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SUMMARY – Durum wheat (*Triticum turgidum* L. var durum) breeding began in Canada in the early 1950s with emphasis on improvement of yield, end-use quality and sustainable production through use of genetic resistance to insects and diseases. Genetic grain yield potential has increased by about 1% per year since release of the first cultivar in 1963. This was achieved within tightly-controlled end-use quality specifications for traits such as protein concentration, which was maintained at the level of the standard check cultivar Herucles. Gluten strength was increased in the 1960s to improve market opportunities and has recently been increased further, providing "conventional" durum cultivars with gluten index of 50 to 70%, and "strong gluten" cultivars with gluten index greater than 90%. Both semolina and pasta yellowness have been increased in recent cultivars, and cadmium concentration has been reduced by approximately 50%. There is genetic potential for further yield increases.

Introduction

Canadian durum wheat is grown principally in the semiarid "Brown" and "Dark Brown" soil zones of the southern prairies of western Canada as a spring crop, planted in early May and harvested in late August or in September. The uncertainty of precipitation in this semiarid environment, and the fact that producers receive no production subsides, influences crop management decisions. Fertilizer application rates are low, and agrochemical application is principally in the form of herbicides for weed control. These factors have contributed to the cultivar development strategy for durum wheat, which emphasizes genetic resistance to insects and diseases, and high genetic potential for grain protein concentration. Registration and release of new durum cultivars is strictly controlled, and all must meet agronomic, disease resistance and end-use quality standards (Clarke *et al.*, 1998).

Disease resistance

The emphasis on genetic resistance to diseases to reduce production costs means that there is no routine usage of fungicides on durum wheat grown in Canada, contributing indirectly to sustainability and environmental goals. The major diseases are leaf rust (caused by *Puccinia triticina* Eriks.), stem rust (caused by *P. graminis* Pers.: Pers.), common bunt [caused by *Tilletia laevis* Kuhn in Rabenh., and *T. caries* (DC.) Tul. & C. Tul.], loose smut [caused by *Ustilago tritici* (Pers.) Rostr.], and leaf spot diseases caused by *Pyrenophora tritici-repentis* (tan spot) and *Septoria* sp. All currently grown cultivars are highly resistant to the races of common bunt and moderately susceptible to the races of loose smut prevalent in the area.

Leaf and stem rust caused major economic losses in the past, but breeding of resistant cultivars has virtually eliminated yield losses. The genetic basis of the rust resistance of current cultivars has not been explored because of the generally good resistance present (Zhang and Knott, 1993), but it is likely multigenic. The recently identified leaf rust race BBG/BN in Mexico (Herrera-Foessel *et al.*, 2005) is virulent on all Canadian cultivars, so work has started to introduce resistance. Similarly a new stem rust race, Ug99, detected in Uganda (CIMMYT, 2005) is virulent on current major cultivars, so incorporation of resistance genes would be required if the race spreads to North America.

Diseases affecting the kernel, such as red smudge (primarily associated with *P. tritici-repentis*) and black point (*Alternaria* spp. and *Cochliobolus sativus*), are important factors affecting commercial grades of durum. Screening for resistance to these diseases is difficult because of variability in expression of symptoms due to environmental factors (Fernández *et al.*, 1998).

Resistance to leaf spot diseases has been improved in recent cultivars through selection in field environments where the disease complex occurred naturally. Sources of improved resistance include introduced germplasm from CIMMYT. Recent studies have shown that fungicide application to control leaf spot in Saskatchewan has no economic benefit (Wang *et al.*, 2002).

The incidence of Fusarium head blight, caused primarily by *Fusarium graminearum*, has been low in the durum production area. The disease does appear to be spreading westward (Clear and Patrick, 2000). The mycotoxins associated with Fusarium damage, particularly the trichothecene deoxynivalenol, are a food safety hazard. Fusarium damage also has negative affects on pasta quality, particularly colour (Dexter *et al.*, 1997).

There have been recent increases in the occurrence of stripe rust *Puccinia striiformis* Westend. f. sp. *tritici* Eriks.& Henn. in durum. Historically, stripe rust has been widespread in the north-western US, which often spreads into south-western Alberta, Canada (Line, 2002). To date no effort has been put into breeding for stripe rust resistance.

Insect resistance

The wheat stem sawfly, *Cephus cinctus* (Norton) has been the major insect pest in the durum production area. Larvae cause yield loss by feeding on the inside of the stem wall, reducing the amount of nutrients available to the kernel, and by girdling the stems at ground level just before harvest which causes them to fall over. The insect cannot be effectively controlled by insecticides. Solid stems provide a physical barrier and resistance to sawfly larvae damage. There are currently no solid stem durum cultivars grown in Canada, but breeding is underway due to increases in the incidence of sawfly. The solid stem trait is under simple genetic control (Clarke *et al.*, 2002).

Recently the wheat midge, *Sitodiplosis mosellana* (Gehin) (Diptera: Cecidomyiidae) has become a problem. The midge larvae cause yield loss and quality loss in the case of nearly-mature kernels damaged by feeding. An antibiosis mechanism was identified in bread wheat (Ding *et al.*, 2000), but a survey of diverse durum germplasm found no antibiosis (Lamb *et al.*, 2001), so it has been transferred from common wheat.

Protein concentration and grain yield

Efficiency of use of nitrogen is becoming important due to restrictions on rates of nitrogen fertilizer application to reduce contamination of surface and sub-surface waters. Production of "organic" or "biological" wheat has also prompted interest in exploiting genetic improvement of grain protein concentration. High grain protein concentration is a requirement for durum cultivar registration in Canada. The rationale for this is to maintain protein concentration at as high a level as possible in the low input wheat industry.

The cultivar 'Hercules' was for many years the quality standard for Canadian durum. New cultivars generally maintained grain protein concentration similar to Hercules, while increasing yield potential relative to 'Hercules' (Table 1). The cultivars 'AC Avonlea' and 'Strongfield' have substantially increased grain protein concentration relative to 'Hercules'. Strongfield and other lines derived from crosses with 'AC Avonlea' show both high protein and high yield potential (Clarke *et al.*, 2003).

The requirement to maintain protein concentration has limited the rate of genetic gain for grain yield potential. Rate of genetic improvement in grain yield since the release of the first Canadian cultivar, 'Stewart 63', in 1963 has been about 0.7% per year (Clarke *et al.*, 2003). This is less than other reports of rate of yield genetic gain, such as 4% per year since 1948 for common wheat in the United Kingdom (Austin, 1999), an average rate of about 1% per year since the mid 1960s (Reynolds *et al.*, 1999), and somewhat higher rates in some semiarid areas starting from a low yield base (Trethowan *et al.*, 2002).

The lower rate of genetic gain for yield in Canada is probably partly attributable to the need to select for high protein. Data from two unselected doubled haploid populations suggests that a 0.6% unit protein difference, such as for 'AC Morse' *vs* 'AC Avonlea' (Table 1), would impose a 17 to 20%

loss in yield potential. A protein difference of this magnitude can be generated by about 24 kg/ha more available N in our environment (Selles *et al.*, 2006).

Table 1. Yield and grain protein concentration of Canadian durum cultivars relative to the standard cultivar 'Hercules'

Cultivar	Year of release	Grain yield (% 'Hercules')	Protein (%)
'Hercules'	1969	100.0	13.5
'Kyle'	1984	113.2	13.3
'Plenty'	1990	121.3	13.2
'AC Melita'	1994	117.0	13.2
'AC Morse'	1996	121.1	13.4
'AC Avonlea'	1997	122.5	14.0
'AC Navigator'	1998	110.9	13.2
'Napoleon'	2001	125.8	13.2
'Strongfield'	2003	130.9	14.1
'Commander'	2004	122.5	13.5

The potential for further gain in yield at high protein concentration was assessed by comparing candidate cultivars to the highest yielding check (Table 2). In 2005, 10 candidates had numerically higher yield than 'Strongfield', but the highest yielding line with acceptable protein exceeded 'Strongfield' by only 2%. In pre-registration trials in 2005 (not shown), 45 lines out-yielded 'Strongfield', also by a maximum of 8%. Of these, the highest yielding line with "acceptable" protein concentration, derived from a cross with 'Strongfield', out-yielded 'Strongfield' by 6%. Therefore, there is genetic scope for further modest gains in grain yield potential at the high protein concentrations required in Canada.

Table 2. Number of lines with higher grain yield than the best check in Canadian durum registration trials, 2001-2005

Year	Best check	Number of lines > check	Yield of best line relative to check (%)
2001	'AC Avonlea'	8	108
2002	'AC Morse'	13	112
2003	'Strongfield'	11	104
2004	'Commander'	2	101
2005	'Strongfield'	10	108

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