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Breeding of Feed Grains for Western Canada

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ABSTRACT

The production of livestock in western Canada is moving from a small farm system to a highly mechanized, intensive system of production with animals having superior genetics. With this change, the feed demand by the industry has been moving from using the cheapest feed available to the best quality available. Defining that quality has been a challenge. Different classes of livestock have different feed demands. As well, adoption of production practices to maintain sustainability has meant a shift from maximization of inputs/outputs to integrated crop management and optimization of resource use. Through development of tools to enhance selection, and maintenance and development of diverse germplasm, breeding of the feed grains barley (*Hordeum vulgare* L.) and triticale (X *Triticosecale* Witt.) has been an evolving effort throughout western Canada. In this review, we present the changes and challenges of feed grain breeding with focus on the breeding program at the Field Crop Development Centre (FCDC), Lacombe, AB.

Keywords: barley, biomass, feed, feed quality, grain, silage, triticale

Abbreviations: ADF, acid detergent fiber; **ADG**, average daily gain; **ADL**, acid detergent lignin; **BMBRI**, Brewing and Malting Barley Research Institute; **BMP**, best management practices; **C**, carbon; **C/N**, carbon nitrogen ratio; **CMBTC**, Canadian Malting Barley Technical Centre; **CHO**, carbohydrate; **CP**, crude protein; **CWB**, Canadian Wheat Board; **DE**, digestibility energy (swine); **DM**, dry matter; **DMD**, dry matter digestibility; **DMI**, dry matter intake; **DON**, deoxynivalenol; **FCDC**, Field Crop Development Centre; **FHB**, fusarium head blight; **NDF**, neutral detergent fiber; **GE**, gross energy; **NE_g**, net energy for gain (ruminant); **NE_l**, net energy for lactation; **NIRS**, near infra-red reflectance spectroscopy; **NRC**, National Research Council; **NUE**, nitrogen use efficiency; **TME**, true metabolizable energy (poultry); **TME_n**, nitrogen corrected true metabolizable energy (poultry); **QTL**, quantitative trait loci; **WUE**, water use efficiency

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INTRODUCTION

Expansion of the livestock industry in western Canada has been possible because of a bountiful supply of feed grains. However, in some years, severe disease, drought, and other adverse environmental conditions have limited feed supplies and put livestock production at risk. Breeding of feed grains was begun in western Canada in an effort to ensure adequate feed supplies for our livestock. As animal genetics has improved and intensive management systems have been implemented, the demand for superior feeds has increased. As well, improved resource utilization is becoming more important to reduce environmental footprints and meet the reality of resource limitations in grain production systems.

HISTORY OF BREEDING FEED GRAINS FOR WESTERN CANADA

Barley

Barley was introduced to western Canada from Europe by the earliest settlers. Improved types came in the 1800s as later settlers moved north and west from Ontario and the USA. Generally these early barleys were both two- and six-rowed types. While very early barley production in eastern Canada was for the malting industry, trade barriers halted that industry and barley production turned to feed (Metcalfe 1995). As the population increased, domestic demand for malting barley increased and breeding efforts to improve

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barley for malting began. As the malting industry in Canada preferred the six-rowed types, they became predominant. Metcalfe (1995) provides an excellent history of barley development in Canada until the mid 1990s.

In Alberta, six-rowed remained the predominant barley grown until the 1990s with both malting and feed cultivars being six-rowed. From the 1960s to 1990s two-rowed barley was predominantly grown in southern Alberta (south of Hwy 1) and six-rowed in central and northern Alberta. Six-rowed barley remained the dominant barley in Manitoba while the picture began changing in Saskatchewan. With the advent of the two-rowed malting barley cultivar 'Harrington' (Harvey and Rossnagel 1984), the whole picture of barley production in western Canada changed. 'Harrington' was a phenomenal malting barley that replaced six-rowed barley across the prairies. By the 1990s 'Harrington' had become the king of barleys and was grown on 50% of the western Canadian barley acreage [Brewing and Malting Barley Research Institute (BMBRI) 1999].

But all reigns come to an end and by the arrival of the 21st century 'Harrington' was being outpaced by newer malting cultivars. Yield increases in both two- and six-rowed barleys made producers eager to switch. It took the malting industry longer to adjust, and still they wanted to concentrate on just one barley so 'AC Metcalfe' (Legge *et al.* 2003) was crowned the heir apparent and in 2005 finally overcame 'Harrington' in acreage. By 2009, 'Harrington' was no longer recommended by the Canadian Malting Barley Technical Centre (CMBTC) as a malting barley for production in western Canada.

One of the other changes occurring with 'Harrington' on so many acres was the noticeable improvement in productivity of general purpose barleys that often outyielded 'Harrington' by up to 25%, and had much better disease resistance packages (FCDC unpublished data). This yield advantage was first seen in the general purpose cultivar 'CDC Dolly' (Rossnagel and Harvey 1994), a two-rowed barley with very plump seed, high test weight, and moderate resistance to scald (*Rhynchosporium secalis*). The recommendation that barley for feed be over 48 lb/bushel led to the widespread adoption of 'CDC Dolly'. In Alberta by 2005, acres seeded to malting cultivars declined from 60% in the mid 1990s (BMBRI 1998) to 45% by 2009 [Canadian Wheat Board (CWB) 2009]. In 1999 a new two-rowed cultivar 'Xena' toppled 'CDC Dolly' and has became the first general purpose cultivar to be grown on 30% of the acreage in Alberta (CWB 2009). It combines high test weight with high grain yield.

Triticale

Triticale can be viewed as the first man-made crop species. It is a cross between wheat (*Triticum* spp.) and rye (*Secale cereale* L.). Although the first crosses were made between the hexaploid wheats (*T. aestivum*) and rye, these octoploid triticales were often difficult to maintain and had very shrunken kernel traits. The crosses between tetraploid wheats (*T. durum*) and rye to produce hexaploid triticale have proven to be better germplasm for conventional breeding of triticale with improved plant and kernel traits, and these types have become the standard triticale being commercialized throughout much of the world. In Canada, early triticale breeding was initiated by the Rosner Chair at the University of Manitoba, and Larter (1995) did an excellent review of the early work done on triticale in Canada. While triticale has not become a popular food crop in North America due to poorer bread and pasta making qualities than wheat, it has gained popularity as a feed and silage crop in western Canada. In Alberta, the work of Dr. Don Salmon (FCDC) and Dr. Vern Baron (AAFC, Lacombe Research Centre) on the use of triticale as a silage and pasture crop has stimulated continued interest in triticale. Dr. Salmon has created new high yielding triticales of both spring and winter types for swath grazing and annual pasture use. The search for high starch grains for the bio-ethanol industry has also promoted interest in this crop.

Alberta's Feed Grains Breeding Program

In 1973 the Government of Alberta began a feed grains research project. Originally planned as a high lysine barley breeding project under sponsorship of the Alberta Pork Producers, to attract a new young research scientist in the name of Dr. Jim Helm to head the project, it was expanded to a feed grains breeding program. Originally housed out of the University of Alberta, the program was moved in 1978 to its present location in Lacombe. While the program has undergone some changes over the years as funding has expanded and contracted, and responsibilities have been added and removed, it has essentially concentrated on the production of triticale and barley for feed. Dr. Don Salmon was brought on in 1980 to support the breeding effort in triticale. In 1992, the barley program was expanded with the signing of the Alberta-Canada barley agreement to include malting barley, and Dr. Bob Wolfe joined the group as a barley breeder. With Bob's retirement, Dr. Pat Juskiw joined the breeding contingent, and in 2001, Dr. Joseph Nyachiro joined the force.

Feed quality

In his review, Metcalfe (1995) saw the history of barley breeding in Canada for feed as beginning with the closure of market access to the USA for malting barley. Barley became a clean-up crop in Canada for weed suppression and quality declined due to improper management and weediness. However with the advent of modern breeding programs across the country, the quality and yields of barley were dramatically improved. Metcalfe (1995) concluded that early improvement in feed barley was due to improved purity, yield, and disease resistance. The second phase of improvement in feed barley in Canada was due to breeding for adaptation to local environments and included breeding of short-season cultivars such as 'AC Albright' (Wolfe *et al.* 1995a) and 'AC Stacey' (Wolfe *et al.* 1995b) by Dr. Bob Wolfe when he was stationed at the AAFC Beaverlodge Station. During this period, malting barley was again becoming more dominant and much of the acreage moved away from feed types to malting types. The third phase of improvement in feed barley was based on breeding for quality traits and while this generally was selection for higher percent plump and kernel and test weights, groups at the University of Saskatchewan and Crop Development Centre (CDC), Saskatoon under the leadership of Drs. Brian Rossnagel and Ron Bhatty and in Alberta under the leadership of Drs. Jim Helm (FCDC) and Wilhelm Sauer (University of Alberta), were working with animal nutritionists to better define feed quality. This work led to the release of hulless barleys that had greatly improved digestible energy for the pig over hulled types. At the same time in Montana, Dr. Tom Blake was working with Dr. Jan Bowman on the improvement of barley for ruminants.

The fourth phase of improvement of feed quality is currently underway and includes many feed grains. This project, under the leadership of Dr. Jim Helm, is development of Near Infra-red Reflectance Spectroscopy (NIRS) calibrations such that many quality traits can be determined on commercial lots of seed. Dr. Helm is working with animal nutritionists to develop calibrations for feed quality traits based on animal work. The second step of this NIRS development work will be to begin evaluating for feed quality the materials from the triticale and barley breeding programs throughout western Canada.

DEFINING FEED QUALITY

One of the most difficult challenges facing breeding programs for cereal grains is defining feed quality. There are several reasons for this, the two major factors being 1) the differences in feed requirements between livestock species and 2) the effect of growth or finishing stage on feed requirements within species. For instance the feed demands of chickens and pigs are very different from ruminants. The feed demands of a lactating dairy cow are very different from those of a cow-calf pair. The feed demand of a weaner pig is very different from those of a sow. While specifics of quality may differ between livestock classes, barley grain as a feed mainly serves to provide energy (Bhatty and Rossnagel 1981).

Campbell *et al.* (1995) found that test weight was positively correlated with starch content and negatively correlated to neutral detergent fiber (NDF) and acid detergent fiber (ADF) for barley grown in Manitoba. These types of results led to the general recommendation that test weight was a measurement of nutrient density and therefore would be a good criterion for predicting feed quality. However, within two-row barley, Juskiw *et al.* (2005) reported no significant correlation between test weight and feed composition for swine, including protein digestibility, digestible energy content, starch content, β-glucan content, or lipid content. The contradiction with the earlier study was probably due to confounding in the Campbell *et al.* (1995) study of row-type with composition, as the six-rowed cultivars had lower starch, higher fiber, and lower test weights than the two-row types.

Grain composition

1. Carbohydrates: Starch

Barley contains both large and small starch granules (MacGregor and Fincher 1993). Within these granules are amylose and amylopectin, with the proportion of each starch type dependent on barley genotype (You and Izydorczyk 2002). You and Izydorczyk (2002) found that amylose starches had low molecular weights while amylopectin starches have high molecular weights. Normal and high amylopectin (waxy) barleys had bimodal distribution of starch granules although proportions of large and small granules did differ between types. High amylose types had a unimodal distribution of starch granules with a high proportion of small granules. The different genotypes differed in the composition of their amylose. These differences may affect physico-chemical and functional properties of the starches.

Campbell *et al.* (1995) found that two-row barleys grown in Manitoba had higher starch content on average than six-row cultivars, but that malting types did not differ from feed types for this trait. The range in starch content was from 48 to 65% depending on cultivar and environment of growth. Edney *et al.* (1992) found a starch content of 63% in the hulless barley ‘Condor’ (Helm *et al.* 1992) that was significantly higher than the 58% for ‘Harrington’ hulled barley, and similar to Canadian Red Spring wheat at 65%. Damiran and Yu (2010) reported a starch content of 53% for normal hulless barley ‘CDC McGwire’ [Canadian Food Inspection Agency (CFIA) 2010], 48% for both waxy hulless barley ‘CDC Rattan’ (CFIA 2010) and zero-amylose waxy hulless barley ‘CDC Fibar’ (CFIA 2010), and 57% for high amylose barley HB08302 grown in Saskatchewan. Khorasani *et al.* (2000) reported that starch content of 40 barley lines and cultivars grown in Alberta in 1993 ranged from 48 to 63%. The hulless types contained a higher proportion of starch than the hulled types, and the two-rowed types more than the six-rowed types.

At FCDC, starch measurements within the barley program have been measured using NIRS (**Table 1**). The hulless barleys, as expected due to lower hull content, had higher starch contents than the hulled material and the two-rowed cultivars had higher contents than the six-rowed cultivars. The triticale had a similar starch content to the two-rowed barley. Starch contents in general were higher than reported by Khorasani *et al.* (2000) but the range in the FCDC material encompassed the previously reported range, and would be expected due to the wider range of growing conditions reflected in the FCDC data.

Table 1 The mean, standard deviation and range of starch, β-glucan, total dietary fiber, protein and lipid in the grain as measured by NIRS, for barley and triticale grown at FCDC research sites in Alberta from 1995 to 2008.

Parameter	Six-rowed†	Hulless	Two-rowed	Triticale
	Starch (%)			
Mean	59.5	64.5	61.1	61.1
Standard Deviation	1.5	3.1	1.5	3.2
Minimum	54.9	55.4	56.6	53.6
Maximum	67.9	75.3	68.4	65.6
	β-glucan (%)			
Mean	3.08	47.6	3.6	--‡
Standard Deviation	0.64	0.68	0.58	--
Minimum	0.59	0.67	0.46	--
Maximum	5.78	6.48	5.75	--
	Total dietary fiber (%)			
Mean	20.7	15.9	19.0	--
Standard Deviation	0.9	1.1	0.9	--
Minimum	8.0	6.7	8.4	--
Maximum	24.1	21.2	22.5	--
	Protein (%)			
Mean	10.9	13.8	11.9	13.4
Standard Deviation	1.5	2.1	1.9	1.7
Minimum	4.73	7.6	6.1	10.1
Maximum	15.79	21.2	25.3	16.3
	Lipid (%)			
Mean	2.36	2.31	2.63	--
Standard Deviation	0.26	0.27	0.22	--
Minimum	1.36	0.06	1.78	--
Maximum	3.01	2.91	3.35	--

† Selected cultivar data for the six-rowed barley were ‘AC Lacombe’, ‘Kasota’, ‘Manny’, ‘Sundre’, ‘Trochu’, ‘Tukwa’ and ‘Vivar’; for the hulless barley, ‘CDC McGwire’, ‘Condor’, ‘Falcon’, and ‘Tyto’; for the two-rowed barley, ‘AC Metcalfe’, ‘Bentley’, ‘Busby’, ‘CDC Bold’, ‘CDC Copeland’, ‘CDC Dolly’, ‘CDC Kendall’, ‘CDC Mindon’, ‘Champion’, ‘Conlon’, ‘Harrington’, ‘Newdale’, ‘Niobe’, ‘Ponoka’, ‘Seebe’, ‘TR05671’, and ‘Xena’; and for the triticale, ‘Bunker’, ‘Pronghorn’ and ‘Tyndal’.
‡ Data not available.

2. Non-starch polysaccharides: pentosans, β-glucans

Arabinoxylans (also called pentosans) account for approximately 20% of non-starch polysaccharides found in barley while β-glucans account for 70 to 75% of this component (Fincher 1975). The arabinoxylans are generally found in the aleurone layer of the seed while the β-glucans are found surrounding the starch granules in the endosperm. Fleury *et al.* (1997) found that arabinoxylan contents in barley grown in western Canada was dependent upon genotype and environment, with a range of 3.72 to 6.42% in total arabinoxylan contents. Six-rowed types tended to have higher contents than two-rowed or hulless types, but there was a wide range in contents within types that could mean potential gain through breeding and selection.

Bengtsson *et al.* (1990) found that for hulless barley, dietary or soluble fiber ranged from 13 to 21% of the barley grain, with β-glucan accounting for 5% of the grain in normal types but up to 10% in the cultivar ‘Arizona’. Molecular weights of the β-glucans differed between cultivars, with higher weights leading to higher viscosity of viscous slurries. In the FCDC program, β-glucan contents were higher in the hulless barley than in the hulled types, again as would be expected due to the lack of hull (**Table 1**).

3. Fiber

Total fiber in cereal grains is composed of soluble fiber, such as the pentosans and β-glucans, and the insoluble fiber such as cellulose, hemicellulose and lignin. In barley cultivars where the hull remains attached to the kernel, up to 21% of the total grain weight can be fiber (**Table 1**). Total dietary fiber in barley had a wider range than that reported by Bengtsson *et al.* (1990) as would be expected due to the soluble fiber being only one component of the total fiber in the grain. The hulless barley in FCDC studies had 3 to 5% lower total fiber contents than the two-rowed materials, again as would be expected due to lack of hull attachment (**Table 1**). In triticale, the hull is removed during threshing and total fiber content will be lower than in barley.

Campbell *et al.* (1995) found that two-row barleys grown in Manitoba had lower neutral detergent fiber (NDF) and acid detergent fiber (ADF) than six-row cultivars. The hulless barley 'Condor', due to its lack of hulls, was found to have about 70% less ADF than the hulled barley 'Harrington' (Edney *et al.* 1992). In the study by Du *et al.* (2009), 'CDC Cowboy' and 'McLeod' were found to have the highest NDF, ADF, and acid detergent lignin (ADL) contents of the six cultivars studied while 'CDC Dolly' and 'CDC Helgason' had the lowest fiber contents. Damarian and Yu (2010) found little variation in ADF of hulless barleys that varied in starch composition, however NDF was lower for the normal starch type 'CDC McGwire' than the waxy type 'CDC Rattan' that was lower than for the high amylose type HB08302 that was lower than for the zero-amylose, waxy type 'CDC Fibar'.

Lignin is a cell wall component composed of heteropolymers of primarily three hydroxycinnamyl alcohol monomers, *p*-coumaryl M1H, coniferyl M1G, and sinapyl M1S (Boerjan *et al.* 2003). Variations in the hydroxylcinnamyl alcohol monomers do exist due to incomplete biosynthesis and side-chain differences. Du *et al.* (2009) found that the hydroxycinnamyl acids in 6 two-rowed barley cultivars grown in Saskatchewan were ferulic acid with amounts ranging from 555 to 663 µg/g and *p*-coumaric acid with amounts ranging from 283 to 345 µg/g. These researchers found significant differences between cultivars in their ferulic acid contents, with 'McLeod' having the highest, and 'CDC Dolly', 'CDC Trey' and 'CDC Helgason' the lowest. With regards to *p*-coumaric acid, 'CDC Cowboy' and 'McLeod' had the highest content, while 'AC Metcalfe', 'CDC Dolly', 'CDC Trey' and 'CDC Helgason' had the lowest. The high *p*-coumaric acid contents in 'CDC Cowboy' and 'McLeod' were associated with high hull content in these cultivars.

4. Protein

Campbell *et al.* (1995) found that crude protein (CP) content of barley grown in Manitoba ranged from 9.3% to 18.2% depending on cultivar and environment of growth but could not attribute any pattern of difference to barley type. Edney *et al.* (1992) found that CP contents were very variable in the hulless barley 'Condor' but that essential amino acids tended to be higher in 'Condor' than NRC values for covered barley. Damiran and Yu (2010) reported that zero-amylose, waxy hulless barley 'CDC Fibar' had a higher protein content than waxy hulless barley 'CDC Rattan' that was higher than normal hulless barley 'CDC McGwire' or high amylose hulless barley HB08302. Khorasani *et al.* (2000) reported for 40 barley lines grown in Alberta, a range in CP content of 11 to 16% with hulless barleys having higher contents than the hulled types, but no differences between two and six-rowed types were noted. The data from FCDC supports these finding, although the range in the FCDC values was greater again reflecting the range of environments and years of assessment (**Table 1**). Triticale had higher CP content than the hulled barley and was similar to the hulless barley (**Table 1**).

5. Lipid

Campbell *et al.* (1995) found that lipid content of barley grown in Manitoba ranged from 1.3 to 3.2% but could not attribute the cultivar differences found to any specific type. Wang *et al.* (1993) found that in hulless waxy barley, the lipid fraction was composed of 55.8% α-tocotrienol and 25.3% polyunsaturated fatty acids. In the FCDC materials, the range in lipid content in barley was similar to those reported by Campbell *et al.* (1995). In the FCDC material, the two-rowed barley tended to have higher lipid contents than the hulless and six-rowed material (**Table 1**).

Ruminants

1. Grain

To be available to the ruminant microbial populations that break them down, starch granules within the barley grain must be exposed by processing or breakage of the kernels. The starch found in barley is easily degraded by the bacteria and has been associated with acidosis and other metabolic disorders of the gut. For the ruminant therefore, studies to improve barley quality have been focused on ways to reduce starch degradation in the rumen, or improve by-pass starch. In their review of starch digestion by ruminants, Cerrilla and Martinez (2003) discussed the importance of rumen micro-flora on digestion, the importance of adaptation to feed source in the prevention of metabolic disorders, and the importance of processing (both extent and method) on starch digestion.

Dry matter digestibility or disappearance (DMD) is the extent of feed breakdown in the rumen. McAllister *et al.* (1993) proposed that endosperm protein and the protein starch matrix were important determinants of DMD. Extent of DMD can vary greatly between genotypes, ranging from 8.2 to 62.1% in 1480 spring barley accessions from the USDA National Small Grains Collection (Bowman *et al.* 2001). Khorasani *et al.* (2000) reported that DMD was highest for 'Falcon' hulless barley (Helm *et al.* 2006a) and lowest for 'WX-Betzes', a waxy barley, however the rate of DMD was highest for 'BT 550' and lowest for 'CDC Guardian'. The soluble DM fraction was positively associated with starch content while the degradable DM fraction was related to test weight and CP content. Lehman *et al.* (1995) had earlier reported a range in soluble and degradable DM fractions in barley grown in Alberta, with two-rowed cultivars being more degradable than six-rowed, and hulless more degradable than hulled. Variations in these traits within types were found. Increasing grain hardness has been proposed as a means to reduce DMD. Camm (2008) in her thesis studies found that grain hardness of barley as measured by milling energy was closely associated with CP and β-glucan contents of the grain but was not consistently associated with rate of DMD. Du *et al.* (2009) reported that while there were significant differences in barley cultivars in hull content, particle size distributions, ferulic acid content, and *p*-coumaric acid content, these traits were not always related to *in situ* rumen DM degradability, and further study was needed.

McAllister *et al.* (1993) proposed that ruminal starch digestion was not a function of starch granule size, but was a function of protein and structural carbohydrate associateons within the grain. In their review, Kennelly *et al.* (1995) postulated that the effectiveness of by-pass starch would be dependent upon the amount of bypass protein, as a means of inducing amylase release by the intestinal wall for the digestion of starch in the intestine. Yu *et al.* (2004) found that the starch in 'Valier' barley was more closely associated with the protein matrix than in 'Harrington' barley, and proposed that this accounted for the slower digestion of starch from 'Valier' compared with 'Harrington'. Walker (2007) found that for the barley cultivars 'CDC Bold', 'CDC Dolly', 'Harrington' and 'Valier', that decreasing starch: protein ratio corresponded to a decreasing rate of digestion for DM, CP and starch with the order 'CDC Bold'>'CDC Dolly'>'Harrington'>'Valier'. This was found to be associated with CHO: Amide I ratios using thermal-source Fourier Transform Infrared Microspectroscopy, however further studies were recommended to validate these relationships over a wider range of genotypes.

Silveira *et al.* (2007a, 2007b) found that the reduced dry matter intake (DMI) by cows fed barley versus corn (*Zea mays*) was not due solely to the fermentability of the grains or the hypophagic effect of propionate. Higher starch content of barley grains coupled with higher total tract starch digestibility led to higher milk yield. Overall, these researchers found that marked differences in barley grain properties (whether from genetics or environment was not ascertained from these studies) can have significant effects on nutrient metabolism and milk production by cows, effects greater than species (barley versus corn) and concentrate content. Zinn *et al.* (1996) found that hulless barley 'Condor' had some better quality traits for ruminants than the six-row hulled 'Leduc' (Wolfe *et al.* 1988) including higher starch and net energy for gain (NE_g), lower ADF, and higher total tract digestibility of organic matter, starch, ADF and energy; but in the end average daily gain (ADG) did not improve with feeding the hulless barley over the hulled barley. The speculation was that the improved digestibility led to metabolic disorders that limited growth. Damarin and Yu (2010) reported that zero-amylose, waxy and high amylose hulless barleys had much lower soluble and intermediate-degradable carbohydrate than waxy and normal starch hulless barleys, but much higher slowly degradable carbohydrate. Therefore altered starch in hulless barley, especially high amylose barley, that would provide greater rumen undegraded starch for digestion in the small intestine, could be a way to reduce acidosis in grain-fed animals.

Beauchemin *et al.* (1997) in their study of hulless versus hulled barley proposed that the differences in response of lactating cows to the two types of barley were due to differences in effects of processing on the two different hull types rather than net energy for lactation (NE_L). Hironaka *et al.* (1992) showed the effects of processing by steam rolling of barley, with over-processed and whole-barley diets being detrimental to gain in beef cattle. As for waxy (high amylopectic) barley versus normal starch barley, Foley *et al.* (2006) reported that degradability of normal barley starch was greater than that of waxy barley as was total tract apparent digestibility of DM and organic matter. Again these researchers suggested that the differences found between the two types of barley were probably due to differences in response to processing as much as it was to differences in starch and chemical composition, as the index they used to determine processing was higher for the waxy barley (88%) versus the normal barley (79%), even with identical roller settings. In their review of the role of microbial attachment on rumen digestion, McAllister *et al.* (1994) postulated that the reason for processing effects on apparent digestion and DMI of small grain cereals was due to the differential effect of processing on the barrier that the hull presents to microbial attachment and digestion, while over processing after hull penetration results in problems due to digestive disturbances.

Ramsey *et al.* (2001) studied the relationships of grain characteristics with *in vivo* digestibility of both rolled and ground grain barley. These researchers found that DM disappearance from rolled barley grain was not related to *in vivo* digestibility. There were measurable differences in apparent digestibility of barley grain in cattle with *in vivo* DM digestibility being related to ruminal DM disappearance and grain ADF content. Ruminal DM and starch disappearance rates were not correlated. When looking at the effects of the same barley varieties on bloat, liver abscess and performance of feed lot steers, Ramsey *et al.* (2002) reported that bloat and liver abscesses in the rumen increased with the rate of solubilization and degradation of DM and starch, and that these effects were profoundly affected by grain processing. The Montana group of Boss *et al.* (2003) found that bulk density (test weight) did not affect ADG rates in steers; however processing did have a significant affect. Ahmed *et al*. (2010) found that starch disappearance in the rumen for hulled barley could be enhanced by screening for specific kernel size and adjusting roller size accordingly. By separating the barley by kernel size these researchers were able to roll the small kernels without overprocessing the large kernels and thereby reduced the production of fines that lead to acidosis. Dehghan-banadaky *et al.* (2007) concluded from their review of the literature that quality (including fiber, starch, soluble DM, potentially degradable fraction and rate of DMD) of the barley grain before processing could affect the optimum method and extent of the effects of processing but that few studies have reported on the barley grain characteristics prior to processing, and that this was an area that required more study. Dry rolling tends to lead to unpredictability due to shattering and the production of fine particles. Steam rolling and temper rolling can reduce the formation of fine particles and allow more uniform particle size. However, no common evaluation standard exists for the comparison of barley grain processing methods, further confounding our ability to understand possible genotypic effects on the feeding value of barley for ruminants.

'Valier' barley was registered by Montana Agricultural Experimental Station (Blake *et al.* 2002). This cultivar was proposed to have larger particle size after rolling, lower ADF content and lower *in situ* extent of DMD (Surber *et al.* 1999) than other sister lines. Many studies on 'Valier' have been done since its release with variable results. Endecott *et al.* (2001) found no differences between *in vivo* DM digestibility of 'Valier' and its parents 'Lewis' (Hockett *et al.* 1985) and 'Baronesse' and their effects on final steer weight, ADG, intake, gain/feed ratio or carcass characteristic of steers. In a study by McDonnell (2004), DMD was higher for diets containing 'Valier' than diets containing 'Harrington' barley, but no differences were found in starch digestibility between the two diets, and no significant effects of cultivar were found on ADG or carcass characteristics. Grove *et al.* (2006a) reported that NE_g, starch intake and DM digestibility for 'Valier' was similar to corn, and these traits were higher than for two other barleys 'H3' and 'Haxby' tested; however, no difference is steer ADG or carcass characteristics were found. In a study by Iversen *et al.* (2006), 'Valier' had lower NE_g than corn, but again no differences in steer performance were found between corn and 'Valier' based diets. Grove *et al.* (2006b) found in their study that corn had higher energy content and higher starch intake than 'Valier' leading to better feed conversions, although no differences in ADG or carcass characteristics were found. Yu *et al.* (2003) found that fine processing of 'Valier' barley made it very similar in feed value to 'Harrington', although the two varieties had markedly different chemical composition.

Boles *et al.* (2005) attributed color stability of beef steaks to varietal differences in barley. However, they did not identify if it was due to genetic differences in the varieties or whether it was due to environmental effects on growth and development of the grain.

Bowman *et al.* (2001) found that in their sub-selections from the core collection, that six-row types generally had greater particle size, DM and ADF content, and lower starch content, DMD, ruminal starch digestibility and digestible starch content than two-rowed types. Hulless types had greater starch content and lower ADF and DM content than hulled types. While these generalizations are of interest, the important finding from their study was that great variation exists within each type, and from the breeding prospective could be accessed for future quality improvements in barley. However, in their comparison of 'AC Metcalfe' to five feed barley cultivars, Hart *et al.* (2008) concluded that despite significant differences in CP, NDF, ADF, non-structural carbohydrates, total digestible nutrients, fermentable cell wall carbohydrates, starch, soluble DM fraction, starch degradation rates, and ruminally degradable starch concentrations, that these differences were not large enough to effect feeding traits and *in situ* degradation kinetics.

Beta-glucan is assumed to be completely digested in the rumen of cattle. However, Grove *et al.* (2006c) found that barley β-glucan digestibility varied between cultivars, with the β-glucan in 'Valier' being less digestible than in 'Hockett' or 'Harrington'. The implication is that greater by-pass β-glucan will then be available to stimulate the immune system in the ruminant animal. In a subsequent study, Grove *et al.* (2008) reported that there were some improvements in immune response of calves consuming 'Valier'-based diets although in this study it did not translate into improved animal performance.

Goonewardene *et al.* (1994) found that the feed to gain ratio for triticale-fed steers was similar to barley, but ADG was lower in triticale than barley, and this was felt to be do to lower feed intake. However, this study was with 'Carman' triticale, a cultivar that does not have the plump kernel characteristic of modern triticale.

2. Whole plant (silage, greenfeed, straw)

Baron *et al.* (1992) found no significant relationship between time after heading and *in vitro* digestible organic matter content of whole plant biomass from six-rowed, hulled barley grown at Lacombe, AB but that relative whole plant yield was maximized at about 300 degree days (>5°C) after heading. Subsequently, Khorasani *et al.* (1997) found that the chemical composition of silages made from cereal grains was dependent upon yield component composition and that this composition was dependent upon the stage of maturity of the plants. Juskiw *et al.* (2000b) also showed that time of harvest after heading of cereal grains for whole plant biomass significantly affected the distribution of that biomass between leaves, stems, and heads, and related this composition to the quality of the forage (Juskiw *et al.* 2000a). Because of this interaction of growth stage with quality, defining quality traits for forage becomes even more difficult than for grain traits.

In a study by Khorasani *et al.* (1993), triticale silage was found to be as effective in dairy cow performance as barley or oat (*Avena sativa*) silage when fed *ad libitum*. All three cereal silages were found to be as effective as alfalfa (*Medicago sativa*). ZoBell *et al.* (1992) had found triticale silage was a satisfactory feed for steers.

One of the problems associated with barley forage is the rough awn trait, with the perception that rough awns get caught in the mouth and may cause or aggravate mouth abscesses (Karren *et al.* 1994). Hooded varieties have been proposed as means to alleviate this problem. However Todd *et al.* (2003) found that the awned cultivar 'Valier' had as good of DMI, ADG and feed efficiency as the hooded varieties 'Westford' and 'Haybet' (Hockett *et al.* 1990).

Swath grazing of cereal grains is an alternative feed strategy for beef cows over the winter (Aasen *et al.* 2004). Baron *et al.* (2006) found that there was little nutritive decline over the winter, but that as the cows fed, the quality declined as they preferentially consumed the best quality material within the swath first and trampled the remaining swath. McCartney *et al.* (2008) reviewed the use of cereals for grazing by beef cattle. Some of the options for supplementary grazing included swath grazing, grazing the regrowth after harvest for silage of spring/winter cereal mixtures, or grazing of spring or summer planted spring/winter cereal monocrops or mixtures. In the latter case some problems with high nitrate and potassium contents can lead to health concerns in cattle (Juskiw *et al.* 1999).

Very little work has been done on the evaluation of straw quality in western Canada. In their review, McCartney *et al.* (2006) reported that cereal straw has very little economic value due to its low nutritive value, but that due to availability can be a substantial feedsource for beef cows. Quality of straw in western Canada was dependent upon many factors including stage of maturity, harvest methods, weathering, cultivar and species. Mathison *et al.* (1999a) were able to determine differences between barley genotypes for straw quality traits of NDF, CP, and effective rumen degradability of DM. These researchers found that straw from two-rowed barley had higher CP than from six-rowed types, straw from hulless barley contained more NDF than straw from hulled types, and that straw from semi-dwarf barley had more CP, NDF, and 9% higher effective rumen DM degradability than straw from hulled types. Mathison *et al.* (1999b) determined that degradability was also closely related to lignin content of the straw. Cultivar differences in ADF, ADL, carbon (C), nitrogen (N) and C/N were reported by Stubbs *et al.* (2009) and while values varied with year and location, the relative rankings of the cultivars were stable. The feed cultivars evaluated ('Xena' and 'Baronesse') tended to have the lowest ADL values while the malting varieties 'AC Metcalfe' and 'Harrington' had the highest values.

Swine

Much of the work on determining the nutritive value of barley for swine in western Canada has been due to the development of hulless barley. Bhatty *et al.* (1979) and Bhatty and Rossnagel (1981) first reported on the nutritional quality that could be obtained from hulless barley. In their studies, Bhatty and Rossnagel (1981) reported that hull content (hulless versus hulled) was the only significant factor affecting digestible energy (DE) when fed to either mice or swine. Digestible energy was not related to kernel weight, test weight or plumpness. Juskiw *et al.* (2005) also reported on the lack of relationship between grain physical traits and feed quality for swine.

While gain in swine is related to content of DE, Bell and Keith (1994) found that barley hulls from the hulless cultivar 'Condor' could have a positive effect on feed efficiency of wheat-based diets but not in hulless barley-based diets. These researchers postulated that barley hulls may contain dietary fiber such as β-glucans that had a positive effect on feed efficiency in grower and finisher diets. Bell and Keith (1993) previously reported that higher wheat ratios in barley:wheat finisher diets improved dressing percentage and carcass weight but resulted in a lower carcass index value due to increased carcass fat content. In their study of the effects of hull content on the feeding value of 'Condor' hulless barley to growing swine, Darroch *et al.* (1996) found that the addition of hulls decreased CP content, CP digestibility, energy digestibility, and increased ADF and NDF contents. 'Condor' did have higher DE than hulled barley or wheat, so would reduce the need for fat supplementation to the swine diet thereby reducing costs.

Fan *et al.* (1993) found variability in the digestibility of amino acids in barley, but that overall digestibility was related to CP content in the barley, with higher protein leading to better digestibility.

Phytic acid (phytate) is the form in which most plants store phosphorus. Phytate is not digestible by monogastric animals, necessitating the addition of phosphorus to the diet or the enzyme phytase to break down the phytate. The low phytate trait, where a mutation in the phosphorous pathway blocks the formation of phytate, may be a means of improving feed quality of cereal grains. Thacker *et al.* (2003) compared diets containing the hulled barley 'CDC Bold' (normal phytate content) with hulled lines with 68, 41, and 3% normal phytate contents and hulless barley 'CDC Dawn' (normal phytate content) with a hulless line with 54% normal phytate content when fed to finishing pigs. Phosphorus digestibility increased as the content of phytate in the barley declined. The low phytate trait had no effect on digestibility of the DM, CP or GE. Thacker and Rossnagel (2006) found that performance of swine fed low-phytate hulless barley without supplemental inorganic phosphorus but with phytase was equivalent to that of animals fed normal phytate barley supplemented with inorganic phosphorus.

Beltranena *et al.* (2008) reported that triticale could be used successfully in weaned pig rations and that the four spring triticale cultivars tested had slightly higher protein, calcium, phosphorus and energy digestibility compared to wheat thereby resulting in higher feed efficiency.

Poultry

Scott *et al.* (1998) found that actual metabolizable energy (AME) as measured by GE minus ash and excreta in barley fed to broiler chicks ranged from 2,810 to 3,480 kcal kg^{-1}. Classen *et al.* (1988) found that hulless barley was equivalent to wheat in diets for laying hens, and was superior to conventional barley. However, barley based diets benefit from β-glucanase supplementation, especially if the barley is high in β-glucan (Campbell *et al.* 1989). Zhang *et al.* (1994) found that nitrogen-corrected true metabolizable energy (TME_n) from 91 barley samples ranged from 13.1 to14.6 MJ kg^{-1}, and that this trait was positively correlated with fat, starch and test weight, and negatively correlated with NDF. However, only the relationship with NDF accounted for a significant portion of the variation in TME_n. Ankrah *et al.* (1999) found that waxy barley could be effectively used as a feed for broiler chicks if β-glucanase was added to the formulation, and the waxy barley offered better thermostability and lower heat requirement for gelatinization in the formation of pellets.

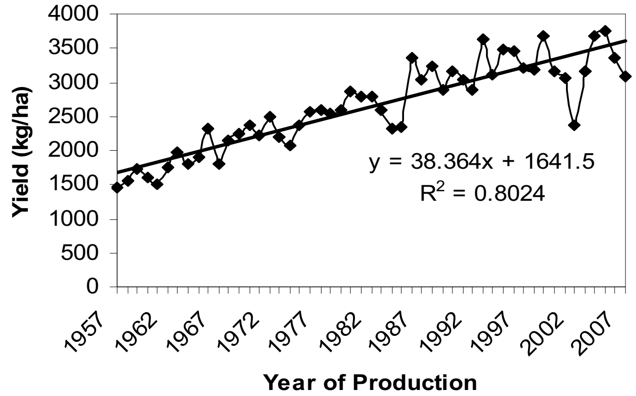

Fig. 1 Grain yields for barley grown in Alberta, Canada, from 1957 to 2007. Adapted from production numbers in Alberta Agriculture and Rural Development (2008).

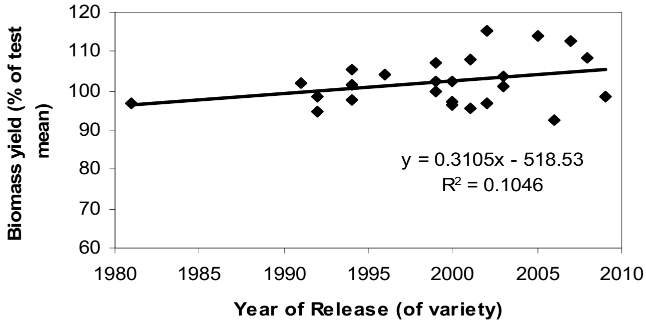

Fig. 2 Biomass yields at the soft dough stage of cultivars released in western Canada from 1981 to 2009. Biomass yields were measured at the Field Crop Development Centre, Lacombe research site, from 2003 to 2008. Measurements per entry varied from one to eight years.

BREEDING OBJECTIVES AND GOALS

Yield

1. Grain

Increasing yields has probably been the most effective way to increase the carrying capacity of barley in western Canada. In Canada, there has been an approximate 1% increase in yield per year due to genetic improvement of the barley crop (Bulman *et al.* 1993; Jedel and Helm 1994a). Over the 50 year period from 1957 to 2006, the average grain yields for barley grown in Alberta increased by approximately 38 kg ha^{-1} yr^{-1} (**Fig. 1**). This increase in productivity was due to the combination of increased inputs (especially fertilizer) and higher yielding varieties. Given that 2002 was one of the driest years on record since the dirty 30s of the 20th century and average yields were about one-third lower than normal for that 10 year period, the yield increase as measured by slope of the yield versus year graph have been substantial.

In our early work on assessing the optimal barley ideotype for Alberta (Jedel and Helm 1994a), we determined that yield increases in spring barley were associated with increased harvest indices (more grain to total biomass) and reduced lodging. Yield losses have been significantly associated with lodging, with greatest yield and quality losses occurring when the lodging occurred at the milk or soft dough stages of development (Jedel and Helm 1991). Jedel and Helm (1994a) suggested that future yield increases in six-rowed barley would be possible if harvest indices could be held constant and vegetative biomass could be increased, the pre-stem elongation period could be lengthened (increased leaf numbers leading to higher vegetative biomass), and increasing culm widths (associated with improved resistance to lodging) (Jedel and Helm 1994a, 1994b). The cultivar 'Vivar' (Helm *et al.* 2003) reflects the six-rowed ideotype with high yields associated with excellent resistance to lodging. In two-rowed barleys, Jedel and Helm (1994a) recommended increasing harvest indices, vegetative yield, kernel weights and kernel numbers per spike, and increasing culm widths to improve lodging resistance. As well increasing leaf widths may offer a way to improve vegetative yields and be associated with wider culms. The cultivar 'Bentley' (Juskiw *et al.* 2009a) reflects an advancement in the two-rowed ideotype with high grain and vegetative yields.

2. Whole plant

Improvements in whole plant biomass productivity are somewhat lagging as yield and quality are related to time of harvest. Jedel and Helm (1994a) reported that while grain yields have increased in western Canada in cultivars released from 1910 to 1987, the yield increases have been associated with increased harvest indices (ratio of grain to biomass), and no significant increases in biomass productivity were noted in their study. When we look at the biomass yields at the soft dough stage of cultivars released from 1981 to 2009, again no significant increases have been made in biomass yields in general over two- and six-rowed hulled varieties (**Fig. 2**). However, there has been a trend in recent years to release cultivars with higher biomass yields, such as 'Sundre' (Nyachiro *et al.* 2007) and 'Bentley', or specifically for their forage yields such as 'CDC Cowboy' and 'Binscarth' (Therrien 2006) released in 2004, and 'Desperado' (Therrien 2009) released in 2007.

With the perception that rough awns may aggravate mouth lesions and affect palatability for cattle, FCDC has made an effort to produce smooth-awned barleys such as 'Falcon', 'Trochu' (Helm *et al.* 2002), 'Tyto' (Helm *et al.* 2004), 'Sundre', and 'Chigwell'. In triticale, FCDC has released two reduced-awn spring triticales, 'Bunker' (Salmon *et al.* 2007a) and 'Tyndal' (Salmon *et al.* 2007b), and three reduced-awn winter triticales, 'Bobcat' (Salmon *et al.* 2000), 'Luoma' and 'Metzger'.

For forage use, mixtures may be the option of choice. However, the choice of cultivars within a mixture must be based on the needs of the producer. We found in mixture studies that intraspecific mixtures offered some yield and quality advantages, especially if there was a range of maturity in the different components of the mixture (Juskiw *et al.* 2000a). In interspecific mixtures, especially of barley and triticale, we found that the window of opportunity to harvest with high yields and quality was much broader than with the intraspecific mixtures. In all cases we found that some cultivars were much more competitive than others, and we recommended selection for competitive ability in breeding for cultivars suitable for mixture use. Another option is planting a spring/winter mixture for silage/pasture use. In this case, it is important that the spring cultivar not be an aggressive competitor so that the winter cereal canopy does receive adequate light during the early growing season for root establishment to nurture regrowth in the fall after harvest for silage (Jedel and Salmon 1995).

Grando *et al.* (2005) have identified several quantitative trait loci (QTL) related to forage quality traits in barley. Ten QTL were identified for ADF, one for NDF, eleven for lignin, twelve for organic matter digestibility, twelve for intake and four for CP (although dependent upon location). These authors present their findings as relating to straw, however no indication was given of growth stage at harvest. At FCDC we are currently working on a project to improve fiber digestibility in barley and triticale, especially for use as silage. Fiber digestibility was found to be 8% better in the barley cultivar 'Falcon' compared to the cultivar 'Tyto' (Swift *et al.* 2009).

3. Resource utilization efficiencies

In the 1980s, ICM practices referred to intensive crop management that involved production practices, such as high fertilizer rates and the use of pesticides, fungicides and growth regulators, to maximize grain yields (Jedel and Helm 1992). These practices were focused on yield as the ultimate crop production goal, with input costs and adverse environmental impacts (including environmental footprints) not being considered. In the late 1990s and the early 2000s, ICM changed to being integrated crop management. In this crop production scenario, a holistic production system is being promoted that looks at integration of production practices such as zero-tillage to reduce land cultivation, reduced herbicide usage, rotations to decrease disease, and increasing seeding rates to improve crop competition with weeds (O'Donovan *et al.* 2008).

As a further refinement to the best management practices (BMP) of ICM, we are also looking at resource utilization efficiencies especially for water and nitrogen. Anbessa *et al.* (2009) found that there is good genetic variability in our spring barleys for nitrogen use efficiency (NUE). Selection of genotypes that perform well (yield) under low N conditions should be a successful strategy for improving NUE. As well at FCDC, we routinely screen our advanced generation material for water use efficiency (WUE) and have found significant differences within barley and triticale genotypes (FCDC unpublished data). There are both environmental and genotypic components of resource utilization efficiencies, and while we can search for those genotypes that have better utilization, it needs to be under a plethora of production and environmental environments that can limit selection efficiencies. If we can develop genetic markers for traits or more effective screening technologies, more rapid advancement in trait selection may be possible.

Quality

Because feeding trials and reference methods to evaluate feed quality are time-consuming and expensive, near infrared reflectance spectroscopy (NIRS) analysis offers potential to be a rapid, non-destructive, and relatively in-expensive alternative. However, calibrations need to be developed based on accurate and repeatable reference methodologies, and the development of these calibrations can be time consuming and expensive. Edney *et al.* (1994) showed that robust calibrations could be developed for true metabolisable energy (TME), *in vitro* DM digestibility, NDF, CP, and kernel plumpness in feed barley. Helm *et al.* (2000) reported on the successful development of NIRS calibrations for protein digestibility, energy digestibility and DE content (reference method was pig assays using nylon bags) and for CP and GE [reference methods: CP determined by Leco FP-428 Nitrogen Analyzer (Leco Corporation, St. Joseph, MI, USA); GE determined by Adiabatic Bomb Calorimeter (Parr Instruments, Moline, IL, USA)].

Juskiw *et al.* (2005) showed that for two-rowed barley grown in Alberta, the traditional quality measurements of test weight, kernel weight and percent plump were often not significantly related to feed quality traits such as protein digestibility and DE content, or were actually negatively related to quality traits. However, these traditional quality measurements may be related to uniform processing that is important to feed quality. Improvements in lodging resistance can also improve processing quality, as lodged barley often has lower percent plump, kernel weights, and test weights (Jedel and Helm 1991; FCDC unpublished data). Xi *et al.* (2000) also found that resistance to scald was effective in maintaining kernel weights when there were significant yield losses due to the pathogen.

1. Carbohydrates: Starch

As cereals grains are primarily used as a source of energy in feed rations for all classes of livestock, higher starch contents would seem to be a way to provide this energy content. However in ruminants, the metabolic problems associated with high rates of digestion due to rapidly converted starch in the rumen has led to the proposal that changes should be made in starch composition in barley to increase the amount of by-pass starch (thereby decreasing the DM digestibility). Li *et al.* (2004) reported that hydrolysis of starch was dependent on type of starch with normal and high amylose starches being more resistant than waxy starch (high amylopectin). The differences were attributed to differences in granule structures with the starch in the granules of waxy hulless barley being more open than normal or high amylose types. Waxy types have been incorporated into triticale at FCDC and marker development for the waxy types in triticale is underway by Dr. Jennifer Zantinge (FCDC).

Starch and CP contents are negatively correlated within the grain, so effort to increase the starch component of the grain can be made by decreasing the protein component. However, the latter may be detrimental to improving by-pass starch, as McAllister *et al.* (1993) and others have speculated that it is the protein matrix around the starch granule that improves resistance to rapid starch degradation. The cultivar 'Valier' is an excellent example of selection for improved protein:starch ratio, reduced rumen starch digestibility, etc., and yet in many studies, there has been no difference in ADG and meat quality. This lack of positive response leads us to question whether we are measuring the correct factors and if the hypotheses are correct.

Certainly for swine, DE in two- and six-rowed barley was positively related to starch content in FCDC long-term quality data (**Table 2**). However, in hulless barley the relationship was negative. Protein digestibility was positively correlated to starch content in six-rowed barley, but not in hulless or two-rowed barley.

2. Non-starch polysaccharides

Li *et al.* (2008) in their study of a low β-glucan ('CDC Bold') x high β-glucan ('TR251') doubled haploid population found several major QTL governing this trait, with two on chromosome 5H and one in the centromere region of 7H, that could be used in development of high and low β-glucan normal starch barley types. Because β-glucans can have some positive health benefits depending on the class of livestock, but are negatively associated with gain in weaner pigs and poultry, it is still unclear in what direction breeding efforts in feed quality should take this trait. Beta-glucanase enzyme is added to poultry and sensitive animal rations, so low contents may not be necessary for these classes of livestock depending on the economics of enzyme addition. In the FCDC data, DE was negatively related to β-glucan content in hulled barley but was positively related in the hulless barley (**Table 2**). Protein digestibility was negatively related to β-glucan contents in all three barley types. These relationships were also found for total dietary fiber, except that for hulless barley, DE was negatively related.

3. Fiber

Grabber *et al.* (2009) found that additions of various monolignols increased the ruminal fermentation times for hemi-

Table 2 Correlations of protein digestibility and digestible energy content for swine with starch, beta-glucan, total dietary fiber, protein and lipid content in the grain as measured by NIRS of selected six-rowed, hulless, and two-rowed barley cultivars (as noted for **Table 1**) grown at FCDC research sites in Alberta from 1995 to 2008.

Component (%)	Six-rowed	Hulless	Two-rowed
	Digestible energy (Kcal/kg)		
Starch	0.205***†	-0.264**	0.080***
β-glucan	-0.247***	0.341***	-0.215***
Total dietary fiber	-0.665***	-0.319***	-0.534***
Protein	0.128***	0.403***	0.412***
Lipid	0.353***	0.255**	0.455***
	Protein digestibility (%)		
Starch	0.173***	-0.159***	-0.022NS
β-glucan	-0.638***	-0.564***	-0.567***
Total dietary fiber	-0.155***	-0.245***	-0.302***
Protein	0.224***	0.670***	0.232***
Lipid	0.131***	-0.206***	0.068***

† Where *** indicates that the correlation was significant at P<0.001, ** at P<0.01 and NS indicates the correlation was non-significant at P>0.05.

cellulose. They postulated that reduced lignification or ferulate-lignin cross-linking would improve fiber digestibility more than shifting lignin composition. An improvement in fiber quality in corn has been associated with the brown mid-rib trait and a number of alleles for this trait have been found to be associated with mutations in the enzyme *o*-methyltransferase which is involved in lignin biosynthesis (Vignols *et al.* 1995). These mutants have reduced lignin production. Du *et al.* (2009) found that reduced fiber content in barley was associated with reduced hull content. Therefore, it should be possible in hulled barley to reduce fiber content simply by reducing hull content, so long as peeling does not become a problem. Loose hulls may cause processing problems.

From the food side, Ugartondo *et al.* (2009) found that lignins have potential health benefits as they reduce hydrogen peroxide induced lipid peroxidation (production of oxygen-derived free radicals). Effectiveness of the lignins was related to their molecular weight, with lighter molecules being more effective scavengers than heavier molecules. It is possible that some lignins in feed rations may lead to improved gut health in older animals such as sows. Further study in this area is needed to identify the types of lignin that are most effective in promoting animal health.

4. Protein

Barley and triticale are fed as an energy source, so protein content is not a major objective of the breeding program at FCDC. However, cereals can be a good source of essential amino-acids, so digestibility of the protein for non-ruminants is an important consideration. At FCDC, a wide range in protein digestibility has been measured, and selection for improvements in this trait is underway. Protein content in barley was positively related to DE and protein digestibility in the FCDC data (**Table 2**).

5. Lipid

The range in lipid content in barley and triticale is small, and cereals are not used as an oil source. Small increases in lipid content could be possible, leading to higher DE content as lipid content was positively related to DE content and protein digestibility for hulled barley in the FCDC data (**Table 2**). Little attention has been made to increasing lipid content in barley due to the narrow range in this trait. Parsons and Price (1974) assayed 60 barley lines from the United States Department of Agriculture Barley World Collection and found seven barleys with lipid contents ranging from 9 to 35% higher than the cultivar 'Prilar' (Price 1974). The highest content was found in CI12116 with a lipid content of 4.6%. Subsequent studies with this line at FCDC could not validate the high lipid content of this line (Helm, pers. comm.). As well, lipids in malting barley can reduce foam stability in beer, so high contents of lipids are not desirable, and breeding for malting quality has focused on reducing lipid content in the barley germplasm.

6. Phytic acid

Phosphorus in phytic acid is not digestible by monogastric animals without the inclusion of phytase enzyme (Thacker and Rossnagel 2006); however, reduced phytate genotypes that have a mutation in the phytate pathway are available. Roslinsky *et al.* (2007) have found that *Lpa*1-1 locus which causes a 50% reduction in phytic acid contents can be marked by a SCAR marker on chromosome 2HL. The *lpa*2-1 gene was found to be marked to chromosome 7HL. The *lpa*3-1 gene that causes a 75% decrease in phytate was found to be located to chromosome 1HL and could be identified by a LP75 marker. The *lpa*3-1 gene was found to mark to a similar chromosome area as the mutation in 'M955' (a 95% decrease in phytate) so those mutations may be allelic. Bretgitzer and Raboy (2006) found that the low phytate genes except for *lpa*1-1 were associated with yield losses in barley, mainly due to poor adaptation to low-rainfall conditions. A roadblock to the inclusion of the low phytate trait in barley has been imposed by the Canadian Food Inspection Agency's classification of rations made with low phytate grains as novel.

Disease resistance

When disease pressure is high, those cultivars with resistance can maintain yields and quality. In Fusarium head blight (FHB), the pathogen *Fusarium graminearum* produces mycotoxins such as deoxynivalenol (DON). High levels of DON can make grains unacceptable for human and animal consumption. Hogs are particularly sensitive to DON (levels must be < 1 ppm), while cattle can tolerate much higher levels. For the feed industry, improvements in FHB resistance in feed grains will be better supply of feed with lower DON levels and better feed conversions.

In central Alberta, Rauhala and Turkington (2009) reported the presence on barley of scald, the net-form of net blotch (*Pyrenophora teres* f. *teres*), the spot form of net blotch (*Pyrenophora teres* f. *maculate*) and some alternaria leaf spot (*Alternaria* spp.). Common root rot caused by *Cochliobolus sativus* and Fusarium spp. was also found at low levels in most fields. Stripe rust caused by *Puccinia striiformis* was found in one commercial field. In the previous year, Rauhala and Turkington (2008) noted scald, the net and spot forms of net blotch, physiological leaf spot and Septoria (*Septoria* spp.). Common root rot was also noted at low levels. No stripe rust was noted on barley although it was present in wheat fields. Lee *et al.* (2001) showed that seed from susceptible cultivars of barley could be a source of the scald during the next growing season, even when the seed did not show appreciable symptoms of the disease. Therefore, even when disease pressure is not strong in one year, it may escalate in a subsequent year, if the cultivar lacks disease resistance and the environmental conditions are conducive to growth of the pathogen.

As part of the breeding program at FCDC, foliar diseases of scald and net blotch on barley, and leaf spots on triticale are regularly screened in an effort to provide producers with resistant cultivars. Efforts are also underway to evaluate and improve resistance in barley and triticale to FHB. In triticale, resistance to ergot (*Claviceps purpurea*) is also targeted, with this resistance being improved through better fertility of the modern triticale cultivars. In barley, resistance to loose smut (*Ustilago nuda*), covered smut (*U. hordei*), and false-loose smut (*U. nigra*) are also routinely evaluated. In recent years, resistance to stripe rust and spot blotch (*C. sativus*, *Bipolaris sorokiniana*) have been added to our disease priorities. Resistance to common root rot is also a priority, although selection for resistance is difficult as screening for resistance is difficult due to year to year variation in the presence of the disease and lack of good sources of genetic resistance.

Good sources of resistance to scald are available, but due to the ever changing race structure of this pathogen, deployment of genes has posed a challenge (Xi *et al.* 2000, 2003). At FCDC and elsewhere in western Canada, breeding programs continue to evaluate germplasm from around the world for resistance to scald (Singh *et al.* 2003). Many introductions that are considered resistant in their origin country have proven to be ineffective against the races of scald present in Alberta. As well, adult plant screening for this disease is required as seedling reactions may differ from the adult plant response (Xue *et al.* 1995), as is seen in the cultivars 'Seebe' (Helm *et al.* 1996b) and 'Busby' (Juskiw *et al.* 2009b). By screening our breeding material at multiple locations in Alberta and Mexico, we have been able to develop cultivars such as 'Manny' (Nyachiro *et al.* 2005) and 'Sundre' that have multiple gene resistance to the pathogen.

Resistances to net blotch and spot blotch have originated from the breeding programs of Dick Metcalfe (AAFC-Cereal Research Centre) and Jerry Franckowiak (North Dakota State University). The line 'TR251' from Bill Legge (AAFC-Brandon Research Centre) has as its parents sources of resistance from both programs (TR229// AC Oxbow/ND7556) and is now serving as an excellent source of resistance to these two diseases in two-rowed barley cultivars. The genes for spot blotch resistance in the two-rowed germplasm come from six-rowed cultivars (Jerry Franckowiak, pers. comm.).

For loose smut, the *Run8* gene has proven to provide a durable resistance source, and is used extensively in the breeding programs across western Canada. Eckstein *et al.* (2002) have developed a marker for the gene located on the long arm of 1H. Resistance to covered smut is also thought to be controlled by a limited number of resistance genes although screening is complicated by getting effective inoculation (Grewal *et al.* 2006).

Legge *et al.* (2004) reported on the collaborative work that is being done in western Canada to improve resistance to FHB in barley. Screening for FHB takes place in the main nursery at AAFC Brandon Research Centre, with minor screening at off-stations in Charlottetown PEI, Ottawa ON, and Portage-la-Prairie MB. Screening for reduced DON levels has been the primary focus of selection for resistance in barley. At the FCDC, we also send material, both barley and triticale, to Mexico for screening by the International Centre for Agricultural Research in the Dry Areas (ICARDA) and The International Wheat and Maize Improvement Centre (CIMMYT).

CONCLUDING REMARKS

As population demands for food, fuel and fiber and awareness of environmental issues increase, we are faced with the crisis of producing more with less. Resource limitation will be a reality of all future productivity whatever it is for. To address these efficiencies and produce the best quality feed possible for improved animal genetics, breeding feed grains continues to be about producing the highest yields possible. But this aim must be possible with the lowest inputs possible. As well to improve feed efficiency, the feed produced must have the highest intake possible, the highest conversion possible, the least output in manure, and it must address the growing knowledge we have on how animal feed contributes to animal health. The whole issue of fiber, both soluble and non-soluble, has only been rudimentarily studied. The right types and amounts of fiber may improve gut healthy that in the end may lead to better feed efficiencies in the animal. As well we need to be concerned not just with ADG, milk production or egg production, but also with the quality of the products being produced. The healthier or more desirable these products are for the consumer, the more efficiently they will be used.

Variability for many of the traits that we can currently measure has been found, but one of the major limitations to data from many of the animal studies is that it is difficult to partition the variability measured between genetic components and environmental components. Advancements in traits through plant breeding can only be accomplished if we have genetic variability, can accurately measure the desired trait in a non-destructive manner, and are measuring the right traits. However, as there is only so much starch, protein, fiber and lipid that can be put into a seed, any alteration in one component may have a negative effect on another component. Optimal balance of components must be maintained. As well, enzymes, vitamins, and other compounds are routinely added to feed and grain is only one component of the feed ration, so improvements in feed grains must be in balance with other economically viable components.

We can perhaps improve feed quality by paying more attention to the fiber component of feed grains and especially how we can alter the β-glucan/protein matrix around the starch granule to optimize feed utilization by different classes of livestock. By working closely with animal nutritionists, these questions can be addressed and further improvements in feed grains can be made. Specific feed quality traits must have an economic value to the animal producer by improving the amount and quality of the end product produced.

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REFERENCES

Aasen A, Baron VS, Clayton GW, Dick AC, McCartney DH (2004) Swath grazing potential of spring cereals, field pea and mixtures with other species. *Canadian Journal of Plant Science* **84**, 1051-1058

Alberta Agriculture and Rural Development (2009) Alberta Agriculture Statistics Yearbook, 2008. Available online: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd12885

Ahmad M, Gibb DJ, McAllister TA, Yang WZ, Helm J, Zijlstra RT, Oba M (2010) Adjusting roller settings based on kernel size increased ruminal starch digestibility of dry-rolled barley grain in cattle. *Canadian Journal of Animal Science* **90**, 275-278

Ankrah NO, Campbell GL, Tyler RT, Rossnagel BG, Sokhansanj SRT (1999) Hydrothermal and beta-glucanase effects on the nutritional and physical properties of starch in normal and waxy hull-less barley. *Animal Feed Science and Technology* **81**, 205-219

Anbessa Y, Juskiw P, Good A, Nyachiro J, Helm J (2009) Genetic variability in nitrogen use efficiency of spring barley. *Crop Science* **49**, 1259-1269

Baron VS, Dick AC, McCartney D, Basarab JA, Okine EK (2006) Carrying capacity, utilization, and weathering of swathed whole plant barley. *Agronomy Journal* **98**, 714-721

Baron VS, Dick AC, Wolynetz MS (1992) Characterization of barley silage – maturity relationships for Central Alberta. *Canadian Journal of Plant Science* **72**, 1009-1020

Beauchemin KA, Rode LM, Yang WZ (1997) Effects of non-structural carbohydrates and source of cereal grain in high concentrate diets of dairy cows. *Journal of Dairy Science* **80**, 1640-1650

Bell JM, Keith MO (1993) Effects of combinations of wheat, corn or hulless barley with hulled barley supplemented with soybean meal or canola meal on growth rate, efficiency of feed utilization and carcass quality of market pigs. *Animal Feed Science and Technology* **44**, 129-150

Bell JM, Keith MO (1994) Effects of adding barley hulls and linseed meal to wheat and hulless barley diets fed to growing pigs. *Animal Feed Science and Technology* **45**, 177-191

Beltranena E, Salmon DF, Goonewardene LA, Zijlstra RT (2008) Triticale as a replacement for wheat in diets for weaned pigs. *Canadian Journal of Animal Sci*ence **88**, 631-635

Bengtsson S, Aman P, Graham H, Newman CW, Newman RK (1990) Chemical studies on mixed-linked beta-glucans in hull-less barley cultivars giving different hypocholesterolaemic responses in chickens. *Journal of the Science of Food and Agriculture* **52**, 435-445

Bhatty RS, Christison GI, Rossnagel BG (1979) Energy and protein digestibilities of hulled and hulless barley determined by swine-feeding. *Canadian Journal of Animal Science* **59**, 585-588

Bhatty RS, Rossnagel BG (1981) Nutritional requirements in feed barley. In: *Barley Genetics IV Proceedings of the Fourth International Barley Genetics Symposium*, Edinburgh, pp 341-347

Blake T, Bowman JGP, Hensleigh P, Kushnak G, Carlson G, Welty L, Eckhoff J, Kephart K, Wichman D, Hayes PM (2002) Registration of 'Valier' barley. *Crop Science* **42**, 1748

Boerjan W, Ralph W, Baucher M (2003) Lignin biosynthesis. *Annual Review of Plant Biology* **54**, 519-546

Boles JA, Bowman JGP, Boss DL, Surber LMM (2005) Meat color stability affected by barley variety fed in finishing diet to beef steers. *Meat Science* **70**, 633-638

Boss DL, Bowman JGP, Surber LMM, Sattoriva DG, Blake TK (2003) Effects of barley processing and bulk density when fed to backgrounding calves. *Proceedings, Western Section, American Society of Animal Science* **54**, http://www.asas.org/westernsection/proceedings03.asp

Bowman JGP, Blake TK, Surber LMM, Habernicht DK, Bockelman H (2001) Feed-quality variation in the barley core collection of the USDA National Small Grains Collection. *Crop Science* **41**, 863-870

Bregitzer P, Raboy V (2006) Effects of four independent low-phytate mutations on barley agronomic performance. *Crop Science* **46**, 1318-1322

Brewing and Malting Barley Research Institute (1998) 50th Annual Report, BMBRI, Winnipeg, MB, 16 pp

Brewing and Malting Barley Research Institute (1999) 51st Annual Report, BMBRI, Winnipeg, MB, 12 pp

Bulman P, Mather DE, Smith DL (1993) Genetic improvement of spring barley cultivars grown in eastern Canada from 1910 to 1988. *Euphytica* **71**, 35-48

Camm GA (2008) Grain hardness and slow dry matter disappearance rate in barley. MSc thesis, University of Saskatchewan, Saskatoon, 82 pp

Campbell GL, Rossnagel BG, Classen HL, Thacker PA (1989) Genotypic and environmental differences in extract viscosity of barley and their relationship to its nutritive value for broiler chickens. *Animal Feed Science and Technology* **26**, 221-230

Campbell LD, Boila RJ, Stothers SC (1995) Variation in the chemical composition and test weight of barley and wheat grain grown at selected locations throughout Manitoba. *Canadian Journal of Animal Science* **75**, 239-246

Canadian Food Inspection Agency (CFIA) (2010) Barley. Available online: http://www.inspection.gc.ca/english/plaveg/pbrpov/cropreport/bare.shtml

Canadian Wheat Board (2009) 2009-2010 Variety Survey. Available online: http://www.cwb.ca/public/en/farmers/surveys/variety/09-10/

Cerrilla MEO, Martinez GM (2003) Starch digestion and glucose metabolism in the ruminant: A review. *Interciencia* **28**, 380-386

Classen HL, Campbell GL, Rossnagel BG, Bhatty RS (1988) Evaluation of hulless barley as replacement for wheat or conventional barley in laying hen diets. *Canadian Journal of Animal Science* **68**, 1261-1266

Damiran D, Yu P (2010) Chemical profile, rumen degradation kinetics, and energy value of four hull-less barley cultivars: comparison of the zero-amylose waxy, waxy, high-amylose, and normal starch cultivars. *Journal of Agricultural and Food Chemistry* **58**, 10553-10559

Darroch CS, Aherne FX, Helm J, Sauer WC, Jaikaran S (1996) Effects of dietary level of barley hulls and fiber type on protein and energy digestibilities of Condor hulless barley in growing swine. *Animal Feed Science and Technology* **61**, 173-182

Dehghan-banadaky M, Corbett R, Oba M (2007) Effects of barley grain processing on productivity of cattle. *Animal Feed Science and Technology* **137**, 1-24

Du L, Yu P, Rossnagel BG, Christensen DA, McKinnon JJ (2009) Physicochemical characteristics, hydroxycinnamic acids (ferulic acid, *p*-coumaric acid) and their ratio, and *in situ* biodegradability: Comparison of genotypic differences among six barley varieties. *Journal of Agriculture and Food Chemistry* **57**, 4777-4783

Eckstein PE, Krasichynska N, Voth D, Duncan S, Rossnagel BG, Scoles GJ (2002) Development of PCR-based markers for a gene (*Un*8) conferring true loose smut resistance in barley. *Canadian Journal of Plant Pathology* **24**, 46-53

Edney MJ, Morgan JE, Williams PC, Campbell LD (1994) Analysis of feed barley by near infrared reflectance technology. *Journal of Near Infrared Spectroscopy* **2**, 33-41

Edney MJ, Tkachuk R, MacGregor AW (1992) Nutrient composition of the hull-less barley cultivar, Condor. *Journal of the Science of Food and Agriculture* **60**, 451-456

Endecott RL, Bowman JGP, Surber LMM, Boss DL, Robison KN, Blake TK (2001) Feeding value of Lewis and Baronesse barley lines for finishing steers. *Proceedings, Western Section, American Society of Animal Science* **52**, http://www.asas.org/westernsection/proceedings01.asp

Fan MZ, Sauer WC, Li S (1993) The additivity of the digestible energy and apparent ileal digestible amino acid supply in barley, wheat and canola meal or soybean meal diets for growing pigs. *Journal of Animal Physiology and Animal Nutrition* **70**, 72-81

Fincher GB (1975) Morphology and chemical composition of barley endosperm cell walls. *Journal of the Institute of Brewing* **81**, 116-122

Fleury MD, Edney MJ, Campbell LD, Crow GH (1997) Total, water-soluble and acid-soluble arabinoxylans in western Canadian barleys. *Canadian Journal of Plant Science* **77**, 191-196

Foley AE, Hristov AN, Melgar A, Ropp JK, Etter RP, Zaman S, Hunt CW, Huber K, Price WJ (2006) Effect of barley and its amylopectin content on ruminal fermentation and nitrogen utilization in lactating diary cows. *Journal of Dairy Science* **89**, 4321-4335

Goonewardene LA, ZoBell DR, Basarab JA (1994) Comparison of growth and feed efficiency of steers fed barley and triticale diets. *Canadian Journal of Animal Science* **74**, 159-161

Grabber JH, Mertens DR, Kim H, Funk C, Lu F, Ralph J (2009) Cell wall fermentation kinetics are impacted more by lignin content and ferulate cross-linking than by lignin composition. *Journal of the Science of Food and Agriculture* **89**, 122-129

Grando S, Baum M, Ceccarelli S, Goodchild A, Jaby El-Haramein F, Jahoor A, Backes G (2005) QTLs for straw quality characteristics identified in recombinant inbred lines of a *Hordeum vulgare x H. spontaneum* cross in a Mediterranean environment. *Theoretical and Applied Genetics* **110**, 688-695

Grewal TS, Rossnagel BG, Scoles GJ (2006) Inheritance of resistance to covered smut [*Ustilago hordei* (Pers.) Lagerh.] in barley. *Canadian Journal of Plant Science* **86**, 829-837

Grove AV, Bowman JGP, Boss DL, Blake TK (2006a) Feeding value of corn, 'Haxby', 'Valier', and 'H3' barley varieties for finishing steers. *Proceedings, Western Section, American Society of Animal Science* **57**, 370-373

Grove AV, Bowman JGP, Surber LMM, Blake TK (2006b) Feeding value of corn, 'Valier' barley, and corn/Valier combinations for finishing steers. *Proceedings, Western Section, American Society of Animal Science* **57**, 378-381

Grove AV, Kaiser CR, Iversen N, Hafla A, Robinson BL, Bowman JGP (2006c) Digestibility of barley beta-glucan in cattle. *Proceedings, Western Section, American Society of Animal Science* **57**, 367-369

Grove AV, Kaiser CR, Wiley JA, Harmsen AG, Bowman JGP (2008) Feeding barley beta-glucans to stimulate the immune system of calves challenged with BVDV. *Proceedings, Western Society, American Society of Animal Science* **59**, 387-390

Hart KJ, Rossnagel BG, Yu P (2008) Chemical characteristics and in situ ruminal parameters of barley for cattle: Comparison of the malting cultivar AC Metcalfe and five feed cultivars. *Canadian Journal of Animal Science* **88**, 711-719

Harvey BL, Rossnagel BG (1984) Harrington barley. *Canadian Journal of Plant Science* **64**, 193-194

Helm JH, Cortez MJ, Juskiw PE, Salmon DF, Stewart WM (2002) Registration of 'Trochu' barley. *Crop Science* **42**, 1379

Helm JH, Cortez MJ, Salmon DF, Jedel PE, Stewart WM (1996a) Registration of 'Falcon' barley. *Crop Science* **36**, 807

Helm JH, Cortez MJ, Salmon DF, Jedel PE, Stewart WM (1996b) Registration of 'Seebe' barley. *Crop Science* **36**, 808-809

Helm JH, Cortez MJ, Salmon DF, Juskiw PE, Nyachiro J (2003) Registration of 'Vivar' barley. *Crop Science* **36**, 1129-1130

Helm JH, Nyachiro JM, Cortez M, Oro M, Juskiw PE, Salmon DF (2004) Registration of 'Tyto' barley. *Crop Science* **44**, 343-344

Helm JH, Juskiw PE, Oatway L, Sauer WC (2000) Genetic and Environment Effects on the Feed Quality of Hulless Barley. Final report Farming for the Future Project #94M616, Alberta Barley Commission Project #60-057, 66 pp

Helm JH, Salmon DF, Dyson DH, Stewart WM (1992) Registration of 'Condor' barley. *Crop Science* **32**, 278

Hironaka R, Beauchemin KA, Lysyk TJ (1992) The effect of thickness of steam-rolled barley on its utilization by beef cattle. *Canadian Journal of Animal Science* **72**, 279-286

Hockett EA, Gilbertson KM, McGuire CF, Bergman JW, Wiesner LE, Robbins GS (1985) Registration of 'Lewis' barley. *Crop Science* **25**, 570-571

Hockett EA, Welty LE, Carlson GR, Wichman DW, Ditterlie RL, Larson RA (1990) Registration of 'Haybet' barley. *Crop Science* **30**, 230

Iversen NL, Bowman JGP, Grove AV, Robinson B, Blake TK (2006) Feeding value of corn and 'Valier' barley for finishing steers. *Proceedings, Western Section, American Society of Animal Science* **57**, 363-366

Jedel PE, Helm JH (1991) Lodging effects on a semidwarf and two standard barley cultivars. *Agronomy Journal* **83**, 158-161

Jedel PE, Helm JH (1992) Agronomic response of six-row barley cultivars to supplemental fertilization and late-season fungicide treatments. *Canadian Journal of Plant Science* **72**, 1121-1130

Jedel PE, Helm JH (1994a) Assessment of western Canadian barleys of historical interest: I. Yield and agronomic traits. *Crop Science* **34**, 922-927

Jedel PE, Helm JH (1994b) Assessment of western Canadian barleys of historical interest: II. Morphology and phenology. *Crop Science* **34**, 927-932

Jedel PE, Salmon DF (1995) Forage potential of spring and winter cereal mixtures in a short-season growing area. *Agronomy Journal* **87**, 731-736

Juskiw PE, Helm JH, Oatway L, Nyachiro J (2005) Breeding for feed quality in hulled two-row barley. *12th Australian Barley Technical Symposium*, Hobart, TAS, Australia Sept. 11-14, 2005

Juskiw PE, Helm JH, Oro M, Nyachiro JM, Salmon DF (2009a) Registration of 'Bentley' barley. *Journal of Plant Registrations* **3**, 119-123

Juskiw PE, Helm JH, Oro M, Nyachiro JM, Salmon DF (2009b) Registration of 'Busby' barley. *Journal of Plant Registrations* **3**, 209-213

Juskiw PE, Helm JH, Salmon DF (2000a) Forage yield and quality for monocrops and mixtures of small grain cereals. *Crop Science* **40**, 138-147

Juskiw PE, Helm JH, Salmon DF (2000b) Postheading biomass distribution for monocrops and mixtures of small grain cereals. *Crop Science* **40**, 148-158

Juskiw PE, Salmon DF, Helm JH (1999) Annual forage production from spring-planted winter cereal monocrops and mixtures with spring barley. *Canadian Journal of Plant Science* **79**, 565-577

Karren DB, Goonewardene LA, Bradley JA (1994) The effect of feed type on mouth lesions in slaughter cattle. *Canadian Journal of Animal Science* **74**, 571-573

Kennelly J, Okine E, Khorasani R (1995) Barley as a grain and forage source for ruminants. *Advances in Dairy Technology* **7**, 259-282

Khorasani GR, Helm J, Kennelly JJ (2000) *In situ* rumen degradation characteristics of sixty cultivars of barley grain. *Canadian Journal of Animal Science* **80**, 691-701

Khorasani GR, Jedel PE, Helm JH, Kennelly JJ (1997) Influence of stage of maturity on yield components and chemical composition of cereal grain silages. *Canadian Journal of Animal Science* **77**, 259-267

Khorasani GR, Okine EK, Kennelly JJ, Helm JH (1993) Effect of whole grain cereal grain silage substituted for alfalfa silage on performance of lactating dairy cows. *Journal of Dairy Science* **76**, 3536-3546

Larter EN (1995) Triticale. In: Slinkard AE, Knott DR (Eds) *Harvest of Gold*, University Extension Press, University of Saskatchewan, Saskatoon, SK, pp 122-129.

Lee H, Tewari J, Turkington T (2001) Symptomless infection of barley seed by *Rhynchosporium secalis*. *Canadian Journal of Plant Pathology* **23**, 315-317

Legge WG, Metcalfe DR, Haber S, Harder DE, Noll JS, Tekauz A, Thomas PL (2003) AC Metcalfe barley. *Canadian Journal of Plant Science* **83**, 381-384

Legge WG, Therrien MC, Tucker JR, Banik M, Tekauz A, Somers D, Savard ME, Rossnagel BG, Lefol E, Voth D, Zatorski T, Harvey BL, Scoles G (2004) Progress in breeding for resistance to fusarium head blight in barley. *Canadian Journal of Animal Science* **26**, 436-442

Lehman KB, Okine EK, Mathison GW, Helm J (1995) *In situ* degradabilities of barley grain cultivars. *Canadian Journal of Animal Science* **75**, 485-487

Li JH, Baga M, Rossnagel BG, Legge WG, Chibbar RN (2008) Identification of quantitative trait loci for β-glucan concentration in barley grain. *Journal of Cereal Science* **48**, 647-655

Li JH, Vasanthan T, Hoover R, Rossnagel BG (2004) Starch from hull-less barley: V. *in-vitro* susceptibility of waxy, normal, and high-amylose starches towards hydrolysis by alpha-amylases and amyloglucosidase. *Food Chemistry* **84**, 621-632

Mathison GW, Hsu H, Soofi-Siawash R, Recinos-Diaz G, Okine EK, Helm J, Juskiw P (1999a) Prediction of composition and ruminal degradability characteristics of barley straw by near infrared reflectance spectroscopy. *Canadian Journal of Animal Science* **79**, 519-523

Mathison GW, Soofi-Siawash R, Okine EK, Helm J, Juskiw P (1999b) Factors influencing composition and ruminal degradability of barley straw. *Canadian Journal of Animal Science* **79**, 343-351

MacGregor AW, Fincher GB (1993) Carbohydrates of the barley grain. In: MacGregor AW, Bhatty RS (Eds) *Barley Chemistry and Technology*, American Association of Cereal Chemists, St. Paul MN, pp 73-130

McAllister TA, Bae HD, Jones GA, Cheng KJ (1994) Microbial attachment and feed digestion in the rumen. *Journal of Animal Science* **72**, 3004-3018

McAllister TA, Phillippe RC, Rode LM, Cheng KJ (1993) Effect of the protein matrix on the digestion of cereal grains by ruminal microorganisms. *Journal of Animal Science* **71**, 205-212

McCartney DH, Block HC, Dubeski PL, Ohama AJ (2006) The composition and availability of straw and chaff from small grain cereals for beef cattle in western Canada. *Canadian Journal of Animal Science* **86**, 443-455

McCartney D, Fraser J, Ohama A (2008) Annual cool season crops for grazing by beef cattle. A Canadian Review. *Canadian Journal of Animal Science* **88**, 517-533

McDonnell MF (2004) Effects of barley cultivar and growing environment on feedlot performance and carcass characteristics of finishing beef cattle. MSc thesis, Montana State University, Bozeman, Montana, 51 pp

Metcalfe DR (1995) Barley. In: Slinkard AE, Knott DR (Eds) *Harvest of Gold*, University Extension Press, University of Saskatchewan, Saskatoon, SK, pp 82-97

Nyachiro JM, Helm JH, Cortez M, Oro M, Juskiw PE, Salmon DF (2005) Registration of 'Manny' barley. *Crop Science* **45**, 788-789

Nyachiro JM, Helm JH, Oro M, Juskiw PE, Salmon DF (2007) Registration of 'Sundre' barley. *Journal of Plant Registrations* **1**, 35-36

O'Donovan JT, Clayton GW, Grant CA, Harker KN, Turkington TK, Lupwayi NZ (2008) Effect of nitrogen rate and placement and seeding rate on barley productivity and wild oat fecundity in a zero tillage system. *Crop Science* **48**, 1569-1574

Parsons JG, Price PB (1974) Search for barley (*Hordeum vulgare* L.) with higher lipid content. *Lipid* **9**, 804-808

Price PB (1974) Registration of 'Prilar' barley. *Crop Science* **14**, 604

Ramsey PB, Mathison GW, Goonewardene LA (2001) Relationships between ruminal dry matter and starch disappearance and apparent digestibility of barley grain. *Animal Feed Science and Technology* **94**, 155-170

Ramsey PB, Mathison GW, Goonewardene LA (2002) Effect of rates and extent of ruminal barley grain dry matter and starch disappearance on bloat, liver abscesses, and performance of feedlot steers. *Animal Feed Science and Technology* **97**, 145-157

Rauhala NE, Turkington TK (2009) 2008 Barley disease survey in central Alberta. *Canadian Plant Disease Survey* **89**, 53

Rauhala NE, Turkington TK (2008) 2007 Cereal disease survey in Central Alberta. *Canadian Plant Disease Survey* **88**, 51-52

Roslinsky V, Eckstein PE, Raboy V, Rossnagel BG, Scoles GJ (2007) Molecular marker development and linkage analysis in three low phytic acid barley (*Hordeum vulgare*) mutant lines. *Molecular Breeding* **20**, 323-330

Rossnagel BG, Harvey BL (1994) CDC Dolly two-row feed barley. *Barley Newsletter* **38**, 109

Salmon DF, Cortez MJ, Helm JH, Juskiw PE, Albers S, Baron VS, Duggan TR (2000) Registration of 'Bobcat' triticale. *Crop Science* **40**, 1191

Salmon DF, Helm JH, Juskiw PE, Nyachiro J, Albers S, Bergen C, Oro M (2007a) Registration of 'Bunker' triticale. *Journal of Plant Registrations* **1**, 101

Salmon DF, Helm JH, Juskiw PE, Nyachiro J, Albers S, Bergen C, Oro M, Chapman B (2007b) Registration of 'Tyndal' triticale. *Journal of Plant Registrations* **1**, 100

Scott TA, Silversides FG, Classen HL, Swift ML, Bedford MR, Hall JW (1998) A broiler chick bioassay for measuring the feeding value of wheat and barley in complete diets. *Poultry Science* **77**, 449-455

Silveira C, Oba M, Beauchemin KA, Helm J (2007a) Effect of grains differing in expected ruminal fermentability on the productivity of lactating dairy cows. *Journal of Dairy Science* **90**, 2852-2859

Silveira C, Oba M, Yang WZ, Beauchemin KA (2007b) Selection of barley grain affects ruminal fermentation, starch digestibility, and productivity of lactating dairy cows. *Journal of Dairy Science* **90**, 2860-2869

Singh AK, Scoles GJ, Pickering RA, Rossnagel BG (2003) Allelic studies of new sources of scald (*Rhynchosporium secalis* Davis) resistance in barley. *Canadian Journal of Plant Science* **83**, 709-713

Stubbs TL, Kennedy AC, Reisenauer, Burns JW (2009) Chemical composition of residue from cereal crops and cultivars in dryland ecosystems. *Agronomy Journal* **101**, 538-545

Suber LMM, Bowman JGP, Blake TK, Blackhurst TC, Rolando SJ (1999) Variation in feed quality characteristics in the Lewis x Baronesse recombinant inbred barley lines. *Proceedings, Western Section, American Society of Animal Science* **57**, 370-373

Swift ML, Juskiw PE, Oba M, Helm JH (2009) Whole plant barley NDF digestibility and its relationship with chemical constituents and dry matter yield. Joint Meeting American Association of Animal Science, American Association of Dairy Science, Canadian Society of Animal Science, Montreal PQ July 11-16, 2009

Thacker PA, Rossnagel BG (2006) Performance and carcass traits of finishing pigs fed low phosphorus containing diets based on normal hulled or hulless barley of a low-phytate hulless barley with and without phytase. *Journal of Animal and Veterinary Advances* **5 (5),** 401-407

Thacker PA, Rossnagel BG, Raboy V (2003) Phosphorus digestibility in low-phytate barley fed to finishing pigs. *Canadian Journal of Animal Science* **83**, 101-104

Therrien M (2006) Registration of 'Binscarth' barley. *Crop Science* **46**, 2714-2715

Therrien M (2009) Registration of 'Desperado' six-row barley. *Journal of Plant Registrations* **3**, 1-4

Todd AL, Bowman JGP, Surber LMM, Thompson MA, Kincheloe JJ, McDonnell MF, Hensleigh PF (2003) Effect of barley varieties harvested for forage on backgrounding steer performance and diet digestibility. *Proceedings, Western Section, American Society of Animal Science* **54**, http://www.asas.org/westernsection/proceedings03.asp

Ugartondo V, Mitjans M, Vinardell MP (2009) Applicability of lignins from different sources as antioxidants based on the protective effects on lipid peroxidation induced by oxygen radicals. *Industrial Crops and Products* **30**, 184-187

Vignols F, Rigau J, Torres MA, Capellades M, Puigdomenech P (1995) The *brown midrib3 (bm3)* mutation in maize occurs in the gene encoding caffeic acid *o*-methyltransferase. *The Plant Cell* **7**, 407-416

Walker AM (2007) FTIR microspectroscopy as a tool for evaluating the digestibility characteristics of cereal grains fed to ruminants. MSc thesis, University of Saskatchewan, Saskatoon, 117 pp

Wang L, Newman RK, Newman CW, Jackson LL, Hofer PJ (1993) Tocotrienol and fatty acid composition of barley oil and their effects on lipid metabolism. *Plant Foods for Human Nutrition* **43**, 9-17

Wolfe RI, Dolfing SM, Davidson JGN, Clarke PJ (1995a) AC Albright barley.

Canadian Journal of Plant Science **75**, 457-459

Wolfe RI, Faris DG, Davidson JGN, Clarke PJ (1995b) AC Stacey barley. *Canadian Journal of Plant Science* **75**, 461-463

Wolfe RI, Irvine RB, Campbell KW (1988) Leduc barley. *Canadian Journal of Plant Science* **68**, 221-223

Xi K, Turkington TK, Helm JH, Briggs KG, Tewari JP, Ferguson T, Kharbanda PD (2003) Distribution of pathotypes of *Rhynchosporium secalis* and cultivar reaction on barley in Alberta. *Plant Disease* **87**, 391-396

Xi K, Xue AG, Burnett PA, Helm JH Turkington TK (2000) Quantitative resistance of barley cultivars to *Rhynchosporium secalis*. *Canadian Journal of Plant Pathology* **22**, 217-223

Xue AG, Burnett PA, Helm J, Rossnagel BG (1995) Variation in seedling and adult-plant resistance to *Rhynchosporium secalis* in barley. *Canadian Journal of Plant Pathology* **17**, 46-48

You S, Izydorczyk MS (2002) Molecular characteristics of barley starches with variable amylose content. *Carbohydrate Polymers* **49**, 33-42

Yu P, Christensen DA, Christensen CR, Drew MD, Rossnagel BG, McKinnon JJ (2004) Use of synchrotron FTIR microspectroscopy to identify chemical differences in barley endosperm tissue in relation to rumen degradation characteristics. *Canadian Journal of Animal Science* **84**, 523-527

Yu P, Meier JA, Christensen DA, Rossnagel BG, McKinnon JJ (2003) Using the NRC-2001 model and the DVE/OEB system to evaluate nutritive values of Harrington (malting-type) and Valier (feed-type) barley for ruminants. *Animal Feed Science and Technology* **107**, 45-60

Zhang WJ, Campbell LD, Stothers SC (1994) An investigation of the feasibility of predicting nitrogen-corrected true metabolizable energy (TMEn) content of barley from chemical composition and physical characteristics. *Canadian Journal of Animal Science* **74**, 355-360

Zinn RA, Montano M, Shen Y (1996) Comparative feeding value of hulless vs covered barley for feedlot cattle. *Journal of Animal Science* **74**, 1187-1193

Zobell DR, Goonewardene LA, Engstrom DF (1992) Use of triticale silage in diets for growing steers. *Canadian Journal of Animal Science* **72**, 181-184

Don Salmon

We dedicate this paper to the memory of our colleague, Dr. Don Salmon, who passed away on August 28, 2010. Dr. Salmon worked tirelessly to improve and promote triticales in Alberta and around the world.

Don was born in Birtle, Manitoba to Harold and Lillian Salmon. Don received his B. Sc. in Agriculture and his Ph.D. in Plant Breeding and Genetics from the University of Manitoba. After graduating, Don was employed by the Saskatchewan Wheat Pool, first as a Wheat Breeder in Zambia, Africa and then in Watrous, Saskatchewan, Canada.

In 1980, "Dr. Don" began his career with the Field Crop Development Centre in Lacombe, Alberta, Canada. His focus was on the development of winter and spring triticale varieties, and along the way this included improving winter wheat. He was instrumental in raising the profile of these crops in Alberta and across Canada. Don was highly regarded by the seed producers of Alberta and other growers of triticale, as he shared his knowledge with them and supported them in their efforts in crop production.

Don was highly respected within the national and international scientific community for his knowledge and efforts to increase utilization of triticale. He mentored many graduate students in his role as an Adjunct Professor with the University of Alberta. He formed strong bonds with breeding programs in Oregon, Mexico, Australia, and others around the world. The germplasm he developed is in use globally and contributes to the provision of a stable food source in many countries.

Don's breeding efforts produced nine varieties of triticale that have been grown across Canada and internationally. The newest of his triticale varieties are highly productive reduced-awn types for livestock feed, livestock forage, and ethanol production. Don worked closely with Dr. Vern Baron, to study the use of winter and spring cereal mixtures for forage use. Together these two researchers developed a production model for annual forage production using spring/winter cereal mixtures to improve the quality of cereal silage and extend the growing season for grazing. They characterized the carbon balance of the winter cereal within the spring/winter mixture that was fundamental to the fall grazing potential and overwintering of the winter cereal. Currently they were studying the use of cereals for swath grazing.

Don's contributions to the agriculture industry will not be forgotten. He will be missed by those in the industry and especially by his co-workers with the Field Crop Development Centre for his knowledge, his practicality, his sense of humor and most importantly his friendship.

Don is survived by his wife, Ferne Gudnason, his mother, Lillian Salmon, his brother and sister-in-law, Ray and Sandra Salmon, and their son, Tyson. Don had a deep love of horses that was shared by his late father, his brother and his nephew. Don's breed of choice was the Morgan. He served for many years as the ring master at Morgan horse shows in Alberta and was Zone Director for the Canadian Morgan Horse Association.

Patricia E. Juskiw, James H. Helm (December, 2010)

1) Dr. Salmon making crosses – the early years at Field Crop Development Centre (FCDC). **2**) The triticale breeders L-R Dr. Bob Metzger (Oregon State University), Matt Kolding (Oregon State University), Susan Albers (FCDC) and Dr. Don Salmon (FCDC). **3**) Dr. Salmon at Field Day, summer tour at FCDC field site. **4**) Mentoring with the Nova Scotia Agricultural College (NSAC) L-R Dr. Don Salmon (FCDC), Scott Veitch (NSAC), Doug MacDonald (NSAC), and Colin Bergen (FCDC).