Barley Grain for Postmodern Ruminants: A Treasure or a Tragedy

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Abstract: Barley grain (BG, *Hordeum vulgare* L.) is characterized by its fibrous coat, ß-glucans and simply-arranged and less concentrated starch granules. With about 150 million metric tones world annual BG yield, European Union, Canada, US and Australia are among major BG producers and exporters. World production of BG is about 30% of that of Corn Grain (CG). The average BG is the third most readily degradable of cereals subsequent to oats and wheat. The average starch content in BG and CG are respectively 570 g kg^{-1} and 720 g kg^{-1} with crude protein of 115 g vs. 88 g kg^{-1} of DM. Besides greater protein, BG is more concentrated in methionine, lysine, cysteine and tryptophan compared to CG. Due to its greater rumen starch fermentation relative to ground CG (e.g., 850 vs. 500 g kg^{-1}), BG provides more rapidly synchronous energy and nitrogen release than CG which may improve substrate incorporation efficiency into microbial mass. Hence, rumen fermentation may achieve its optimum potentials in Volatile Fatty Acids (VFA) and microbial mass yields more realistically with feeding BG vs. CG. Consequently, BG feeding can reduce needs for supplemental protected escape proteins. However, such exceptionalities in fueling microbial metabolism remain until rumen acidity is maintained within optimal ranges (e.g., >5.8-6.0) below which microbial maintenance requirements increase and as such mass yields decrease. In addition, microbial endotoxines release causes proinflammatory responses that weaken immune function and depress productive longevity. Thus, mismanagement in processing and feeding BG can easily make a debacle from the pearl of cereals. The paper delineates comparisons in physical and chemical structures between BG and other common cereals as well as differences in their response to processing techniques and feeding strategies. In so, doing, nutritional uniquenesses and conversely, disturbing consequences of improper BG feeding to ruminants are underscored. Steam-rolling may improve feed efficiency and post-rumen starch digestion; however, it may not improve production and feed intake.

Due to limited BG responses to processing comparing corn, sorghum and wheat, setting more consistent and global standards for feeding and processing should be more feasible for BG than for other cereals. In high-starch diets, optimum feeding of BG reduces requirements for effective small intestinal starch assimilation, subsequently reducing hindgut starch use and fecal nutrient losses. Barley in many ruminant industries is usually less expensive and more available than corn and wheat which are highly demanded by non-ruminants and humans. With its nutritional exclusivities underlined, BG use will be a factual art that will either matchlessly profit or harm rumen microbes, cattle production, farm economics and the environmental.

INTRODUCTION

Barley Grain (BG) is a cereal derived from the annual grass Hordeum Vulgare. Barley (*Hordeum* spp.) is one of the first crops planted and a historic food and medical source of essential nutrients. The multipurpose grain deserves a top place in the farm for livestock and in the kitchen for humans. Similar to oats, barley is rich in soluble fiber and so can lower human blood cholesterol (DRIS, 2007). Hulled or whole barley is the form with greatest benefits, especially in terms of fiber and B vitamins of mainly thiamin. Pearled barley is the common form for human consumption with kernel bran removed (Fig. 1). As a result, the grain has lower Fe, Mn, P and vitamin B_1 levels. However, it is still adequately nutritious and appetizing. Barley flakes are often used to prepare breakfast cereal foods and mixes. Along with Cu, P and Zn, BG is rich in soluble fibers of β-glucans and pectin, potentially helping to lower blood cholesterol and prevent constipation (DRIS, 2007). What can make BG a treasure among cereals is its invaluable place in modern human and livestock diets. Irreplaceable by any other grain in beef and dairy diets for capacious rumen microbial yields, BG products in human diets help to lower risks from cardiovascular complexities (DRIS, 207). This review describes exclusively the world status of BG and highlights major opportunities for its optimum use by rumen microbes, host ruminants, farmers and the environment.

World production and distribution of barley: In a 2007 ranking of cereal crops in the world, barley was fourth both in terms of quantity produced (136 million tons) and in area of cultivation (566,000 km²) (UNFAO). World production of barley in 1994-95 was estimated at 166 Million Metric Tons (MMT) or about 30% of that for corn. Sorghum, oats and rye are relatively minor contributors to total coarse grain production. At 264 MMT the US. is the primary world supplier of coarse grains. Among other important producers are China, the European Union (EU), Russia, India and Brazil (Table 1). The US (1.8 MMT), Japan (1.1 MMT) and Saudi Arabia (0.6 MMT) are the main importer of Canadian barley. Barley makes up 40% of feed grain usage in Canada, equivalent to 7.3 MMT compared to 5.4 MMT for CG. Barley is the primary feed grain used in beef and dairy cattle diets in western Canada. Estimates for 2010-11 indicate 1088 million MMT world production of coarse grains of which the contributions of the US, China and EU-27 are 336, 173 and 139 MMT, respectively (Anonymous, 1998).

During 2004, approximately 2000 kt of barley and wheat grains were used by livestock in Australia, representing 60% of all cereals used. Oats, sorghum and triticale contributed respectively 20, 10 and 10%. About 40% of BG was fed to feedlot cattle, 34% to dairy cows, 20% to pigs, 6% to grazing ruminants and <1% to poultry. Large differences exist among individual barley samples in terms of available energy and animal performance (Boss and Bowman, 2016; Van Barneveld, 2002).

Variability in nutritional value of BG samples: Nutrient composition of BG compared with other cereals is detailed in Table 2. Considerable differences exist in the accessible energy of individual BG samples among different animal species. In an Australian assessment pigs obtained greater energy from BG than other animals (Fig. 2) whereas cattle utilized the least energy from BG. Correlations for the utilizable energy of BG between broilers and other animals were 0.77 for layers, 0.56 for pigs and 0.09 for cattle. The correlation between pigs and cattle was 0.71. These coefficients indicate significant differences among livestock in digestion capacity of individual barleys. Some samples are rather more digestible by ruminants than pigs or poultry and certainly vice versa. Figure 2 shows that sample 1 was almost poorly digested by all animals. The useable energy of sample 4 was low for cattle and pigs but medium for poultry. However, sample 5 had provided low energy to cattle, high energy to poultry and medium energy to pigs. The available energy of sample 17 was higher for cattle, lower for pigs and much lower for poultry. The sample 18 generated more energy for cattle and pigs, low energy for broilers and medium for layers. Such versatilities in energy value of BG originate from differential digestive system and assimilative capacity among livestock and disparities in chemical and physical properties of different grain samples.

Accordingly, assortment measures for barley breeding most suitable for different livestock can be developed. Barleys with low hull and fiber content, fragile

Fig. 1(a-d): Top: Barley varieties of two-rowed and six-rowed. Bottom: whole barley (right), naked or hull-less barley (middle) and pearled barley (left) grains

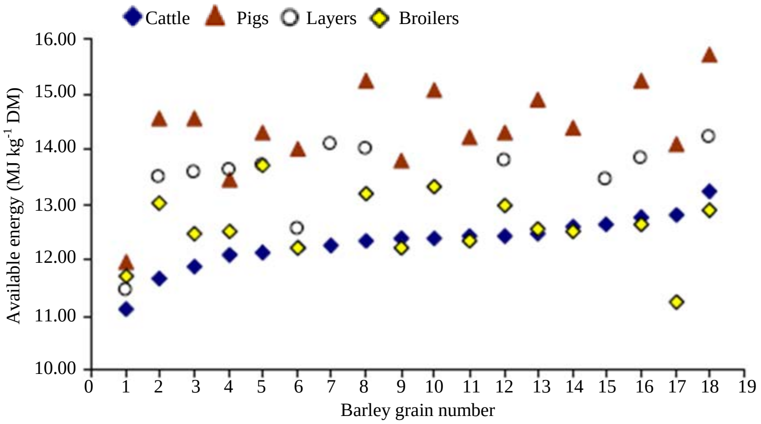

Fig. 2: Available energy for 18 barley samples for livestock fed ad libitum (Adopted from Black *et al*., 2007)

Table 1: Nutrient composition of barley grain comparing other major cereals (g kg^{-1} of DM)

Nutrient (as fed)	Barley	Hull-less barley	Corn	Wheat	Sorghum	Rye
DM	880	880	880	880	880	880
CP	115	132	88	135	110	121
Undegradable CP (g kg^{-1}) CP	280	350	500	250	550	200
NDF	181	120	108	118	161	180
ADF	60	20	30	40	90	100
Starch	570	650	720	770	720	620
Fat	19	20	38	22	29	15
Ash	23	19	14	17	18	19
Lysine	4.3	5.0	2.1	3.5	2.7	4.0
Methionine+Cysteine	4.2	5.6	3.0	5.1	3.0	3.6
Tryptophan	1.8	1.5	0.9	1.5	0.9	1.4
Phosphorous	3.4	3.5	2.6	3.7	2.9	3.2
NE_L, Mcal/kg	1.71	1.75	1.78	1.82	1.62	1.71

Data from Huntington (1994, 1997), Nikkhah *et al*. (2004)

cell walls and thus low soluble arabinoxylans and ß-glucans and rapidly accessible starches are optimal for pigs. For poultry, samples with lower non-starch polysaccharides and thus with lower viscosity and low condensed tannins are greatly needed. For ruminant, on the other hand, cultivars with higher fiber and soluble arabinoxylans and specifically with harder kernels of slower rumen starch degradation rates (i.e., low acidosis index) are preferred. Near Infrared Reflectance Spectroscopy (NIRS) calibrations are developed for premium grains of livestock program to predict available energy intakes for poultry, pigs with other grain

Table 2: Top world barley producers (million metric tons)

Countries	Values
European Union (EU)	57.7
Russia	15.7
Canada	11.8
Spain	11.7
Germany	11.0
France	9.5
Turkey	7.4
Ukraine	6.0
Australia	5.9
United Kingdom	5.1
United States	4.6
World Total	15.3

UN Food and Agriculture Organization (FAO, 2008) EU includes Spain, Germany, France and UK

Table 3: Average density and nutrient composition of North Dakota two-rowed and six-rowed barley varieties

Nutrient	Two-row	Six-row
Test weight, kg/bushel	48.4	46.2
DM (g kg^{-1})	908	906
NDF (g kg^{-1})	200	214
ADF (g kg^{-1})	62	66
CP (g kg^{-1})	129	124
Calcium (g kg^{-1})	0.5	0.5
Phosphorous (g kg^{-1})	3.6	3.7
Magnesium (g kg^{-1})	1.4	1.4
Potassium (g kg^{-1})	5.4	5.4

Data from regional information during 1991-1997 (Lardy and Bauer, 2010)

properties such as acidosis index for ruminants. These calibrations help to monitor grains within barley breeding programs and to assign most suitable grain samples to different livestock.

Little differences exist in nutrient composition between some barley varieties, such as two-rowed and six-rowed barleys (Table 3). Nevertheless, there are considerable dissimilarities, particularly in starch content and rumen fermentation patterns, between some barley cultivars (Silveira *et al*., 2007). Knowledge to such differences can help farmers select and feed most appropriate varieties that optimize production without major compromises for rumen and host animal health.

Barley grain nutritional and chemical properties: A cup (e.g., 237 mL) of cooked pearled barley contains 193 calories while the whole hulled grains have 270 calories with the same protein amount as a cup of milk. The respective protein, carbohydrates and fiber contents are 4, 44 and 9 g for pearled barley and 7, 59 and 14 g for whole hulled BG.

Dehulled barley or covered barley is used after removing the inedible, fibrous outer hull of the kernel. Dehulled barley still possesses bran and germ and is a nutritious and trendy food. Pearl barley or pearled barley is dehulled barley that is steam-processed to eliminate the bran. Dehulled barley can as well be processed to produce barley flour, flakes and grits. The pearled form possesses 17 mg Ca, 85 mg P, 246 mg k, whilst the values are 26, 230 and 230 mg for whole BG. The differences are obvious. The whole BG is higher in almost all nutrients except Na, Thiamin and Niacin, in which the pearled barley is slightly richer. The nutrients lacking in BG include vitamin C and vitamin B_{12}. A half cup of uncooked pearled barley contains 352 calories, 1.2 g total fat, 0.2 g saturated fat, 0.1 g monounsaturated fat, 0.6 g polyunsaturated fat, 16 g fiber, 10 g protein, 78 g carbohydrate, 9 mg Na, 0.2 mg thiamin, 4.6 mg niacin, 0.3 mg Vitamin B6, 2.5 mg Fe, 79 mg Mg, 1.3 mg Mn, 221 mg P, 38 mcg Se and 2.1 mg Zn. According to recent findings, whole grain barley can regulate blood sugar and decrease blood glucose response to meals during 10 h post-feeding, compared to white or even whole-grain wheat with similar glycemic index (DIRS, 2007). Such beneficial effects are in part attributable to hindgut indigestible carbohydrates fermentation.

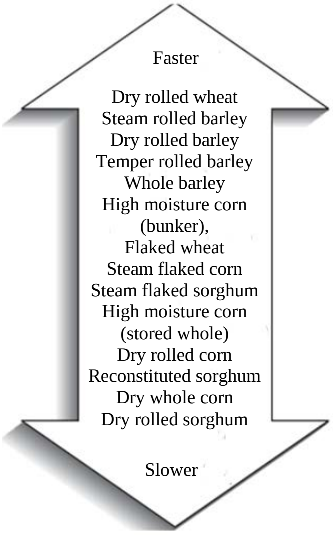

Fig. 3: Rumen dynamics of processed BG comparing other cereals. Barley grain is on the top side with fastest degradation rates, only preceded by dry-rolled wheat

As presented in Table 4, BG is the richest in K and vitamin-A among cereals. Barley grain contains 5 times more Ca than oats. With twice as much Cu and Mo and >twice as much Mn, BG is superior to CG. Also richer in S by about 30%, BG is however poorer in Zn compared to CG (Fig. 3). Besides greater protein (e.g., 12 vs. 9%), BG is richer in Met, Lys, Cys and Trp than CG. These properties support the major contribution of BG to meeting energy requirements of high-producing ruminants.

Antinutritional factors also occur in BG. A mycotoxin that grows on barley plant and BG is Deoxynivalenol (DON) known as vomitoxin. It is generated by fusarium that grows on moist barley and

Table 4: Mineral and vitamin contents of the major global cereal grains (g/kg of DM)

Nutrient	Barley	Corn	Wheat	Oats	Sorghum
Calcium	0.5	0.3	0.5	0.1	0.4
Phosphorous	3.5	3.2	4.4	4.1	3.4
Potassium	5.7	4.4	4.0	5.1	4.4
Magnesium	1.2	1.2	1.3	1.6	1.7
Sodium	0.1	0.1	0.1	0.2	0.1
Sulfur	1.5	1.1	1.4	2.1	1.4
Copper (ppm)	5.3	2.5	6.5	8.6	4.7
Iron (ppm)	59.5	54.5	45.1	94.1	80.8
Manganese (ppm)	18.3	7.9	36.6	40.3	15.4
Selenium (ppm)	-	0.14	0.05	0.24	0.46
Zinc (ppm)	13.0	24.2	38.1	40.8	1.0
Cobalt (ppm)	0.35	-	-	0.06	-
Molybdenum (ppm)	1.16	0.60	0.12	1.70	-
Vit A, 1000 IU kg^{-1}	3.8	1.0	0.0	0.2	0.05
Vit E, 1000 IU kg^{-1}	26.2	25.0	14.4	15.0	12.0

NRC (2001, 1996)

wheat under humid conditions and in early heading stages. Nonetheless, evidence suggests no vomitoxin effects on feed intake or milk production of cows (Anderson and Schroeder, 2010; Ingalls, 2002). Cows fed overly high amounts of rapidly fermentable starches as BG are very likely to experience periods of Subacute Rumen Acidosis (SARA) which can increase laminitis (Kelly and Leaver, 2010; Nocek, 1997). High levels of ground cereals are thought to predispose cattle to lameness, resulting from SARA. However, recent evidence suggests that with optimal BG inclusion in dairy rations, ground BG can be as palatable and effectively utilizable as steam-processed BG (Nikkhah *et al*., 2004). Thus, it is not virtually grinding that is problematic but rather both moderately and very high dietary levels of BG. The latter introduces rumen and cow metabolism and immunity with serious challenges (Emmanuel *et al*., 2008; Nikkhah *et al*., 2004).

Feeding ruminants BG with other grains and enzymes: Apart from processing as high as >900 g kg^{-1} barley starch and as low as <500 g kg^{-1} of corn starch are digested in the rumen (Nikkhah *et al*., 2004; Waldo, 201; Theurer, 1986). Mixtures of grains offer advantages in beef and dairy cattle feeding (Lehmann and Meeske, 2006). This is due to more versatile extent and rate of rumen starch fermentation (Bock *et al*., 2016; Kreikemeier *et al*., 1987). Such blends can alleviate SARA usually occurring by feeding highly fermentable grains and mainly BG (Fig. 4). Blending barley and corn grains preflaking has been found feasible without compromising cattle performance (Zinn and Barajas, 1997). Recently in grazing Jersey cows, BG replacing 50% of CG in concentrates increased milk production, suggesting a positive additive effect (Lehmann and Meeske, 2006). Adding xylanase-based fibrolytic enzymes to high concentrate (e.g., 950 g BG kg^{-1} of diet DM) diets has improved feed efficiency without affecting daily gain and feed intake (Beauchemin *et al*., 1997).

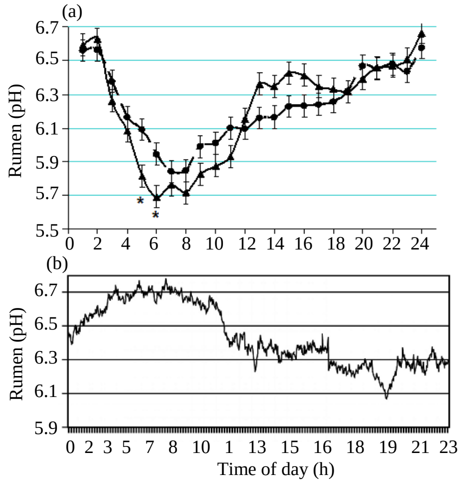

Fig. 4(a, b): Top: post-feeding rumen pH patterns in 8 cows fed once daily at either 0900 or 2100 h (Nikkhah *et al*., 2004). Bottom: Minute-based averaged continuous 24-h rumen pH measured by an indwelling pH meter in 16 Holstein dairy cows through 6 weeks of lactation. Feed delivered at 0700 and 1300 h (Duffield *et al*., 2004)

Processing BG for beef and dairy cattle: Grain processing can considerably affect rate, extent and site of protein, fiber and starch digestion (Mathison, 2002) (Fig. 3). Due to inability to properly chew and break the husky kernels, whole BG cannot be fed to large ruminants (Valentine and Wickes, 1980). As a result, BG is commonly either rolled, tempered, steam-flaked, ground, roasted or pelleted (Nikkhah, 2014). Tempering, dry-rolling and steam-rolling are common in North America, Australia and Western Europe (Yang *et al*., 2000; Zinn, 1993) while grinding is the most common and preferred technique to process barley for dairy cows in Iran (Nikkhah *et al*., 2004). Tempering is adding water to increase BG moisture up to 180-200 g kg^{-1} for 24 h pre-rolling. Tempering results in fewer small particles compared to dry rolling (Anderson and Schroeder, 2010). Consequently, starch fermentation rate can decrease and sharply-reduced rumen pH and SARA can be avoided or minimized. As such, tempered BG compared to dry rolled BG improved milk yield by 5%, feed efficiency by 10% and apparent DM digestibility by 6%, NDF 15%, ADF 12%, CP 10% and starch by 4% (Christen *et al*., 2010).

Aggressive and high-pressure heat exposure may reduce BG degradation rate (Ljokjel *et al*., 2003). The reduction is important *in vivo*, especially shortly post-feeding when rumen fermentation peaks. Such moderated degradation rate of BG can improve feed efficiency likely via. increased rumen pH and attenuated SARA during fermentation peaks and increased small intestinal escape or partially-digested starch assimilation (Owens *et al*., 1997). Likewise, flame roasting of BG reduced DM and CP rumen degradation despite no effects on total tract digestibilities (McNiven *et al*., 2003). Feeding roasted BG instead of rolled BG twice daily improved milk yield by 3 kg (McNiven *et al*., 2003).

Feeding yearling steers steam-rolled BG instead of high moisture CG in diets with 650 g grain, 160 g forage, 50 g supplement and 140 g potato residues/kg of diet DM did not affect weight gain but decreased DM intake cubically with increased BG (Duncan *et al*., 2013). In finishing cattle diets with 840 g grain, 120 g alfalfa haylage and 40 g supplement/kg of diet DM, dry-rolled BG and CG affected cattle performance, carcass properties and digestive disorders similarly (Gray and Stallknecht, 1988). Replacing dry-rolled CG with tempered BG with 60 g kg^{-1} forage in finishing diets, Combs and Hinman (1988) found no responses in feed intake and weight gain to different ratios of the two grains. Although, steers fed the blend of the grains had greater carcass weights, yield grades and 12th rib fat than did steers on single grains. These data suggest more efficient use of BG when it is combined with CG compared to when it is fed alone.

Steam-rolled BG was similar to steam-rolled CG in affecting milk yield of lactating cows (Beauchemin and Rode, 1997; Beauchemin *et al*., 2010). The same occurred in complete mixed cubed diets (DePeters and Taylor, 2010) with dry-rolled BG vs. ground CG (Grings *et al*., 1992) or with both in ground forms (Park, 1988; Rode and Satter, 2010). Dry-rolled BG could successfully replace the high-energy dry-rolled sorghum with respect to milk yield and tended to improve feed efficiency (Santos *et al*., 2010). Dry rolled BG and ground CG with and without bovine Somatotropin (bST) similarly affected bST response, milk production, milk somatic cell count and cow body weight (Eisenbeisz *et al*., 2010). However, slight declines in milk production and feed intake were reported for BG vs. CG fed cattle (Casper and Schingoethe, 1989) which might be due to reduced rumen pH and depressed fiber digestion and milk production under suboptimal rumen conditions. With prudent and more moderate uses in dairy diets, ground BG has proved superior to ground broomcorn and similar to steam-flaked broomcorn (Nikkhah *et al*., 2004).

Based on NRC recommendations, dairy diets should contain 25-28% NDF, 75% of which must be supplied by forages. This requirement is for adequate chewing and healthy rumen function, to prevent milk fat depression and laminitis (Nocek, 1997). Barley grain based diets usually supply greater concentrate NDF than CG based diets. However, due to inadequate effectiveness of fiber in BG in stimulating chewing and ensalivation and because of the greater degradation rate of BG than CG, BG fed cows may require greater amount of effective forage fiber than CG fed cows (Beauchemin and Rode, 1997). Cellulolytic bacteria numbers are maintained functionally normal in rumen pH ranges of >6.0-6.2. Thus, as long as BG feeding does not lower rumen pH below that range, BG can replace large portions of the more expensive CG in lactation diets. Recent findings compellingly suggest that finely ground BG is no inferior to expensively steam-rolled BG if dietary BG inclusion rate is kept sensibly moderate at $\leq$300 g kg^{-1} of diet DM (Nikkhah *et al*., 2004; Sadri *et al*., 2007; Soltani *et al*., 2009). At 350 g kg^{-1} BG, except some modest improvement in feed efficiency, milk production and DM intake were similar for ground vs. steam-rolled BG (Nikkhah, 2014). On the other hand, overfeeding BG is an easiest shortcut to SARA and triggered proinflammatory responses that depress immunity (Emmanuel *et al*., 2008). Thus, whilst is BG a matchless source of rapidly released energy for optimal rumen microbial mass and VFA yields, its dietary use must be an art to allow such benefits to optimize ruminant production and health concomitantly (Krause and Oetzel, 2006; Nikkhah, 2014; Nocek and Tamminga, 1991). Whilst being the pearl of cereals indispensable for persistent peaks in beef and dairy production, improper feeding of no other grain can be as much economically and environmentally devastating as BG.

Rumen physiology and health in relation to BG feeding: As illustrated in Fig. 4 and 5, rumen fermentation possesses diurnal patterns in pH and VFA concentrations that depend highly on feed deliveries. As such, most dramatic fluctuations occur shortly around feeding when rumen receives considerable substrates. A common challenge in optimizing rumen fermentation is the asynchrony in fermentation rate and patterns of protein and energy (Fig. 5). Proteins are usually degraded more rapidly than carbohydrates upon feeding. These mean that maximum rumen energetic potential is reached

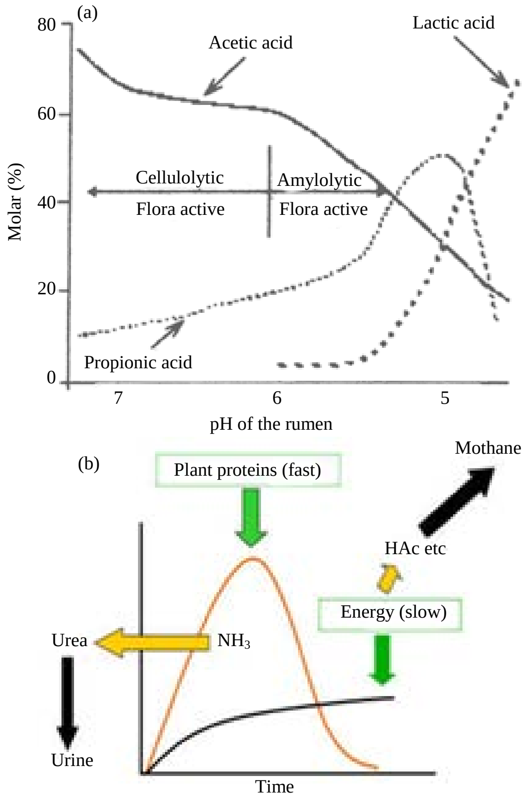

Fig. 5(a, b): Top: Relationships among rumen pH,) differential volatile fatty acids (VFA) and lactate concentrations and cellulolyric versus amylolytic bacteria prevalence Bottom: The naturally slower rate of dietary energy than protein fermentation

when proteins have already passed through maximum degradations. Thus, nitrogen and energy wastage as ammonia, methane and carbon dioxide will occur. In such scenarios, the matchless BG with its rapid starch degradation can offer unique solutions (Nikkhah, 2014). Feeding BG based diets is expected to alter fermentation patterns of the Fig. 5 (bottom) such that an earlier energy fermentation peak can occur to reduce nutrient asynchronies and improve microbial substrate assimilation and incorporation. Such shifted fermentation patterns will improve energy efficiency and milk biosynthesis and will reduce methane, ammonia and urinary N (Nikkhah, 2014). However, BG must not be overfed. Under rapid fermentation of even moderately overfed barley starch, the rumen pH will drop and persist <5.5 where SARA will durably occur. Dramatic and persistent acidic environment will coexist with and further result in, increased lactic acid (LA) production. Since LA has a lower pKa than VFA (3.8 vs. 4.8), at a given low pH greater proportions of LA will occur in undissociated forms (Krause and Oetzel, 2006). The accumulation of the latter plus that of VFA will progressively interfere with efficient acids absorption, thus exacerbating the problem. In such acidic conditions, microbial mass yield will noticeably decrease and bacteria will lyse, leading to endotoxins release and triggered systemic proinflammatory responses (Emmanuel *et al*., 2008; Stones, 2004). That is certainly a consequence of using too much of a good entity or BG.

CONCLUSION

Barley grain (BG, *Hordeum vulgare L.*) is known for its fibrous coat, ß-glucans and less complicated starch granules. With about 150 million metric tones annual yield, BG world production is about 30% of that of Corn Grain (CG). The average BG is considered rapidly degradable in the rumen with about 570 g starch per kg of DM compared to 720 g in CG and 770 g in wheat grain. Besides greater protein, BG is richer in Met, Lys, Cys and Trp, compared with CG. Owing to the more rapid and extensive rumen starch and N fermentation of BG than ground CG (e.g., 850 vs. 500 g kg^{-1}), BG may provide better nutrient synchrony which can improve microbial substrate integration efficiency.

IMPLICATIONS

Accordingly, proper BG feeding management may reduce requirements for the expensive undegradable proteins. However with improper feeding and processing, no other grain can as easily as BG reduce rumen pH, elongate SARA, cause microbial endotoxin release and suppress immunity. Because of lower BG responses to processing than CG, sorghum and wheat grains, establishing consistent and global standards for feeding and processing could be more viable for BG than for other cereals. From a global standpoint, BG is usually less expensive and less demanded by non-ruminants and humans, comparing corn and wheat. Thus with its nutritional exclusivities underlined, BG use in ruminant diets must be a factual art that will matchlessly profit or impair rumen fermentation, cattle production and farm economics.

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