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; NEg, net energy for gain (ruminant); NEs, net energy for lactation; NIRS, near infra-red reflectance spectroscopy; NRC, National Research Council; NUE, nitrogen use efficiency; TME, true metabolizable energy (poultry); TMEc, 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 (Metcalf 1995). As the population increased, domestic demand for malting barley increased and breeding efforts to improve...
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 1994), 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 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’ topped ‘CDC Dolly’ and has become 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 wheat (*T. durum*) and rye 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 Larster (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 bioethanol 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 Bhatt 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 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 Ross-Nagel 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 amylpectin, with the proportion of each starch type dependent on barley genotype (You and Izydorczyk 2002). You and Izydorczyk (2002) found that amyllose starches had low molecular weights while amylpectin starches have high molecular weights. Normal and high amylose cereal (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 maturing 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 McGiwre’ [Canadian Food Inspection Agency (CFIA) 2010], 48% for both waxy hulless barley ‘CDC Rattan’ (CFIA 2010) and zero-amylose waxy hulless barley ‘CDC Fibrar’ (CFIA 2010), and 57% for high amylose barley HB08302 grown in Saskatchewan.

Khorasani et al. (2000) reported that starch contents of 40 barley lines and cultivars grown in Alberta in 1993 ranged from 48 to 63%. The hulless barleys 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.

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

Arabinofurans (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 arabinofurans 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

<table>
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<tr>
<th>Parameter</th>
<th>Six-rowed†</th>
<th>Hulless</th>
<th>Two-rowed†</th>
<th>Triticale†</th>
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† Selected cultivar data for the six-rowed barley were AC Lacombe, Kanota, Manny, Sundre, Trochu, Tikwa and Vivar; for the hulless barley, CDC McGiwre, Condor, Falcon, and Tyto; for the two-rowed barley, AC Metcalfe, Bentley, Burby, CDC Bold, CDC Copeland, CDC Dolly, CDC Kendall, CDC Mirdon, Champion, Condor, Harrington, Newdale, Niobe, Ponoka, Seebe, TR06571, and Xena; and for the triticale, Bunker, Pronghorn and Tyndal.

‡ Data not available.
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 starchy type ‘CDC McGwire’ than the waxy type ‘CDC Rattan’ that was lower than for the high amylose, waxy type ‘CDC Fibrar’.

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 hydroxycinnamyl 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 Metaelf”, ‘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 Fibrar’ 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. Khorsani 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 findings, 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). Khorsani et al. (2000) reported that DMD was highest for ‘Falcon’ hulless barley (Helm et al. 2006a) and lowest for ‘WX-Betzies’, a waxy barley, however the rate of DMD was highest for ‘BF 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 associates 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 increased rate of by-pass 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 (Ze a 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 containing differences. However, the in vivo degradability of starch and neutral detergent 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 and hulled barley, whereas wet 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 RDF and 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. Beuchemin et al. (2001) found no differences between in vivo DM digestibility of 'Valier' and its parents 'Lewis' (Hockett et al. 1985) and 'Baroness' and their effects on final steer weight, ADG, intake, gain/feed ratio or carcass characteristics of steers. In a study by Iversen et al. (2006), 'Valier' had lower NEg than corn, but again no differences in steer performance were found between corn and 'Valier' based diets. Grove et al. (2006a) reported that NEg, 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 in steer ADG or carcass characteristics were found. In a study by Iversen et al. (2006), 'Valier' had lower NEg 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 vari eties or whether it was due to environmental effects on growth and development of the grain. Lyon et al. (2003) 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-rouged types. Hulless types had greater starch content and lower ADG and DM content than hulled types. While these generalizations are of interest, the important finding from their study was that great variation existed within and across the hulled and hulless types of barley. This variation could be accessed for future quality improvements in barley. However, in their comparison of 'AC Metalife' 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 higher 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.

Goonevardeni 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 due 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 among 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 as 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 lower quality material. Juskiw et al. (2000b) reviewed the use of cereals for grazing by beef cattle. Some of the options for supplemental 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). Vary 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. Cul-tivar 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 Metacliffe’ 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 hulless barley had higher ADG and feed efficiency than barley and the addition of hulless barley to the diet included antidote effects on feed efficiency. Bhatty et al. (1999) determined that degradability was higher in hulless barley than barley and that results for barley cultivars were stable. The feed cultivars evaluated (‘Xena’ and ‘Baronesse’) tended to have the lowest ADL values while the malting varieties ‘AC Metacliffe’ and ‘Harrington’ had the highest values.

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 and Rossnagel (2006) found that the addition of hulless barley to the diet improved fat deposition in swine. Bell and Keith (1993) previously reported that higher wheat ratios in barley: wheat finishing 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 hulless barley decreased fat 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.

Poultry

Scott et al. (1998) found that actual metabolizable energy (AME) as measured by ME minus ash and excreta in barley fed to broiler chicks ranged from 2,910 to 3,480 kcal kg⁻¹. Classen et al. (1988) found that hulless barley was equi-
valent to wheat in diets for laying hens, and was superior to conventional barley. However, barley based diets benefit from \(\beta\)-glucanase supplementation, especially if the barley is high in \(\beta\)-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 to 14.6 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 \(\beta\)-glucanase was added to the formulation, and the waxy barley offered better thermostability and lower heat requirement for gelatinization in the formation of pellets.

**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 ‘Binsear’ (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 fibrousness characteristics in barley, especially related to dry matter digestibility. 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 context, the production of a crop is aimed at, e.g., in triticale, applying the most appropriate and cost-effective applications of inputs, such as seed and fertilizer. The integration of crop management practices involves the use of a strategic mix of inputs. In this context, the grain, so effort to increase the starch component of the grain can be made by decreasing the yield starch 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’) × 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 stalk 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 of 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 mono- and disaccharides increased the ruminal fermentation times for hemi-
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 to 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 Lpa1-1 locus which causes a 50% reduction in phytic acid contents can be marked by a SCAR marker on chromosome 2HL. The lpa2-1 gene was found to be marked to chromosome 7HL. The lpa3-1 gene that causes a 75% decrease in phytate trait is found to be located to chromosome 1HL and could be identified by a LP75 marker. The lpa3-1 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. Bretgert and Raboy (2006) found that the low phytate genes except for lpa1-1 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 (limits 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 (2008) noted scald, the net-form of net blotch (Pyrenophora teres f. teres), the spot form of net blotch (Pyrenophora teres f. maculata) 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 eradicate 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 (FAFC-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 Runb allele 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 future productivity whatever it is for. To address these efficiencies and produce the best quality feed possible for improved animal genetics, breeding feed grains continue 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 intakes possible, the highest conversion possible, the least output in manure, and it must add value to all the 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 health 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 components 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 with economic value to the animal producer by improving the amount and quality of the end product produced.

ACKNOWLEDGEMENTS

We would like to thank the staff of the Field Crop Development Centre for their continued commitment to the improvement of feed grains. Special acknowledgement is made of the current Alberta-Canada working team who are providing the insight into current and future research directions: Jennifer Zantinge, Kequan Xi, Krishan Kumar, Kelly Turkington, John O’Donovan, Neil Harker, Joseph Nyachiro, Mary Lou Swift, Yadeta Kabela, and our partners at the Alberta barley Commission, Alberta Beef Producers, and the Alberta Cereal Industry Development Fund. Our sincere thanks go to Fran Teigt for getting the references together and into proper format and to Mary Lou Swift for correcting the manuscript and educating us on the proper use of feed quality traits.

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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)