Carcass Traits and the Quality of Meat from Cattle Finished on Diets Containing Barley

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ABSTRACT : Research on barley as an animal feed started some decades ago but its utilization in animal production has been limited to countries that grow the crop extensively. Corn has been the most popular energy feed in cattle rations, but the high price of corn and the decreased supply of the grain in the international market have shifted the focus of the animal industry to other cereal crops like barley. Studies have indicated that growth performance of cattle fed barley-based diets has been generally comparable with that of those fed corn-based diets, while results for cattle fed whole-crop barley silage have been more variable. Beef from cattle fed barley-based diets has proved to be as tender and as acceptable for taste as that from animals fed other finishing diets when compared at similar growth rates and degree of finish. The barley crop contains good amounts of antioxidants like 2"-O-GIV isovitexin, so from the meat science point of view, a desirable influence of these components on meat quality traits such as meat color, oxidative stability and sensory characteristics might be expected. Furthermore, the effect of the distinctive fatty acid profile of beef fed from whole-crop barley silage on sensory traits is also an important subject to be elucidated. A lot of studies have been made over past decades on the effect of barley, and especially whole crop barley, on beef cattle production and meat quality, but these data have not been collectively documented in a review. The current review re-visits previous literature to underline the effects of barley in the diet on beef quality traits and to identify areas for further studies. (**Key Words** : Barley Grains, Whole-crop Barley Silage, Carcass Characteristics, Meat Quality, Cattle)

INTRODUCTION

Barley is one of the most important cereal crops in most parts of the world. It is one of the most ancient cultivated crops but its origin is not known (Magness et al., 1971). Barley is used both as human food and animal feed. It is eaten as grain just like rice in some parts of the world like the Middle East, and barley grains are also used to produce flour, breakfast cereals, malt sugar, alcoholic beverages and as an ingredient in soups. Recent research on barley grain and barley grass have unveiled a wealth of nutrients and compounds that play important roles in maintaining good health in humans (Ragaee et al., 2006). These have increased the utilization of barley either as a regular food item or as a health supplement.

In animal feeding, barley is commonly used to substitute for corn. Limited amounts are used in feeding monogastrics because of its high fiber content. However, similar growth performances were observed between pigs fed corn- and hulless barley-based diets (Wu et al., 2000). Yin et al. (2001) noted improved nutrient digestibility of barley grains with the addition of enzymes like β-glucanase, xylanase and protease. Several studies have also indicated that carcass characteristics are similar between corn-fed and barley-fed pigs, however, variations have been observed in some meat quality traits (Nelson et al., 2000; Boles et al., 2004; Boles et al., 2005; Wismer et al., 2008). In dairy cattle, conflicting results have been obtained on the effect of barley on milk yield and milk composition. The variability in experimental results could be attributed to the inclusion level of barley in the diet and the maturity of the barley crop used as silage (Ahvenjarvi et al., 2005; Wallsten et al., 2008). There are numerous studies on pigs and dairy cows but this review focuses on the utilization of barley in finishing diets for beef cattle.

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Barley is less popular as an animal feed compared to corn, possibly because the nutritive value of barley as an animal feed has not been fully revealed or because nutrient utilization is inferior to corn. In temperate countries like the United States, corn is the most popular cereal crop because the climate and soil conditions are suited for corn production. Recently, the utilization of corn for biofuel production has resulted in a short supply of the grain for animal feeding. In addition, climatic changes brought about by the greenhouse effect resulted in temperature fluctuations, flooding and drought that greatly affected corn production in western countries. The shortage and the concomitant increase in the price have forced animal producers to find alternative feeds to corn. For example in Korea, cattle producers have started using barley grains and whole crop barley silage. Barley is grown locally during the winter months and this coincides with the end of the rice season. Barley is preferred over ryegrass because barley, being a shallow rooted plant, does not necessitate extensive land preparation for the succeeding rice planting season. While barley is grown as a winter crop in Canada and Japan and is regularly used in animal feeding, an accessible scientific review has not been available on the effects of barley on beef cattle production and meat quality. Most research has involved comparisons with corn and the need to focus on alternative energy feeds has compelled authors to focus on the utilization of barley in animal feeding. Whole crop barley contains antioxidants that may affect meat quality. The current review considers literature on the effects of barley diet on beef quality traits, and also identifies areas for further study.

Nutritional value and physiological function of barley

In recent years, the utilization of barley grains and barley grass by humans has increased because of the nutrients that the plant contains. Barley seeds have been reported to contain B vitamins, vitamin C and folic acid (Johnson and Mokler, 2001). In addition to the vitamins and minerals that green barley leaves contain, proteins are also present as polypeptides that can be directly absorbed by the body. Poppitt (2007) reported that β-glucan is another substance found in barley that is claimed to impart health benefits. It is a polysaccharide that occurs in the bran of cereal grains like barley and oats at 7% and 5% (w/w), respectively (Poppitt, 2007). Waxy hulless barley has 2 to 4 times more β-glucan soluble fiber than hulled barley. The average β-glucan content of various feed grains is shown in Table 1.

Studies in animals and humans have shown that β-glucan has a cholesterol-lowering effect in animals and humans. Ranhorta et al. (1998) observed that the serum total cholesterol levels in hamsters fed the barley-free diet were elevated compared to those fed diets with 25, 50 and

Table 1. Mean β-glucan content of various feed grains

Grain	β-glucan content (g/kg)
Barley[a]	42.0-79.3
Oats[b]	37.1±0.38 ~ 73.5±0.43
Triticale[c]	17.0
Wheat[c]	8.0
Rye[c]	20.0

[a] Hang et al. (2007).
[b] Chernyshova et al. (2007).
[c] Triticale Grain for Feed-Nutritional Information, http://www1.agric.gov.ab.ca/department/deptdocs.nsf/all/fcd10575

75 percent barley. The exact mechanism on how β-glucan affects serum cholesterol level is not yet clear. Theuwissen and Mensink (2007) noted that a possible explanation is that water soluble β-glucan lowers the absorption of bile acids consequently hepatic conversion of cholesterol into bile acids increases while hepatic pools of free cholesterol decrease. A new steady state is reached in the body thereby, endogenous cholesterol synthesis increases. It was further postulated that hepatic low density lipoprotein (LDL) cholesterol receptors become upregulated to re-establish hepatic cholesterol stores, which will lead to decreased serum LDL cholesterol concentrations. Keenan et al. (2007) tested the effects of concentrated barley β-glucan on blood lipids in hypercholesterolaemic men and women. After 6 weeks of treatment, LDL-cholesterol and total cholesterol levels were decreased. The level of high density lipoprotein (HDL)-cholesterol, however, was not affected by β-glucan treatment. Ranhorta et al. (1998) have shown that a barley cultivar providing 1.8% soluble fiber and 0.6% soluble β-glucans in the diet lowered serum total cholesterol in hamsters. The cholesterol lowering effect is not dose dependent such that inclusion of barley beyond 25% of the diet did not further lower cholesterol level. Ranhorta et al. (1998) noted that the lowering pattern for serum triglycerides suggested a dose dependent response. Batillana et al. (2001) have compared the effect of a diet with or without β-glucan on the serum glucose levels of male subjects. They have demonstrated that the lowered postprandial glucose concentrations in men after ingestion of a meal containing 8.9 g/d β-glucan are due to delayed and reduced carbohydrate absorption from the gut. β-glucan apparently slows down digestion and absorption of complex carbohydrates so serum glucose levels are kept at an even level for a longer period of time. It was deduced that barley has a modulating effect on the serum glucose and insulin levels.

As an animal feed, barley grain compares favorably with corn in terms of nutritive value although the energy content of barley is slightly lower than the energy value of corn and may be partially attributed to its higher fiber content (Table 2).

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Table 2. Nutrient composition of common feed grains

Components	Feed grains			
	Barley	Corn	Wheat	Oats
Total digestible nutrients (%)	88	90	88	77
Crude protein (%)	12.7	10.3	15.9	11.6
Starch (%)	64.3	75.7	70.3	58.1
Digestible energy (Mcal/kg)	3.7	4.1	3.9	3.4
Acid detergent fiber (%)	7.0	3.0	8.0	16.0
Neutral detergent fiber (%)	18.1	10.8	11.8	29.3
Calcium (%)	0.05	0.03	0.05	0.01
Phosphorus (%)	0.35	0.32	0.44	0.41
Potassium (%)	0.57	0.44	0.40	0.51
Magnesium (%)	0.12	0.12	0.13	0.16
Sodium (%)	0.01	0.01	0.01	0.02
Sulfur (%)	0.15	0.11	0.14	0.21
Copper (ppm)	5.3	2.51	6.48	8.6
Iron (ppm)	59.5	54.5	45.1	94.1
Manganese (ppm)	18.3	7.89	36.6	40.3
Selenium (ppm)		0.14	0.05	0.24
Zinc (ppm)	13.0	24.2	38.1	40.8
Cobalt (ppm)	0.35			0.06
Molybdenum (ppm)	1.16	0.60	0.12	1.70
Vitamin A (1,000 IU/kg)	3.8	1.0	0.0	0.20
Vitamin E (1,000 IU/kg)	26.2	25.0	14.4	15.0

Sources: NRC (1996), cited by Lardy and Bauer (1999).

Anderson (1998) reported that the economic feed value of barley is at least equivalent to corn on a weight basis due to the higher protein content of barley (12.5% vs. 10%). Barley grains contain 3.65 Mcal/kg of digestible energy. Like most cereal crops, barley is low in calcium but high in phosphorus (Lardy and Bauer, 1999). It has been further reported that barley is higher in vitamin E than the other major cereal grains. Barley grain contains 35.5 IU vitamin E/kg (O'Sullivan et al., 2002). Hakkarainen et al. (1984) reported, however, that the total concentration of vitamin E in barley varied from 55-65 mg/kg dry matter up to 95-100 mg/kg dry matter at harvest time depending on the harvest year. A study by Hakkarainen et al. (1984) had shown that the biopotency of the total vitamin E in barley was 37% of that of dietary DL-α-tocopherol acetate. In spite of the high proportion of α- and β-tocotrienols in the barley-oil diets (about 60% of the vitamin E content), only traces of these isomers could be detected in the plasma and none could be detected in the liver. Presumably, there may have been a chemical reduction of the α- and β-tocotrienols to the corresponding tocopherols before entering the liver. Thus, barley is not as rich a source of vitamin E as could be supposed on the basis of its total vitamin E content (Hakkarainen et al., 1984). Barley grass, on the other hand, has been reported to contain significant levels of 2"-O-glycosyl isovitexin (2"-O-GIV), an isoflavonoid, that

inhibit formation of malonaldehyde (MA), a marker of lipid oxidation (Johnson and Mokler, 2001). The mentioned isoflavonoid prevents glyoxal from forming as a result of the breakdown of fatty acid esters and inhibits superoxide and hydroxyl radical formation through free radical trapping. Nishiyama et al. (1993) reported that the inhibitory activity of 2"-O-GIV toward malonaldehyde formation from fatty acid esters was similar to that of α-tocopherol.

Research has explored the use of barley grain as a source of energy and protein in animal feeding. It has been observed that processing of the grain is needed to increase digestibility. Processing techniques of barley are classified into cold physical methods, hot physical methods, chemical methods and enzymatic processing (Dehghan-banadaky et al., 2007). Cold physical processing includes grinding, rolling, and tempering while hot physical processing includes steam rolling, steam flaking, pelleting and roasting. Chemical processing is done with the use of sodium hydroxide, ammonia and aldehydes among others. Enzymatic processing involves the use of fibrolytic enzyme supplementation. Mathison (1996) reported that the digestibility of whole barley grain in 6 month to 18 month-old cattle is 15% lower than that of the dry-rolled grain. Bloat increased in cattle fed whole barley relative to rolled barley grains (Yaremcio et al., 1991). On the other hand,

Table 3. Chemical composition[a] of whole-crop silage from corn, wheat and barley

	Whole-crop corn silage	Whole-crop wheat silage	Whole-crop barley silage
Dry matter (g/kg)	301±8.6	488±20.9	491±13.8
Metabolizable energy (MJ/kg DM)	10.9±0.29	11.3±0.18	11.2±0.33
Crude protein (g/kg)	87±3.1	104±3.3	117±4.5
Ash (g/kg)	37±2.0	44±4.5	48±7.9
Neutral detergent fiber (g/kg)	450±23.7	400±21.3	465±48.8
Acid detergent fiber (g/kg)	242±4.7	217±11.3	230±18.6
Starch (g/kg)	279±20.4	343±26.6	289±49.5
Water soluble carbohydrate (g/kg)	11±2.4	12±2.0	14±2.4

Source: Walsh et al. (2008). [a] Mean±SD.

optimum processing should be employed because grain that is too finely processed increases the risk of rumen acidosis (Zinn et al., 1996). That study found lower ruminal pH and increased incidence of liver abscesses in steers fed hulless barley, with both these symptons being indicative of rapid fermentation and excessive accumulation of acid in the rumen.

Whole crop barley has also been tested as a ruminant feed. Walsh et al. (2008) compared whole-crop barley silage to whole-crop corn and whole-crop wheat silage (Table 3). Whole-crop wheat and whole-crop barley silages had higher dry matter and crude protein than whole-crop corn silage. Barley silage was comparable with whole-crop corn and whole-crop wheat silage in terms of preservation characteristics as evidenced by a high lactic acid: acetic acid ratio, low NH_3-N and negligible propionic and butyric acid contents (Walsh et al., 2008).

Recent research has identified high starch content, low acid-detergent fiber (ADF), low ruminal dry-matter digestibility (DMD), and large particle size after dry rolling as desirable barley grain feed-quality characteristics for beef cattle (Bowman et al., 2001). Barley starch is highly digestible thus thoroughly utilized by the animal. The high starch content would provide more available energy to the animal, while low ADF content would reduce the amount of less digestible cellulose and lignin (Hunt et al., 1996). Further, lower rumen DMD of barley would shift more of the starch digestion from the rumen to the small intestine, in effect making barley more like corn in site of digestion. Owens et al. (1986) reported that starch digestion in the small intestine has been estimated to provide 42% more energy than starch digestion in the rumen due to reductions in energy loss via methane production and more efficient use of glucose as an energy source compared with volatile fatty acids. In addition, lower rumen DMD would reduce excessive fermentation acid production and reduce the incidence of bloat, acidosis and laminitis (Hunt, 1996). Larger particle sizes in barley grains have been linked to improvements in palatability and intake by cattle (Hunt, 1996).

Effects of barley on carcass traits and meat quality

Many studies compared the effects of barley with other feedstuffs on beef cattle performance and meat quality, and a number of these studies are summarized in Table 4. This section will discuss the results of these studies highlighting the effects of barley grains and whole crop barley on carcass characteristics and meat quality characteristics of beef. Suggestions will also be made for future studies in this area for the beef industry.

Cattle performance : Barley is fed to beef cattle either as grain or herbage and feeding trials have shown different responses of beef cattle to barley-based diets. Berthiaume et al. (1996) reported that adding rolled barley grain at 60% dry matter (DM) basis to medium cut and late cut grass silage-based diets resulted in an increased DM intake (p<0.05) and weight gains (p<0.05) of crossbred Charolais and Simmental calves. A digestion trial in the same study revealed that apparent digestibility values of the DM for the diets were 68.5% for the early cut silage (control), 60.8% for medium cut, 56.8% for late cut, 70.8% for medium cut silage plus barley and 70.1% for late cut plus barley. Galloway et al. (1993) observed a similar effect, supplementation with ground barley grain for 85 days at 1.07% of body weight of beef steers (English×Continental and English×Brahman, 256±2 kg initial BW) grazing on bermuda grass resulted in improved average daily gain in steers than those fed the non-supplemented diets (0.68 kg/d vs. 0.47 kg/d). The beneficial effect of supplementation appears to be obvious, but some studies highlighted the importance of species of grains used. In the study of Galloway et al. (1993), the effect of supplementation for both barley and wheat on growth rate did not differ, but the same treatment with corn and sorghum resulted in higher live weight gains of steers. The results of their study demonstrated that the performance of growing cattle grazing Bermuda grass, supplemented once daily with grain at 1% of body weight, is affected by grain characteristics. Grains like corn and sorghum that are degraded more slowly in the rumen were used more efficiently than more rapidly degraded grains like barley and wheat. On the other

Table 4. Summary of barley research results on the performance, carcass characteristics and meat quality of beef cattle. References are arranged chronologically with the most recent reports at the start of the table

Experimental design	Findings	Source
Dietary treatments: i) Whole-crop barley, ii) Head-cut barley silage, iii) Whole-crop wheat silage, iv) Head-cut wheat silage, v) Maize silage, vi) *ad lib* concentrate. i) - v): 3 kg concentrate supplement/hd/d. vi): 5 kg grass silage/hd/d. Animal: 90 Limousin, Charolais, Simmental and Belgian Blue cross; Initial weight = 438±31.2 kg; Mean age: 22 months. Feeding: 160 days	Cutting heights of barley or wheat did not improve the growth performance of steers. Growth performance of steers fed corn silage was similar with those fed other crop silages. Feeding *ad libitum* concentrate had better growth rate and feed efficiency than other treatments. Lean color did not differ among treatment but feeding ed *ad libitum* concentrate had a more yellow fat than other treatments.	Walsh et al., 2008
Dietary treatments: i) pasture only, ii) pasture+4.5 kg DM/hd/d barley grain, iii) pasture+1.8 kg DM/hd/d whole roasted soybeans, iv) confinement-fed 60% grass silage/40% barley (DM) basis TMR. Animal: 32 British crossbreds (Hereford cross or Shorthorn cross); Initial weight = 432±47.5 kg. Feeding period: 105 days	Feeding TMR resulted in the highest body weight gain. Supplementation of soybean to pasture-fed animals increased the rate of gain and backfat thickness. Loin eye area was highest in the pure pasture-fed animals. Meat color, tenderness and sensory traits did not differ among treatments.	Duynisveld et al., 2006
Dietary treatments: Finishing diets based on any one of the following grains: corn, Chinook barley, Logan barley or H3 barley; chopped barley straw (6% DM basis). Animal: 80 Angus crossbred steers; Initial weight = 370 kg. Feeding period: Endpoint of feeding period: 70% of steers had 10 cm backfat	Meat from steers fed the Logan barley variety was less red than those from corn, Chinook and H3 barley varieties.	Boles et al., 2005
Dietary treatments: Finishing diets based on corn, Morex barley, Streptoe barley, SM3 barley or SM5 barley; chopped barley straw (6% DM basis). Animals: 45 Angus crossbreds; Initial weight = 391 kg. Feeding period: 112 days	Meat for feeding Morex barley variety and SM5 barley had lighter color. Fat from steers Feeding corn had more a yellow fat. Grain source had minimal effect on the fatty acid composition of subcutaneous fat.	Boles et al., 2004
Dietary treatments: i) whole crop barley forage chopped, wilted to 350 g/kg DM and treated with water (control), ii) control+inoculant, iii) control+inoculant+enzymes; 100 g/kg barley grain and 30 g/kg beef supplement was included in each diet. Animals: 90 Hereford×Angus steers; Initial weight = 284 kg. Feeding period: 112 days	The addition of inoculum or a combination of inoculum and enzyme did not improve the growth rate of steers. Improved feed conversion was observed in steers fed silages with inoculum or a combination of inoculum and enzyme. Feed efficiency was superior with those fed barley silage with inoculum and enzyme.	Zahiroddini et al., 2004
Dietary treatments: Traditional liquid diet supplemented with 250 g/calf/d of barley grain or 250 g/calf/d of ground wheat straw. Animals: 24 Polish Friesian male calves; Initial weight = 61 kg. Feeding period: 147 days	Carcass traits and meat quality did not differ between calves fed diets supplemented with barley or ground wheat straw	Cozzi et al., 2002
Dietary treatments: Backgrounding diets containing 350 g/kg DM steam-rolled barley grain, 600 g/kg either barley/ryegrass intercrop silage or pure barley silage and 50 g/kg DM supplement; Finishing diets consisted of 860 g/kg DM steam-rolled barley, 100 g/kg barley/ryegrass silage or pure barley silage and 40 g supplement/kg. Animals: 120 Crossbred steers (mixed Charolais, Simmentals, British breeds and Limousin); Initial weight = 325±16 kg. Feeding period: Backgrounding - 83 days; Finishing period - 49-70 days	Beef from steers fed barley/ryegrass silage had significantly higher carcass weight.	Zaman et al., 2002

Table 4. Summary of barley research results on the performance, carcass characteristics and meat quality of beef cattle. References are arranged chronologically with the most recent reports at the start of the table (Continued)

Experimental design	Findings	Source
Dietary treatments: Finishing diet of 83% concentrate (0, 10, 20% potato by-product+83, 73, 63% dry-rolled corn or barley grain), 10% supplement and 7% alfalfa DM basis. Animals: 144 crossbred steers; Initial weight = 333 kg. Feeding period: 130 days	Meat quality did not differ among treatments. Panel scores indicated that meat from corn-fed steers had a more appropriate, well balanced and well-blended beef flavor and texture but the difference between corn-fed and barley-fed groups was small.	Busboom et al., 2000
Dietary treatments: Finishing diet of 83% concentrate (0, 10, 20% potato by-product+83, 73, 63% dry-rolled corn or barley grain), 10% supplement and 7% alfalfa DM basis. Animals: 144 crossbred steers; Initial weight = 333 kg. Feeding period: 130 days	Gain in weight was not different between the corn-based or the barley-based group but corn-fed steers had better feed efficiency. Similar carcass characteristics were observed but beef from barley-fed steers tended to have whiter fat. Small differences were noted in fatty acid profile, purge, drip loss and muscle pH.	Nelson et al., 2000
Dietary treatments: Diets that contain either Streptoe or Klages barley that were processed by one of the following methods: dry-rolling; tempered and rolled; tempered, ammoniated and rolled; or tempered, ammoniated and fed whole. Animals: 240 crossbred steers; Initial weight = 266 kg. Feeding period: 184 days.	Feedlot performance was not affected by barley variety. Mechanical processing of barley improved growth performance of steers. Carcass characteristics were not affected by barley variety and method of processing barley grains.	Bradshaw et al., 1996
Dietary treatments: High concentrate diets based on corn, Gunhilde barley, Harrington barley or Medallion barley. Animals: 80 Angus×Hereford; Initial weight = 287 kg. Feeding period: 168 days	Corn grain-fed steers grew faster than those fed barley but feed efficiency was better in the barley-fed animals. Harrington barley-fed steers had better growth performance than those fed Gunhilde or Medallion barley. Better carcass characteristics were observed with corn- and Harrington-fed steers.	Boss and Bowman, 1996
Dietary treatments: Finishing diets based on corn or corn/barley or barley grain. Animals: 18 Angus crossbred steers; Initial weight = 364 kg. Feeding period: 103 days	Carcass characteristics did not differ. Descriptive sensory flavor attributes did not differ among treatment groups.	Miller et al., 1996
Dietary treatments: Diets were based on any of the following grain: steam-flaked corn, dry-rolled barley, steam-rolled barley, coarse flake or steam-rolled barley, thin flake. Animals: 96 crossbred steers (Brahman, Hereford, Angus, Shorthorn and Charolais); Initial weight = 260 kg. Feeding period: 172 days feeding trial	Carcasses from barley-fed steers had thicker fat than the corn-fed steers. Degree of marbling was almost similar in the barley-fed and corn-fed treatment groups. Method of grain processing had no effect on carcass characteristics.	Zinn, 1993
Dietary treatments: Finishing diets based on any one of the following silage: wheat, barley, oats or corn. Silage constituted 84-86% of the diet on DM basis. Animals: Trial 1, 120 Hereford steers; Initial weight = 267 kg; Trial 2, 75 mixed-breed steers; Initial weight = 302 kg; Trial 3, 108 Hereford and Angus steers; Initial weight = 291 kg. Feeding period: 87-90 kg	Steers fed barley silage and those fed corn silage had similar rate of weight gain. The animals grew faster compared with those fed the wheat and oat silages. The efficiency of gain was similar between the corn silage and the barley silage fed animals.	Oltjen and Bolsen, 1980
Dietary treatments: Whole crop silage of corn, barley or wheat supplemented with soybean or urea Animals: 126 Hereford, Angus and mixed breeds; Initial weight = 266 kg. Feeding period: 100 days	Steers fed corn and barley silage had similar growth rate and feed efficiency. Rate and efficiency of growth in steers fed wheat silage was lower compared to the corn and barley silage group.	Bolsen et al., 1976

hand, other studies (e.g., Takizawa et al., 1998; Nelson et al., 2000) identified an identical effect of corn and barley diet on weight gain. Nelson et al. (2000) showed that the gain in weight between the corn-fed and the barley-fed steers was similar even though feed efficiency was better with the corn-fed animals (6.3 vs. 5.8 ±0.10 kg DM/kg gain). In this study, steers were fed diets containing 83% concentrate (corn or barley grain plus potato by-product), 10% supplement and 7% alfalfa on a DM basis for 130 days. Kincheloe et al. (2003) did not observe any differences in the average daily weight gain, feed efficiency and starch digestibility in steers fed either corn- or barley-based diet (H3, Harrington and Valier varieties) for 112 days. It has been obvious, based on previous literatures, that improvement in cattle performance can be observed if a barley supplemented diet is compared with the non-supplemented diet. However, varying results between studies comparing performance of barley-fed cattle to those fed corn-based diets are likely attributable to differences in feeding systems and differences in feed composition. The breed of animal used in the experiments may have also affected the performance of steers fed the test diets. In a study comparing Angus-Aberdeen and Holstein-Friesian steers fed either barley-based concentrate or grass-silage diet, average daily gain and final liveweight were significantly different between breeds fed grass silage diet for the 14 month age group (Warren et al., 2008a). Angus-Aberdeen had better growth performance than Holstein-Friesian (0.82 vs. 0.74 kg/d). At 19 months of age, Angus-Aberdeen had significantly higher average daily gain (ADG) than Holstein-Friesian in the grass silage-fed group (0.87 vs. 0.77 kg/d). A study comparing two breeds of lamb (Lacha and Rasa Aragonesa) fed similar barley-based diets showed that breed differences affect growth performance and carcass characteristics (Beriain et al., 2000).

On the other hand, barley variety appears to have a significant effect on animal performance and feed efficiency which was independent of growing conditions or cultural practices (Lardy and Bauer, 1999). In a study comparing Gunhilde, Harrington and Medallion barley varieties with corn, Boss and Bowman (1996) observed that among the barley-fed animals, the Harrington group grew 8% faster than those fed the Gunhilde and Medallion-based diets. All steers fed the barley-based ration had better feed efficiency than those fed corn-based ration, although corn-fed steers had better growth performance. These results were attributed to fiber content and digestibility of each variety. Bradshaw et al. (1996) noticed that acid detergent fiber digestibility of Streptoe barley grain was greater than for Klages barley during the finishing stage. Ovenell-Roy et al. (1998) as cited by Lardy and Bauer (1999) concluded that based on the digestibility of neutral detergent fiber and the other nutrients, Cougbar and Streptoe had lower nutritional

value than other varieties tested that include Andre, Camelot, Clark, Harrington, Boyer and Hesk. These experiments clearly demonstrate that there are some variations in feed quality among different varieties of barley and these could have caused the differences in the effect of barley on beef cattle performance.

Whole crop barley is considered relatively easy to ensile because of its high content of fermentable carbohydrates. Whole crop barley ensiled at approximately 30% DM (without wilting) contained higher concentrations of soluble sugars and lactic acid and had higher ruminal degradability of DM than wilted silage (38% DM) (Hristov and McAllister, 2002). The study of Hristov and McAllister (2002) had shown that the use of lactic-acid bacteria-based inoculants enhanced lactic acid production in barley silage. The dry matter digestibility of the silage, however, was not improved. The results of the study by Moshtaghi and Wittenberg (1999) indicated that microbial inoculants were beneficial in preserving whole crop barley ensiled as large bales and the addition of enzymes had no beneficial effect on the quality of large bale silage.

In a similar way to studies involving feeding barley grain to cattle, barley silage feeding studies have showed variable results between laboratories and experimental designs for the effectiveness of barley silage as a cattle diet. Mowat et al. (1971) reported that steers fed corn silage gained significantly faster and more efficiently than those fed whole crop barley silage. However, Oltjen and Bolsen (1980) in a series of 3 experiments observed similar growth performances in steers fed corn silage and barley silage. Steers fed barley silages (Paoli and Kanby varieties) gained faster and more efficiently than those fed wheat and oat silages. Oltjen and Bolsen (1980) attributed the differences in steer performances to the silage plant species, silage composition and diet. Species accounted for 56.7% of the variation in daily gain, 56.6% of the variation in intake and 84.6% of the variation in feed efficiency.

Several studies have evaluated different methods on how to improve the feeding value of whole crop barley silage. Zaman et al. (2002) noted that pure barley silage was as good as the silage produced from the intercropped barley and ryegrass. Steers fed the barely/ryegrass silage and pure barley silage had similar average daily gains, dry matter intake and feed conversion efficiency in the finishing trial. Walsh et al. (2008) increased the cutting height of the barley crop to increase the proportion of grain in the silage. Results showed that the performance of the steers fed the silage with different cutting heights did not differ. In another experiment, it was determined that treating whole-crop barley silage with bacterial inoculum and/or enzymes improved the feed efficiency of the crossbred steers but not the daily gain in weight (Zahiroddini et al., 2004). The results suggested that the method to be used in improving

the quality of whole-crop barley should focus more on increasing the availability of nutrients for the animals rather than increasing the nutrient content.

A number of studies have attempted to improve the utilization of barley, with an emphasis on the effects of grain processing and test weight on the value of barley as an animal feed. McDonnell et al. (2003) determined that processing (whole vs. cracked) and test weight (heavy vs. light) interaction of barley grain on the weight gain and feed efficiency of crossbred steers fed a finishing diet containing 83% barley grain, 6% chopped straw, 3% oil and 8% supplement. The heavy barley had a test weight of 49 lb/bushel while the light barley had 39 lb/bushel. Weight gain was highest for steers fed cracked heavy and cracked light barley, intermediate for steers fed whole light barley and least for steers fed whole heavy barley. The highest feed efficiency was with steers fed cracked heavy barley followed by cracked light barley, whole light barley and whole heavy barley. Boss et al. (2003) evaluated the effects of light or heavy test weight barley grain fed whole or dry rolled to Angus steers on a backgrounding diet for a 56-day feeding trial. The test weight of barley had no effect on the growth performance of the animals. Dry rolled barley increased animal performance by 17% compared to those fed whole barley. Engstrom et al. (1992) compared the performance of feedlot cattle fed dry-rolled or steam-rolled barley that contained 3.5-4.8% β-glucans, 56.5-65.6% starch and 5.7-9.7% acid detergent fiber. Weight gain, dry matter intake and dry matter to gain ratio did not differ among animals fed the treatment diets. It was noted that steam-rolled barley did not have an added advantage over dry-rolled barley in terms of the growth performance of steers. Bradshaw et al. (1996) reported that the gain-to-feed ratio was greater for steers fed tempered, rolled barley or tempered, ammoniated, rolled barley than those fed the tempered, ammoniated whole barley. Improvement in beef cattle performance was evident with the processing of barley grain. This implies that processing results in better utilization of nutrients from barley grain. The results of studies indicate that simple methods like cracking or dry-rolling of barley grains may be sufficient to improve the utilization of barley. Feeding steam-flaked corn-based diets improved feed efficiency (16.9%) and daily gain (15.2%) while decreasing intake compared with feeding dry-rolled corn-based diets to finishing cattle (Macken et al., 2004). It has generally been concluded (NRC, 1984; Owens et al., 1986; Theurer, 1986; Campling, 1991) that although steam flaking may result in a slight improvement in the energy content of the corn and in feed efficiency, such processing is not economically justifiable. The method and cost of processing are factors to be considered to increase the economic advantage of barley over corn.

Carcass characteristics : Most of the researches that evaluated the effect of barley grain on beef carcass characteristics and meat quality have compared it with corn. Most of these have reported similar observations on carcass characteristics, while different barley varieties have sometimes had an effect on carcass characteristics. Nelson et al. (2000) reported that carcass characteristics did not differ between barley-fed and corn-fed crossbred yearling steers for an average of 130-day finishing period. The finishing diet consisted of 83% concentrate (0, 10 or 20% potato by-product plus 83, 73 or 63% dry-rolled barley or corn), 10% supplement and 7% alfalfa on a dry matter basis. Furthermore, a number of studies indicated in Holstein steers (Takizawa et al., 1998) and cows (Burgwald et al., 1992) that the loin eye area, rib thickness, intermuscular fat thickness and marbling were greater in barley-fed than corn-fed cattle.

Boles et al. (2004) reported that there were no significant differences in hot carcass weight, fat thickness, loin muscle area, percentage of internal fat, yield grade and quality grade in crossbred steers fed diets based on corn and 4 barley varieties that include Morex, Streptoe, SM3 and SM5. Diets were formulated to be isonitrogenous and isocaloric and all grain sources were cracked before feeding. The experimental diets had 83% grain on a dry matter (DM) basis and 6% chopped barley straw on a DM basis as roughage. In a succeeding experiment, Boles et al. (2005) determined the effect of corn- and barley-based diets (Chinook, Logan and H3 varieties) on carcass characteristics. Angus crossbred steers with an initial bodyweight of 370 kg were fed the finishing diets until 70% of the animals had 10 mm fat. It was observed that Chinook, Logan, H3 barley and corn in finishing diets had no effect on carcass weight, yield grade or quality grade. On the other hand, significant differences were observed in kidney, pelvic and heart (KPH) fat percentage, with corn- and H3 barley-fed steers having higher KPH than those fed Chinook and Logan barley varieties. Boles et al. (2005) cited the results of Ovenell-Roy et al. (1998) in which, differences in KPH were reported in steers fed different barley varieties. It was stated that it may not be of biological importance since the variability in the KPH percentages among carcasses was low. In a related study, Boss and Bowman (1996) fed Angus×Hereford steers with diets based on three barley varieties (Gunhilde, Harrington and Medallion) and corn on a 168-day finishing period. Carcass weight was used as a covariate for the analysis of carcass characteristics in this study. No differences in KPH, backfat thickness and longissimus muscle area were observed among treatment groups. Carcass weight, marbling score and carcass quality was higher for Harrington-based diet than Gunhilde- and Medallion-based, and corn-based diets, implying that barley varieties affect carcass traits differently and apparently Harrington had

more positive effects on beef quality.

For grain combination rations in cattle diets, some synergic effects on carcass quality have been reported. Miller et al. (1996) reported that carcass weight, ribeye area, KPH and yield grade and quality grade characteristics did not differ among corn-, barley- and corn/barley-fed crossbred Angus steers finished for 102-103 days. It was observed that adjusted preliminary yield grade was higher for carcasses from steers fed corn/barley diet than carcasses from steers fed barley diet. Each treatment diet was isocaloric and was formulated so that corn, barley or equal amounts of corn/barley were the only constituents of the grain source for the ration. Lardy and Bauer (1999) cited the works of Combs and Hinman (1988) that replaced dry-rolled corn with increasing levels of tempered barley in high grain finishing diets. Yield grade and 12th rib fat responded quadratically to increasing level (33, 67, 100%) of barley in the diet but grain combinations of barley and corn had higher yield grades and more 12th rib fat than did single grains. The same trend was observed with the carcass weight. The results imply that corn and barley had a synergestic positive effect on carcass traits. It was also noted that pure barley is comparable to pure corn in terms of its effect on carcass traits.

Studies comparing the effects of processed corn and barley on carcass characteristics were also done. The study by Zinn (1993) used crossbred steers (260 kg initial bodyweight) that were finished for 172 days on a 90% concentrate diet based on one of the following grains: steam-flaked corn, dry-rolled barley, steam-rolled barley, coarse roll and steam-rolled barley, thin roll. It was observed that carcass characteristics of barley-fed steers were comparable with those fed with corn. Carcass weight, dressing percentage, longissimus muscle area, fat thickness, KPH, marbling score, retail yield and preliminary yield grade did not differ among the corn- and barley-fed steers. The study showed that steam rolling and dry rolling of barley have similar effects on carcass characteristics. Bradshaw et al. (1996) tested Streptoe and Klages barley that were processed using four different methods as follows: dry rolling, tempering and rolling, tempering, ammoniating and rolling, and tempering, ammoniating and feeding whole. Final weight of the steers adjusted to equal 158.73% of the hot carcass weight (63% yield). The results showed that neither barley variety nor processing method had meaningful effects on carcass weight, fat thickness, quality grade, yield grade, longissimus muscle area and KPH in steers. Collectively, the majority of previous studies have reported very limited differences (if any) in carcass characteristics between corn-fed and barley-fed beef cattle. In some other studies, differences were found only on the carcass weight while other characteristics remain the same. Previous studies suggest that barley grains when fed to beef

cattle can produce meat with carcass characteristics comparable with those fed corn grains. grain combination feeding scheme for beef cattle is likely a subject to be elucidated in the near future.

Research that has evaluated the effect of whole crop barley silage on carcass and beef quality are limited. Zaman et al. (2002) compared the carcass characteristics of beef from steers fed pure barley silage and silage containing intercropped barley and annual ryegrass. Carcass weight was significantly higher in beef fed the barley/ryegrass silage compared to beef from the pure barley silage group. However, dressing percentage, fat grade, ribeye area and marbling score did not differ between treatment groups. Walsh et al. (2008) compared carcass characteristics of continental crossbred steers fed any one of the following diets: corn silage, whole-crop wheat silage, head-cut wheat silage, whole-crop barley silage, head-cut barley silage or *ad libitum* concentrates plus grass silage. The first five diets were supplemented with 3 kg concentrates/hd/d. Carcass weights of steers fed *ad libitum* concentrate diet was significantly higher than the forage-fed steers. This was attributed to the higher liveweight gain of concentrate-fed animals. Differences in conformation score was attributed to carcass weight such that the *ad libitum* concentrate group had the highest score. Fat score did not differ among treatments. The results of the experiment showed that increasing the cutting height of crops for silage had no affect on carcass characteristics. Furthermore, carcass characteristics of barley silage-fed steers are comparable with corn and wheat silages. In summary, the majority of the studies reviewed above showed that, in general, beef from cattle fed barley grains or whole crop barley silage do not differ in carcass characteristics compared to cattle fed other grains or whole crop silages. Some differences in carcass weight and fat deposition appeared to be caused by the dietary effect on the growth performance of the animals.

Proximate composition and fatty acid composition of lean beef : Studies have indicated that proximate composition of beef from cattle fed barley grain did not significantly differ between cattle fed different grain diets. Boles et al. (2005) observed no significant differences in the proximate composition of beef fed corn or Chinook, Logan and H3 barley varieties. They noted, however, that steers that had been fed a diet based on Chinook tended to have a higher fat content and this was reflected in the higher marbling score. Similarly, Wismer et al. (2008) detected no differences in moisture, fat, protein and ash components in steaks from barley and corn-fed beef cattle. The study utilized a tempered barley based finishing diet consisted of 91% barley grain, 7% barley silage and 2% supplement (dry matter basis). The tempered corn based finishing diet was composed of 86% corn, 7% barley silage, 2% supplement, 5% canola and urea based protein supplement (dry matter

basis). Similar results were obtained by Shand et al. (1997) and Cozzi et al. (2002). Fat and moisture did not differ when steers were fed the conventional barley-based ration or diets with either brewer' or distiller's grains (Shand et al., 1997). Meat chemical composition was similar in veal calves fed either barley grain or ground wheat straw (Cozzi et al., 2002).

Miller et al. (1996) reported that lipid content and fatty acid composition of steaks did not differ in Angus cross-bred steers fed diets based on corn, corn/barley or barley. The barley grain used in the study had slightly lower level of oleic acid and higher 18:3 fatty acid than the corn. Lipid analysis of the grains showed that the lipid and fatty acid composition of the treatment diets were low thus the lipid component of the grains did not significantly influence the fatty acid profile of the steaks from the experimental animals. In the same way, Nelson et al. (2000) did not observe any significant difference in the crude fat and the total fatty acid content of beef from steers fed corn- or barley-based diet. However, the barley-fed steers tended to have a lower proportion of C14:0 than corn-fed steers (3.6 vs. 3.9 g/100 g fatty acid) and higher proportions of C17:0 (2.0 vs.1.9 g/100 g fatty acid) and C17:1 (1.6 vs. 1.4 g/100 g fatty acid). When barley or soybean supplementation to pasture-fed was compared, soybean treatment increased C18:2 concentration by 34% while barley supplementation reduced C18:3 concentration by 8% in LT. The differences in fatty acid composition between the barley-fed and the soybean-fed group can be attributed to the fact that the lipid content of soybean is eightfold higher than barley. In this case, some of the dietary fatty acids are able to escape rumen biohydrogenation thus are absorbed and deposited in the animal body (Ekeren et al., 1992).

No research data was found that compared the effects of whole-crop barley silage, grass silage or pasture on the fatty acid composition of beef cattle. However, it appears that the fatty acid composition of beef from barley grain-fed animals differs from beef from cattle fed grass-silage or those fed on pasture (Duynisveld et al., 2006). Differences in fatty acid composition could be observed if the difference in the fatty acid content of grains is large as in the case of barley and soybean. A recent study examined the effects of breed and a barley-based concentrate or grass silage diet on beef quality in 14, 19 and 24 month-old cattle (Warren et al., 2008a). In all age groups, the grass silage-fed steers had higher amounts of total lipid, neutral lipid, saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and n-3 PUFA while steers fed the concentrate diet had higher amounts and proportions of PUFA and n-6 PUFA than the other group. Feeding grass silage reduced the PUFA-to-SFA ratio and the n-6:n-3 ratios in muscle in all age groups. Consequently meat with high PUFA obtained from barley-based concentrates group showed greater lipid oxidation at

4 and 7 days of retail display and low level of Vitamin E in muscle tissue. High PUFA for the barley-based diet compared to the grass silage was not expected as other studies (e.g., Duynisveld et al., 2006) clearly demonstrated that pure pasture-fed beef had 25% more polyunsaturated fatty acids (PUFA) and 37% greater cis-9, trans-11 conjugated linoleic acid (CLA) concentrations in *m.longissimus thoracis* (LT) tissue than the total mixed ration-fed beef. The contradictory results can be attributed to difference in pure grass and silage, and different species of grains (Duynisveld et al., 2006) and levels of intramuscular fat (Duynisveld et al., 2006; Warren et al., 2008a; Wismer et al., 2008).

The influence of genetic component to the fatty acid composition is great (Wood et al., 2004) and beef from barley grain-fed animals differs from those fed grass-silage or those fed on pasture. This implies an interaction between breed and feeding scheme on fat deposition and the fatty acid composition. In particular, the effect of whole-crop barley silage on fat deposition and fatty acid composition is not documented. This would be an area for future studies that will assess the potential value of whole crop barley in producing functional beef, i.e. with low saturated fatty acid content and high polyunsaturated fatty acid content particularly n-3 PUFA and will meet the recommended level of P:S and n-6:n-3 for human health of 0.4 and 2-3, respectively. It should also be noted that breed affects fatty acid composition. Warren et al. (2008a) observed that subtle differences in PUFA amounts and proportions were noted between Holstein-Friesian (HF) and Angus-Aberdeen (AA). HF had higher proportions of PUFA abd higher P:S ratios compared with AA, partly due to a higher proportion of phospholipids in total lipids. In phospholipids itself, HF in the 19 and 24 month groups had higher proportions of most n-3 PUFA. In all age groups, the ratio of docosahexaenoic acid (DHA, C22:6n-3) to its precursors, 18:3n-3 was higher in HF.

Beef tenderness : Meat tenderness is a prime concern of beef consumers, and thus a key attribute of meat quality (Hwang et al., 2008), so it is of importance to determine whether barley-based diets (grain or whole crop silage) have an effect on meat tenderness. Miller et al. (1996) did not observe any difference in tenderness between beef from Angus steers that had been fed with barley or corn finishing diets for 102 days during which time they had similar growth rates. It has been well documented that cattle which grow more rapidly pre-slaughter have increased rates of protein turnover, resulting in higher concentrations of proteolytic enzymes in the carcass tissues at slaughter which, in turn, may affect myofibril fragmentation (Aberle et al., 1981; Hall and Hunt, 1982; Miller et al., 1983 as cited by French et al., 2001). In addition, the meat produced from these animals would be expected to contain a larger

proportion of newly synthesized, heat-labile collagen (Muir et al., 1998) that is easily broken down during cooking. Similarly, Mandell et al. (1997) noted that taste panel assessment of tenderness of longissimus muscle was generally not affected by diet and slaughter endpoint. The Charolais×Limousin steers were fed whole barley grain- or corn grain- based diets at two slaughter points of either 7 mm backfat or 568 kg liveweight. Shear and tenderness scores of longissimus muscle were similar across test cattle and purchased ribs, despite intramuscular fat contents of 20.2, 27.1, 35.6 and 49.7 g/kg, for test cattle and trace, slight and small marbled ribs, respectively. The studies collectively suggested that two different diets had limited effect on the endogenous proteolytic system and consequently had no detectable effect on meat tenderness. However, it should be noted that meat tenderness is a function of intrinsic and extrinsic factors such as breed, feeding scheme, length of feeding (i.e., age) and pre- and post-slaughter conditions and thus, it is not easy to identify the magnitude of a single factor such as the diet. An early study (Purchas and Davies, 1974) provided an example of such difficulties. In that study, Friesian steers were fed either a barley-grain based diet or a pasture diet until 467 kg liveweight was attained. The barley grain-fed steers grew 31% faster and had higher fat content, and the pasture-fed group took 69 days longer to reach the slaughter weight. The results showed that the shear force value of *m. semitendinosus* from the barley-fed steers was 50% lower than from the pasture-fed group. There could have been a number of reasons for this difference in tenderness including the fact that the grass-fed group was older, had a lower percentage of intramuscular fat, a greater susceptibility to cold-shortening, and also greater exercise than the barley-fed cattle. Nevertheless, research results have generally shown that beef from barley-fed cattle can be as tender as the beef from other feeding systems. This is on the premise that the animals fed barley and other diets have similar growth rates.

Color : Meat color is the most important single factor affecting meat quality for the consumer at the time of purchase. Fat and fiber color are determined in different ways in terms of metabolism, but the feeding scheme is a significant determinant for meat color, and finishing diets based on different barley varieties affect meat color differently. Boles et al. (2004) reported that longissimus muscle of Angus crossbred steers fed Morex and SM5 barley grains tended to be lighter than that from steers fed corn, Streptoe and SM3 barley. Furthermore, fats from steers fed the corn-based diets tended to be more yellow than fat from the barley group. In another study by the same research group (Boles et al., 2005) it was reported that steaks from steers fed the Logan barley variety were less red at 10 days of storage at 4°C than meat from those fed

Chinook barley or H3 barley or corn, indicating a lower color stability of beef colour for the former.

An experiment comparing short-term feeding with barley grain (30% pasture silage and 70% barley grain) and pasture grazing showed that grain-finishing resulted in brighter and in more red meat, and also significantly lighter fat color in grain-fed steers (Muir et al., 1998). However, it should be stressed that color differences were only observed after 16 weeks of the feeding treatment, but not at 10 weeks, suggesting that the effect of diet on color stability was influenced by the length of the feeding period. The difference in lean color was attributed to differences in myoglobin content, since the muscles of free-range animals are reported to have more myoglobin and hence produce darker beef than their feedlot counterparts with limited exercise (Varnam and Sutherland, 1995). The results can be ascribed to the reports of higher heme pigments in beef from bulls finished on barley-based diets than that from bulls finished on silage diets (Maltin et al., 1998) and a lower carotene concentration in grains than pasture (Strachan et al., 1993). There was indirect evidence for this rational in that the fat of steers fed the concentrate/grass silage diet had a higher Hunter b* value than those fed whole crop silage implying a more yellow color (Walsh et al., 2008) that could have been due to differences in pigment contents of cereal crops and grasses.

On the contrary, Cozzi et al. (2002) reported that visual assessment and instrumental measurement of meat color did not show a significant difference when male Friesian veal calves were fed either barley grain or ground wheat straw for 147 days. Similarly, Nelson et al. (2000) observed that lean beef color score did not differ between barley-fed and corn-fed beef. In the study of Cozzi et al. (2002), despite the difference in the iron content of barley grain and wheat straw, there was no difference in meat color. The authors concluded that meat color is not strictly correlated with the iron content of feedstuffs. The result and conclusion are not surprising and rather expected because the response of meat color is significantly affected by experimental design. An example of this can be found from a data reported by Duynisveld et al., 2006) showing that after 14 days ageing, neither fat nor meat color of beef differed among cattle that were fed a total mixed ration (60% grass silage, 40% rolled barley), pasture, pasture plus barley supplement (4.5 kg DM/h/d) or pasture plus soybean supplement (1.8 kg DM/h/d). The lack of an effect of diet on fat color is likely associated with the high inclusion rate of forages in all diets thus contributing the yellowish color to each treatment. Furthermore, the importance of experimental design to determine the effect of feeding scheme on color can be seen from the results of one study where the effects of a barley grain-based diet versus a grass-silage were different at ages of 14, 21, and 24 months (Warren et al., 2008b).

Based on published reports, it seems that the effect of barley on meat color is variable. However, the differences in research findings could be ascribed to barley-variety effects, breed of cattle, finishing period and slaughter age of the animal. The influence of diet on meat color may be attributed to the iron and pigment contents. However, it should be stressed that postmortem factors including handling of carcasses and packaging method can also influence meat color on display.

Sensory characteristics : It is not surprising that the effect of diet on sensory characteristics of beef varies between countries and laboratories, as sensory traits determined by consumers are greatly influenced by demographic parameters, as well as experimental design (Hwang et al., 2008). An early study of Larick et al. (1987) suggested that flavor may be affected by the diet, but Duynisveld et al. (2006) showed that diet had no influence on the sensory characteristics of beef. In the latter study, pasture feeding, combination of pasture and barley/soybean grain supplementation or feeding with a barley-based total mixed ration for 105 days did not influence the color, aroma, texture or taste of beef. This was ascribed to the relatively small differences in the backfat and marbling grade score of beef from all treatment groups. The study demonstrated that beef eating quality does not necessarily differ between beef from pasture-fed and grain-finished steers as long as similar high energy intake and high liveweight gains can be achieved by cattle at pasture. Likewise, Miller et al. (1996), and Busboom et al. (2000) for crossbred steers and Mandell et al. (1997) for Limousin and Charolais steers, reported that descriptive meat palatability attributes and descriptive sensory attributes for juiciness, muscle fiber tenderness, connective tissue amount, overall tenderness and flavor intensity did not differ among the corn grain-, barley grain- and corn/barley grain-fed animals. The fact that the cattle in the experiment were fed the treatment diets for the same number of days (102-103 days) and had similar marbling score probably accounted for the insignificant differences in sensory attributes. In addition, the fatty acid profile of beef from different treatment groups was similar and this may explain why there were no differences in flavor.

Species specific flavors are due to differences in fatty acid composition and aromatic flavor compounds that are stored in the lipid depots along with volatile components of lipids within meat. The fatty acid composition is also significantly correlated with flavor (Larick and Turner, 1990). Generally, however, when similar biological types of cattle are fed an isocaloric diet for almost the same length of time, the use of either corn, barley or corn/barley in the diet results in no detectable differences in flavor attributes of cooked beef steaks.

In a related study, Wismer et al. (2008) compared the sensory quality of beef from Canadian exotic crossbred beef steers fed barley-grain-based and corn grain-based diets for 190 days, and the trained panelists perceived the steaks to be similar for gamey, metallic, livery and beefy flavor intensities, juiciness and mouth-coating. In the same study, Canadian consumers revealed a significant overall preference for steaks from barley-fed steers. On the other hand, Japanese consumers showed a significant preference for steaks from the corn-fed animals, while Mexicans preferred steaks from the barley-fed animals and indicated that steaks were more tender and juicy than those from the corn-fed treatment. This reflects the fact that sensory properties of meats have are perceived differently by different consumer groups and this should be taken into account when published data is applied to a certain industry situation.

From the published literature, it appears that the sensory quality of beef from barley-fed animals is comparable in acceptability to beef fed other types of feeds provided the type of animal and breed are similar. It has been shown that preference for beef is influenced by the type of panelists used, but both Miller et al. (1996) and Wismer et al. (2008) have disputed the popular claim of Japanese producers that barley-based feedlot rations result in more desirable flavor attributes in meat. The effects of breed of cattle, production practices and the method of cooking on sensory quality can not be discounted.

CONCLUSION AND IMPLICATIONS FOR INDUSTRY

Generally, the use of barley grains in finishing diets results in improved or comparable weight gain compared with corn, but feed efficiency tends to be lower. The growth performance of cattle fed barley grain diets is influenced by the variety of barley in the diet and the grain processing method used. The response of beef cattle to whole-crop barley silage has been shown to be more variable. Some findings have indicated that growth performance of animals fed whole-crop barley silage is not comparable to corn silage, while other research has indicated otherwise. Differences in the response of animals may be attributed to the maturity of the crops used as silage, the method used in preparing the silage, silage composition, and composition of the finishing diet. Barley has been shown to have minimal effects on carcass characteristics. The fatty acid composition of beef from barley-grain-fed animals differs from that of beef from cattle fed grass silage or those fed on pasture. Proximate composition of beef did not differ in animals fed different barley-based or corn-based finishing diets. Results have indicated that beef from barley-fed cattle can be as tender as the beef from animals fed other diets so long as growth rates of the animals are similar. It has been shown that some barley varieties produce beef with a lighter

color compared to beef from corn-fed animals. A barley variety, Logan, has also been reported to produce beef with lower color stability compared to corn and other barley varieties. Most research findings have indicated that the sensory quality of beef from barley-fed animals is comparable to beef fed other finishing diets. Based on the results of studies included in this review, barley grain and whole-crop barley silage will be good feeds for beef cattle provided good barley varieties are used and proper processing methods for the grain or for the whole crop are adopted.

Much more research has been done on barley grains than on whole crop barley silage. Comparing the effects of whole-crop barley silage, grass silage and pasture feeding on meat quality is an important research area. Vitamin E content of the muscle tissue affects color pigment and lipid oxidation. Recent research findings have shown that barley contains 2'-O-GIV isovitexin, an isoflavonoid antioxidant that should be tested for desirable effects on the oxidative stability of beef by feeding whole-crop barley. The fatty acid composition of beef from cattle fed whole-crop barley silage should be compared with those fed other silages and those fed on pasture.

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