion in the rumen, whole wheat kernels are poorly digested in the rumen, and thus need to be properly processed prior to being fed to animals. In fact, excessive processing of wheat results in fine particle sizes that can cause digestive upsets (rumen acidosis, bloat) that in themselves reduce the profitability of animal production. Conversely, under processing of wheat can result in whole kernels in the diet which are not digested by rumen microorganisms contributing to a loss of valuable starch in the manure.

4.1. Definition of degree of processing

Maintaining an optimum degree of processing that maximizes the utilization of wheat grain, and while ensuring animal health is challenging and critical to the livestock industry. The quality of the processed wheat and its particle size can be affected by kernel uniformity, test weight, kernel plumpness, and wheat variety. Kernel uniformity is a major concern for the efficiency of rolling as grain kernels vary in size and shape, making it impossible to achieve optimal processing for all kernels with a single roller setting.

There is no standardized measurement that has been established to assess the degree of grain processing [4]. Coarse, medium and fine are descriptors commonly used in research reports, but these terms are relative, and specific only to the treatments within a given study [26]. As a consequence, medium-processed grain referred to in one study may actually be equivalent to coarsely processed grain in another study. The need for a quantitative measurement of grain processing is evident. In the feed industry, the degree of grain processing has been described using a processing index, which refers to the volume weight (g/L) of grain after processing expressed as the percentage of its volume weight before processing [26]. This index reflects the fact that the more extensively wheat is processed, the finer the particle will be, hence, the lower the volume weight will be, and consequently, the lower the processing index. However, this processing index is influenced by the processing method used. The values generated with dry-rolling can differ substantially, depending on the hardness of wheat kernels, whereas, temper- or steam-rolling make fractured particles that are more likely to adhere together contributing to reduced fines.

4.2. Grinding versus dry-rolling processing

The rate and extent of dry matter digestion varies among wheat sources and with the extent of processing, but seldom have both of these properties been studied in the same experiment. A batch culture study was conducted to assess the effects of wheat grain source and processing
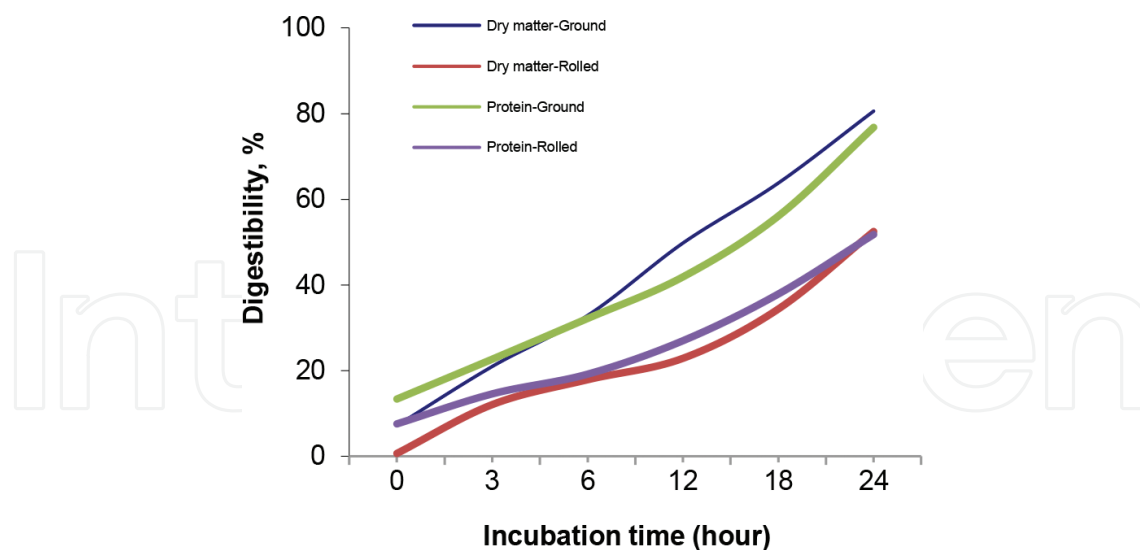
method on dry matter and protein digestibility. Eight wheat samples collected from various sources were either ground through 2-mm sieve or dry-rolled to have processing index of 80%, and incubated for 24 h in batch culture. Dry matter digestibility ranged from 60 to 68% and from 28 to 38%, respectively, for ground and rolled wheat (**Figure 2**). The digestibility of protein varied from 52 to 62% or from 25 to 48%, respectively, for ground and rolled wheat. There was no interaction between wheat source and degree of processing. As expected, the digestibility of dry matter and protein was greater ($P < 0.01$) for ground wheat (64 and 56%) than for rolled wheat (34 and 38%) after 24 h of incubation. In vitro digestibility of dry matter and protein linearly ($P < 0.01$) increased with increasing incubation time and consistently higher ($P < 0.01$) with ground than rolled wheat, whereas no interaction between processing and incubation time was noticed (**Figure 3**). These results showed evident impact of processing method on the extent of wheat digestion in the rumen. The study also demonstrated the variation in the digestive value of commercially available wheat grain and emphasized the need to have an accurate and rapid means of quality assessment at the point of sale.

4.3. Micronization processing

Micronization is a dry-heat process that generates infrared electromagnetic short waves to heat the feedstuff to approximately 110–115°C. It has been used to process grains to increase their utilization [27]. Rapid internal heating is accompanied by a rise in water vapor pressure that the feedstuff is cooked from the inside out and the kernel expands to the point of eversion. This process has been widely used to process grains for livestock consumption [28]. Wang et al. [29] reported that the micronization reduced the in situ dry matter digestibility of both full-fat canola seed and flaxseed. McAllister and Sultana [19] compared three different wheats varying with kernel hardness (i.e., soft, hard and durum) and found that in situ digestibility of dry matter, crude protein and starch were reduced by micronization processing in all three types of wheat. However, the reductions were greater with soft than
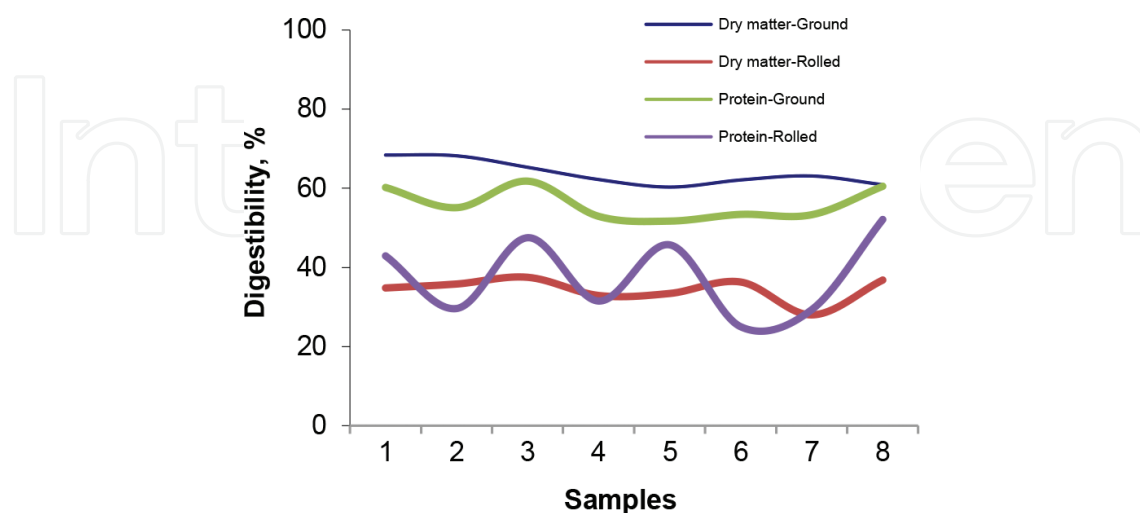
Figure 2. Effects of processing and wheat source on in vitro rumen dry matter and protein digestibility. For dry matter digestibility, SEM = 2.9%, processing ($P < 0.01$), wheat ($P < 0.20$) and process x wheat ($P < 0.45$). For crude protein digestibility, SEM = 4.7%, processing ($P < 0.01$), wheat ($P < 0.01$) and process x wheat ($P < 0.19$).

Figure 3. Effects of processing and incubation time on in vitro rumen dry matter and protein digestibility. For dry matter digestibility, SEM = 1.1%, processing ($P < 0.01$), incubation time ($P < 0.01$) and process x incubation time ($P < 0.68$). For crude protein digestibility, SEM = 2.3%, processing ($P < 0.01$), wheat ($P < 0.01$) and process x wheat ($P < 0.79$).

hard wheat varieties. These authors suggested that the micronization altered the properties of the endosperm in soft wheat that may be more closely resembles that of the harder wheat. The micronization may also change wheat starch that may be related to the nature of the endosperm with alterations of proteins within the fibrillin complex [30]. The reduction of rate and extent of wheat starch digestion using micronization method may provide an effective processing technique to modulate the rate of acid production during the fermentation of wheat in the rumen, thus reduce the severity of rumen acidosis.

4.4. Impact of degree of processing on the feed value of wheat

Recently, a series of experiments using beef cattle were conducted in our laboratory at the Lethbridge Research and Development Centre to determine the maximum level of wheat grain that could be included in finishing cattle rations, the effects of degree of grain processing on wheat utilization and comparison the feeding value between hard versus soft wheat. A study was conducted to compare inclusion of 90% wheat grain processed to processing index of either 75 or 85% on the growth performance of finishing beef cattle [31]. Compared to steers fed dry-rolled wheat with a processing index of 75%, steers fed wheat with a processing index of 85% ate 0.4 kg per day more feed. However, this difference in feed intake did not alter the daily gain or final live weight of steers. As a result, the feed efficiency, expressed as daily per unit of feed consumption, of steers fed wheat with a processing index of 85% was lower than for steers fed wheat with a processing index of 75%. Carcass traits had a trend to be different with higher back fat thickness but lower rib eye area and lower quality grade (% Canada AAA) for steers fed wheat with a processing index of 85% than with a processing index of 75%. The steers fed wheat with a processing index of 85% also had more numbers of liver abscesses. Therefore, a high processing index (85%, i.e., coarsely processed) increased feed consumption but reduced feed efficiency and adversely impacted carcass quality, including saleable meat

yield, back fat thickness, and rib eye area. The greater feed intake but lower feed efficiency for steers fed with coarsely processed wheat may be resulted from an increased an amount of unprocessed whole kernel, in particularly when the uniformity of kernel size is poor and rollers are set to roll the large kernels [32]. The unprocessed wheat kernel is often poorly digested in the digestive tract of cattle because of the seed coat protection from microbial and host enzyme access and its faster passage through the digestive tract as well. Consequently, the digestibility of coarsely processed wheat would be lower and thus animals need to increase feed intake to meet their nutrient requirement. These results appeared to contrast to the general recommendation that wheat should be coarsely processed with processing index of 80 to 85%. The increased feed intake by steers fed wheat with 85% of processing index would contribute to the adverse effects on feed efficiency and risks of liver abscesses. The optimum processing index may depend on starch content of the wheat as well [16].

4.5. Level of wheat in the diet

Wheat grain is generally recommended to be fed to ruminants in combination with more fibrous or slowly fermented feed grains and limited to 40 or 50% of the diet (dry matter basis) because of its rapidly fermentable starch in the rumen. A study using rumen cannulated beef heifers was conducted to compare inclusion level of wheat relative to barley grain in finishing beef cattle rations on measuring rumen pH and fermentation, and digestibility if nutrients in the total digestive tract [33]. In this study wheat was substituted for barley grain at 0, 30, 60, or 90% of the diet dry matter with the remainder of the diet composed of 6% barley silage and 4% vitamin and mineral supplement. All grains were dry-rolled to a processing index of 80%. Increasing wheat level from 30, 60 to 90% in the diet linearly increased the duration of time that rumen pH was under 5.8, but ruminal pH below 5.5 and 5.2 were not affected. These results indicated that subclinical rumen acidosis was not exacerbated with increase of wheat grain up to 90%. Rumen acidosis includes acute acidosis and subacute acidosis (also called subclinical rumen acidosis). The acute acidosis is characterized by sustained low pH (<5.2) without recovery unless intervention is used [12]. The subacute rumen acidosis occurs in repeated bouts where pH is <5.6 for >3 h per day [34], but unlike the situation for acute acidosis, the pH recovers between bouts. The subacute rumen acidosis is a common metabolic disorder in animals fed high-grain diet with rapid fermentation of feed in the rumen and subsequent accumulation of volatile fatty acids (acetate, propionate, butyrate), whereas acute acidosis is caused by accumulation of lactic acid in the rumen and much less happen. Feed intake, animal performance and feed efficiency are adversely impacted when animals suffer from subacute rumen acidosis [12]. However, there was no effect of feeding increasing levels of wheat on rumen fermentation and nutrient digestibility, which suggest that the levels of wheat included in finishing diets of beef cattle could be higher than typically used in the feedlot industry if proper bunk management and processing are employed.

4.6. Impact of wheat type on feed value

Grain hardness is a trait that has been used for decades by the wheat industry to differentiate quality and market classes, and it is characterized as the resistance of the kernel to fracture [35].

The differences in kernel hardness are the result of differences in affinity of starch and protein within endosperm, higher affinity decreases both the rate and extent of starch digestion in the rumen [36]. Although the endosperm within different wheat types differs in hardness, all wheat types are digested rapidly in the rumen. As a result, the information on the rate and extent to which hardness influences the site and extent of starch digestion in wheat is scarce. Soft wheat generally exhibits a faster rate of digestion than hard wheat in the rumen [3, 19]. However, this relationship is also dependent on the processing method used or the degree of wheat processing [31]. The hard wheat kernel may be more susceptible to shattering and generating the fine particles that are readily fermentable in the rumen [37]. Swan et al. [22] reported that starch granules from soft wheat appeared even more resistant to rumen digestion than the starch granules from hard wheat because of greater damage to the surface of starch granules in hard wheat after cracking using a mill. Recently, we conducted a study using rumen cannulated beef heifers fed either soft or hard wheat-based rations [3], there were no differences in the rumen pH and rumen acid concentrations between beef heifers fed soft or hard wheat. The lack of differences between soft and hard wheats can be explained by the fact that wheat grain was processed coarsely (i.e., processing index >80%) to avoid digestive upsets. Similarly, a feedlot study using beef steers that were fed soft or hard wheat with the similar wheat processing as did in the study by Yang et al. [3], did not show the differences in feed intake (averaged 11.3 kg dry matter/day), daily weight gain (1.79 kg), feed efficiency (160 g weight gain/kg dry matter intake), and net energy for growth [38]. It concluded that soft and hard wheat exhibited the similar feed value for feeding feedlot beef cattle if the ration is formulated with the same energy level and wheat is processed at the same degree of processing.

5. Deoxynivalenol content in wheat

Deoxynivalenol, commonly referred to as vomitoxin, is a mycotoxin that may be produced in wheat and barley grain infected by Fusarium head blight or scab [39]. The fusarium head blight may infect grain heads when wet weather occurs during the flowering and grain filling stages of plant development. Although the occurrence of fusarium head blight is not necessary to mean that deoxynivalenol is present, a high level of scabby kernels in the harvested grain means deoxynivalenol will likely be present. Levels of deoxynivalenol do not necessarily correlate with levels of physical damage in grain. The impact of deoxynivalenol in feed grains on animal performance and health vary with type of livestock animals. The evident production losses were observed in non-ruminant animals, in particularly swine when vomitoxin-infested grains were fed [40, 41]. Research conducted with vomitoxin-infested barley indicates no apparent problems when fed to growing and finishing cattle or gestating or lactating beef cows [42]. It appears that cattle can tolerate high levels of vomitoxin (21 mg deoxynivalenol/kg wheat) without impacts on performance or health of the cattle [43]. However, exercise caution with wheat or any grain that has gone out of condition or has mold damage. The possibility exists that molds and toxins will impact feeding value through reduced feed acceptance, intake and performance, as well as higher incidence of morbidity, the possibility of abortion in pregnant cattle and, in some cases, even death. Young calves, gestating cows and animals under nutritional stress are most vulnerable [43].

The deoxynivalenol can be measured using several laboratory procedures. The most common method used by the Federal Grain Inspection Service and most grain handling and processing facilities is the immunological-antibody method called Enzyme Linked-Immunosorbent Assay (ELISA) because it is relatively fast and cheap. The gas chromatography-electron capture (GC-EC) analytical method is quantitative and used to calibrate ELISA test kits.

The inability to feed wheat with high levels of deoxynivalenol to be fed to swine and poultry contributes to the lower price of wheat, but the impacts of deoxynivalenol on the feed value of wheat for beef cattle are largely unknown. According to [5], the level of deoxynivalenol in North American wheat ranges from 0.3 to 1.0 mg/kg, however the level of deoxynivalenol measured in specific lots can reach levels of up to 20 mg/kg. The highest deoxynivalenol levels are also usually associated with soft rather than hard wheat [5]. The maximum tolerated deoxynivalenol level by Canadian Food Inspection Agent in diets for swine, young calves, and lactating dairy animals is 1 mg/kg, and 5 mg/kg in diets for cattle and poultry. Ruminants are considered quite resistant to Fusarium toxins such as deoxynivalenol because of the detoxifying potential of rumen microbes. Previous studies have shown that the epoxide group-bearing parent toxin deoxynivalenol is metabolized to de-epoxy-deoxynivalenol [44]. However, little is known about the effects of Fusarium toxins (i.e., deoxynivalenol, fumonisins, trichothecenes, zearalenone) or their metabolites on the activity of rumen microbes and the consequent effect on feed efficiency in ruminant animals.

6. Sprouted, frosted and drought-damaged wheat

Wheat can be priced competitively with other feed grains because of damage from disease, drought, or sprouting. Wet conditions during fall harvesting can cause widespread sprout damage to the grain crop. Physical and chemical characteristics could be different between sprouted grains and non-sprouted grains such as lower text weight and starch content but higher crude protein due to the concentration effect that occurs when starch is expended during the germination process. However, it has been reported that animal performance is similar when consuming sprout-damaged grain versus non-sprouted wheat grain. Rule et al. [45] reported no differences in growth performance or carcass characteristics when comparing sprouted wheat with non-sprouted wheat in finishing rations containing 77% wheat-based concentrate. Reed et al. [46] concluded that sprouted wheat is palatable, digestible sources of nutrients that can be used in beef cattle diets. These authors further indicated that the sprouted wheat should be processed similar to non-sprouted wheat for optimal utilization by the animal. Growth performance and feed efficiency were improved for steers fed diets containing rolled sprouted wheat compared with whole sprouted wheat [46].

Little data is available regarding the feeding value of frosted wheat. However, research conducted in Western Canada with frosted wheat indicates no difference in feeding value of frosted grain, compared with non-frosted grain when it was fed in feedlot rations. Drought-damaged wheat generally has smaller kernels and is lower in starch content than wheat grown without drought stress. Nitrate toxicity should not be a concern with wheat grain. Wheat does not transfer nitrate into the seed during drought stress.

7. Conclusion

Feed values of wheat used in ruminant animal rations can vary substantially, depending on types of wheat, physical, chemical and biological characteristics, kernel processing, level of wheat in rations, kernel uniformity, kernel damage, contamination of deoxynivalenol, etc. Although wheat grain is high in starch and protein, its rapid starch fermentation in the rumen is a great concern on developing rumen acidosis when high proportion of wheat is included in the ruminant diets. Kernel processing including the selection of processing method and manipulation of degree of processing is critical to optimize the wheat utilization in ruminant diets. Type of wheat (soft and hard) and physical characteristics (kernel hardness, kernel uniformity) could interact with quality of processing, thus impact on feed values of wheat. This information will be useful to wheat breeder to develop suitable variety to improve feed value when wheat that fails quality grade for milling is used as livestock feed. Although the limited information is available, the adverse impact on animal growth performance and health is not apparent for feeding cattle with deoxynivalenol contaminated wheat, sprouted wheat or damaged kernels due to frosting and drought stress.

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References

[1] Herrera-Saldana RE, Huber JT, Poore MH. Dry matter, crude protein, and starch degradability of five cereal grains. Journal of Dairy Science. 1990;**73**:2386-2393. DOI: 10.3168/jds. S0022-0302(90)78922-9

[2] National Academies of Sciences, Engineering, and Medicine (NASEM). Nutrient Requirements of Beef Cattle. 8th ed. Washington: The National Academies Press; 2016. 494 p

[3] Yang WZ, Xu L, Zhao YL, Chen LY, McAllister TA. Impact of hard vs. soft wheat and monensin level on rumen acidosis in feedlot heifers. Journal of Animal Science. 2014; **92**:5088-5098. DOI: 10.2527/jas.2014-8092

[4] McAllister TA, Yang WZ, Oba M. Matching processing with grain size. In: Proceedings of the Western Nutrition Conference; Edmonton, Alberta. September 14-15, 2011. pp. 149-163

[5] Bianchini A, Horsley R, Jack MM, Kobielush B, Ryu D, Tittlemier S, Wilson WW, Abbas HK, Abel S, Harrison G, Miller JD, Shier WT, Weaver G. DON occurrence in grains: A North American perspectives. Cereal Food World. 2015;**60**:32-56. DOI: 10.1094/ CFW-60-1-0032

[6] Hunt CW. Factors affecting the feeding quality of barley for ruminants. Animal Feed Science and Technology. 1996;**46**:41-51. DOI: 10.1016/S0377-8401(96)01004-8

[7] Chandra R, Singh SP, Gupta K. Damping studies in fiber-reinforced composites–a review. Composite Structures. 1999;**46**:41-51. DOI: 10.1016/S0263-8223(99)00041-0

[8] Martin CR, Rousser R, Brabec DL. Development of a single kernel wheat characterization system. Transactions of the ASAE. 1993;**36**:1399-1404. DOI: 10.13031/2013.28477

[9] Allison MJ, Cowe IA, Borzucki R, Bruce F, McHale R. Milling energy of barley. Journal of the Institute of Brewing. 1979;**85**:262-264. DOI: 10.1002/j.2050-0416.1979.tb03919.x

[10] American Assoc. of Cereal Chemists (AOAC). Approved Methods of the American Association of Cereal Chemists. St. Paul: American Assoc. of Cereal Chemists; 1983. Method 39-70A

[11] Morris CF, Rose SP. Wheat. In: Henry RJ, Kettlewell PS, editors. Cereal Grain Quality. London: Chapman & Hall; 1996. pp. 3-54. DOI: 10.1007/978-94-009-1513-8_1

[12] Owens FN, Secrist DS, Hill WJ, Gill DR. Acidosis in cattle: A review. Journal of Animal Science. 1998;**76**:275-286. DOI: 10.2527/1998.761275x

[13] Cheng KJ, McAllister TA, Popp JD, Hristov AN, Mir Z, Shin HT. A review of bloat in feedlot cattle. Journal of Animal Science. 1998;**76**:299-308. DOI: 10.2527/1998.761299x

[14] Galyean ML, Wagner DG, Owens FN. Dry matter and starch disappearance of corn and sorghum as influenced by particle size and processing. Journal of Dairy Science. 1981;**64**:1804-1812. DOI: 10.3168/jds.S0022-0302(81)82769-5

[15] Barlow KK, Buttrose MS, Simmonds DH, Vesk M. The nature of the starch-protein in wheat endosperm. Cereal Chemistry. 1973;**50**:443-454

[16] Koenig KM, Beauchemin KA, Yang WZ. Processing feed grains: Factors affecting the effectiveness of grain processing for beef and dairy cattle production. In: Western Nutrition Conference; Saskatoon. September 24-26, 2013; pp. 62-73

[17] Seifried N, Steingass H, Hoffmann N, Rodehutscord M. In situ starch and crude protein degradation in the rumen and in vitro gas production kinetics of wheat genotypes. Journal of Animal Physiology and Animal Nutrition. 2017;**101**:779-790. DOI: 10.1111/ jpn.12529

[18] Jancewicz LJ, Swift ML, Penner GB, Beauchemin KA, Koenig KM, Chibisa GE, He ML, McKinnon JJ, Yang WZ, McAllister TA. Development of NIRS calibrations to estimate fecal composition and nutrient digestibility in beef cattle. Canadian Journal of Animal Science. 2017;**97**:51-64. DOI: 10.1139/cjas-2016-0107

[19] McAllister TA, Sultana H. Effects of micronization on the in situ and in vitro digestion of cereal grains. Asian-Australasian Journal of Animal Sciences. 2011;**24**:929-939. DOI: 10.5713/ajas.2011.10387

[20] Yang WZ, Oba M, Swift ML, McAllister TA. Short communication: Variation in response to processing, in vitro gas production and fermentation of western Canadian feed barley. Canadian Journal of Animal Science. 2014;**94**:725-729. DOI: 10.1139/CJAS-2014-053

[21] Lanzas C, Fox DG, Pell AN. Digestion kinetics of dried cereal grains. Animal Feed Science and Technology. 2007;**136**:265-280. DOI: 10.1016/j.anifeedsci.2006.09.004

[22] Swan CG, Bowman JG, Martin JM, Giroux MJ. Increased puroindoline levels slow ruminal digestion of wheat (*Triticum aestivum* L.) starch by cattle. Journal of Animal Science. 2006;**84**:641-650. DOI: 10.2527/2006.843641x

[23] McLeod KR, Baldwin RL, Harmon DL, Richards CJ, Rumpler WV. Influence of ruminal and postruminal starch infusion on energy balance in growing steers. In: Chwalibog A, Jakobsen K, editors. Energy Metabolism in Animals. Wageningen, Wageningen Pers; 2001. pp. 385-388

[24] Huntington GB, Harmon DL, Richards DJ. Sites, rates, and limits of starch digestion and glucose metabolism in growing cattle. Journal of Animal Science. 2006;**84**:E14-E24. DOI: 10.2527/2006.8413_supplE14x

[25] McAllister TA, Bae HD, Jones GA, Cheng KJ. Microbial attachment and feed digestion in the rumen. Journal of Animal Science. 1994;**72**:3004-3018. DOI: 10.2527/1994.72113004x

[26] Yang WZ, Beauchemin KA, Rode LM. Effects of barley grain processing on extent of digestion and milk production of lactating cows. Journal of Dairy Science. 2000;**83**:554-568. DOI: 10.3168/jds.S0022-0302(00)74915-0

[27] Mercier C. Effects of various U.S. grain processes on the alteration and in vitro digestibility of starch granule. Feedstuffs. 1971;**43**:33-47

[28] Zollitsch W, Wetscherek W, Lettner F. Use of differently processed full fat soybeans in a diet for pig fattening. Animal Feed Science and Technology. 1993;**41**:237-246. DOI: 10.1016/0377-8401(93)90016-D

[29] Wang Y, McAllister TA, Zobell DR, Pickard MD, Road LM, Mir Z, Cheng KJ. The effect of micronization of full-fat canola seed on digestion in the rumen and total tract of dairy cows. Canadian Journal of Animal Science. 1997;**77**:431-440. DOI: 10.4141/A96-113

[30] White GA, Doucet FJ, Hill SE, Wiseman J. Physicochemical changes to starch granules during micronisation and extrusion processing of wheat, and their implications for starch digestibility in the newly weaned piglet. Animal. 2008;**2**:1312-1323. DOI: 10.1017/S1751731108002553

[31] Moya D, He ML, Jin L, Wang Y, Penner GB, Schwartzkopf-Genswein KS, McAllister TA. Effect of grain type and processing index on growth performance, carcass quality, feeding behavior, and stress response of feedlot steers. Journal of Animal Science. 2015;**93**:3091-3100. DOI: 10.2527/jas.2014-8680

[32] Zhao YL, Yan SM, He ZX, Anele UY, Swift ML, McAllister TA, Yang WZ. Effects of volume weight, processing method and processing index of barley grain on in situ digestibility of dry matter and starch in beef heifers. Animal Feed Science and Technology. 2015;**199**:93-103. DOI: 10.1016/j.anifeedsci.2014.11.005

[33] He ML, Long J, Wang Y, Penner G, McAllister TA. Effect of replacing barley with wheat grain in finishing feedlot diets on nutrient digestibility, rumen fermentation, bacterial communities and plasma metabolites in beef steers. Livestock Science. 2015;**176**:104-110. DOI: 10.1016/j.livsci.2015.03.024

[34] Plaizier JC, Krause DO, Gozho GN, McBride BW. Subacute ruminal acidosis in dairy cows: The physiological causes, incidence and consequences. The Veterinary Journal. 2008;**176**:21-31. DOI: 10.1016/j.tvjl.2007.12.016

[35] Anjum FM, Walker CE. Review on the significance of starch and protein to wheat kernel hardness. Journal of the Science of Food and Agriculture. 1991;**56**:1-13. DOI: 10.1002/jsfa.2740560102

[36] McAllister TA, Rode LM, Major DJ, Cheng KJ, Buchanan-Smith JG. Effect of ruminal microbial colonization on cereal, grain digestion. Canadian Journal of Animal Science. 1990;**70**:571-579. DOI: 10.4141/cjas90-069

[37] Varner LW, Woods W. Influence of wheat variety upon in vitro and in vivo lactate levels. Journal of Animal Science. 1975;**41**:900-905. DOI: 10.2527/jas1975.413900x

[38] Xu L, He ML, Liang RF, McAllister TA, Yang WZ. Effects of grain source and monensin level on growth performance, carcass traits and fatty acid profile in feedlot beef steers. Animal Feed Science and Technology. 2014;**198**:141-150. DOI: 10.1016/j.anifeedsci.2014.10.015

[39] Streit E, Naehrer K, Rodrigues I, Schatzmay G. Mycotoxin occurrence in feed and feed raw materials worldwide: Long-term analysis with special focus on Europe and Asia. Journal of the Science of Food and Agriculture. 2013;**93**:2892-2899. DOI: 10.1002/jsfa.6225

[40] Dıaz-Llano G, Smith TK. Effects of feeding grains naturally contaminated with Fusarium mycotoxins with and without a polymeric glucomannan mycotoxin adsorbent on reproductive performance and serum chemistry of pregnant gilts. Journal of Animal Science. 2006;**84**:2361-2366. DOI: 10.2527/jas.2005-699

[41] Frobose HL, Stephenson EW, Tokach MD, DeRouchey JM, Woodworth JC, Dritz SS, Goodband RD. Effects of potential detoxifying agents on growth performance and deoxynivalenol (DON) urinary balance characteristics of nursery pigs fed DON-contaminated wheat. Journal of Animal Science. 2017;**95**:327-337. DOI: 10.2527/jas2016.0664

[42] Ingalls JR. Influence of deoxynivalenol on feed consumption by dairy cows. Animal Feed Science and Technology. 1996;**60**:297-300. DOI: 10.1016/0377-8401(96)00984-4 60

[43] Aakre D, Flaskerud G, Hellevang K, Lardy G, McMullen M, Ransom J, Sorenson B, Swenson A. DON (Vomitoxin) in Wheat: Basic Questions and Answers. North Dakota State University; Fargo, North Dakota. September, 2005

[44] Swanson SP, Nicoletti J, Rood HD, Buck WB, Cote LM, Yoshizawa T. Metabolism of three trichothecene mycotoxins, T-2 toxin, diacetoxyscirpenol and deoxynivalenol, by bovine rumen microorganisms. Journal of Chromatography B: Biomedical Sciences and Applications. 1987;**414**:335-342. DOI: 10.1016/0378-4347(87)80058-0

[45] Rule DC, Preston RL, Koes RM, McReynolds WE. Feeding value of sprouted wheat (*Triticum aestivum*) for beef cattle finishing diets. Animal Feed Science and Technology. 1986;**15**:113-121. DOI: 10.1016/0377-8401(86)90018-0

[46] Reed JJ, Bauer ML, Loe ER, Caton JS, Lardy GP. Effects of processing on feeding value of sprouted barley and sprouted durum wheat in growing and finishing diets for beef cattle. The Professional Animal Scientist. 2005;**21**:7-12. DOI: 10.15232/S1080-7446(15)31159-1