Radiant hard red winter wheat

J. B. Thomas[1], R. L. Conner[2], and R. J. Graf[3]

[1]Agriculture and Agri-Food Canada, Lethbridge Research Centre, 5403–1st Avenue South, Lethbridge, Alberta, Canada T1J 4B1. LRC Contribution no. 387-11024. Received 9 May 2011, accepted 19 August 2011.

Thomas, J. B., Conner, R. L. and Graf, R. J. 2012. **Radiant hard red winter wheat.** Can. J. Plant Sci. **92**: 169–175. Radiant hard red winter wheat (*Triticum aestivum* L.) is well adapted to the non-hazard region for stem rust (*Puccinia graminis* Pers.: Pers. f. sp. *tritici* Eriks. & E. Henn.) within the Canadian prairies. Based on evaluation relative to Norstar, CDC Osprey, AC Tempest and AC Bellatrix in the Western Winter Wheat Cooperative registration trials, Radiant was similar in grain yield to AC Bellatrix, the highest yielding check. Radiant displayed very good winter survival, relatively late maturity, moderate height, very strong straw, high test weight and large seeds. It is the first Canadian wheat cultivar with resistance to colonization by the wheat curl mite (*Aceria tosichella* Keifer), the sole vector of wheat streak mosaic. Radiant was also shown to have good resistance to the prevalent races of stripe rust. It is susceptible to stem rust, leaf rust and common bunt. Radiant is eligible for all grades of the Canada Western Red Winter (CWRW) wheat class, having demonstrated a desirable combination of grain protein content, milling properties, dough functionality and baking performance. It has gained widespread commercial acceptance, particularly in Alberta.

Key words: *Triticum aestivum* L., wheat (winter), cultivar description, cold tolerance, wheat curl mite, wheat streak mosaic, stripe rust

Thomas, J. B., Conner, R. L. et Graf, R. J. 2012. **Le blé d'hiver roux vitreux Radiant**. Can. J. Plant Sci. **92**: 169–175. Radiant est une variété de blé d'hiver (*Triticum aestivum* L.) roux vitreux bien adaptée à la région des Prairies canadiennes qui n'est pas affectée par la rouille de la tige (*Puccinia graminis* Pers.: Pers. f. sp. *tritici* Eriks. & E. Henn.). Selon les comparaisons avec Norstar, CDC Osprey, AC Tempest et AC Bellatrix réalisées dans le cadre des essais d'homologation coopératifs de l'Ouest sur le blé d'hiver, Radiant a un rendement grainier similaire à celui d'AC Bellatrix, le témoin au rendement le plus élevé. Radiant résiste très bien à l'hiver, parvient à maturité relativement tard, a une taille moyenne, une paille très robuste, un poids spécifique élevé et de gros grains. Il s'agit du premier cultivar de blé canadien à résister à la colonisation par l'acarien ériophyide *Aceria tosichella* Keifer, seul vecteur de la mosaïque-bigarrure du blé. Radiant présente aussi une bonne résistance aux races communes de la rouille jaune du blé. La variété est néanmoins sensible à la rouille de la tige, à la rouille des feuilles et à la carie. Radiant est admissible à l'ensemble des classes de la catégorie « Blé rouge d'hiver de l'Ouest canadien » (CWRW), car il présente une combinaison souhaitable au niveau de la teneur en protéines du grain, des propriétés à la mouture, du pétrissage de la pâte et du rendement à la cuisson. La variété a largement été adoptée dans le commerce, particulièrement en Alberta.

Mots clés: *Triticum aestivum* L., blé (d'hiver), description de cultivar, tolérance au froid, *Aceria tosichella*, mosaïque-bigarrure du blé, rouille jaune du blé

Radiant hard red winter wheat (*Triticum aestivum* L.) was developed by Agriculture and Agri-Food Canada (AAFC) at the Lethbridge Research Centre (LRC), in Lethbridge, AB. It is the first wheat cultivar in Canada with protection from wheat streak mosaic virus, conditioned through resistance to colonization by the wheat curl mite (WCM) (*Aceria tosichella* Keifer) vector. Radiant received registration No. 5839 from the Variety Registration Office, Plant Production Division, Canadian Food Inspection Agency on 2004 Jul. 12. Plant Breeders' Rights certificate No. 2355 was granted on 2005 Dec. 29.

Radiant is well adapted to the non-hazard region for stem rust (*Puccinia graminis* Pers.: Pers. f. sp. *tritici* Eriks. & E. Henn.) within the Canadian prairies and meets the end-use quality attributes of the Canada Western Red Winter (CWRW) wheat class. Since its release, it has been eligible for price premiums under the Canadian Wheat Board's CWRW "Select" identity

[1]*Current address: Agriculture and Agri-Food Canada, Cereal Research Centre, 195 Dafoe Road, Winnipeg, Manitoba, Canada R3T 2M9.*
[2]*Current address: Agriculture and Agri-Food Canada, Morden Research Station, Unit 100, 101 Route 100, Morden, Manitoba, Canada R6M 1Y5.*
[3]*Corresponding author (e-mail: robert.graf@agr.gc.ca).*

Abbreviations: **AAFC**, Agriculture and Agri-Food Canada; **LRC**, Lethbridge Research Centre; **CWRW**, Canada Western Red Winter; **WCM**: wheat curl mite; **WSM**, wheat streak mosaic preserved contract program. The name "Radiant" is in reference to the glowing appearance of its bronze chaff at maturity.

Rationale for Wheat Curl Mite Resistant Cultivars

Wheat streak mosaic (WSM) is a damaging viral disease of wheat in the Great Plains region of North America that has caused sporadic, but extensive losses (Atkinson and Grant 1967; Harvey et al. 1994). Vectored by the WCM (Slykhuis 1955), WSM incidence is enhanced in areas where spring and winter wheat are cultivated extensively, providing the opportunity for WSM to cycle from over-summered wheat plants onto the winter wheat crop in the fall, or onto spring wheat crops from over-wintered wheat plants in the spring (Slykhuis et al. 1957; Christian and Willis 1993). WCM resistance was originally considered for disease control in winter wheat because it had the potential to prevent the spread of both WSM and wheat spot mosaic (Slykhuis 1956). More recently, the high plains virus (Seifers et al. 1997; Mahmood et al. 1998) and *Triticum* mosaic virus (Seifers et al. 2009) were also shown to be vectored by the WCM. The development of mite-resistant cultivars is therefore expected to reduce the occurrence of all of these diseases (Thomas et al. 2004) and could become increasingly important if winter wheat continues to gain popularity in western Canada. WCM resistance has been highly effective in reducing the prevalence of WSM in Kansas (Harvey et al. 1994), but there is compelling evidence that the WCM can evolve to overcome any resistance that is deployed (Harvey et al. 1995a, b, 1997, 1999). To preserve the effectiveness of the WCM resistance gene utilized in Radiant (*Cmc1*), whenever practical, winter wheat producers should continue to use responsible agronomic practices that eliminate the "green bridge" of plant material that serves as a potential disease reservoir for young seedlings of a new crop.

Pedigree and Breeding Method

Radiant hard red winter wheat was selected from the cross Norstar*6/PGR16635// Norwin/UT125512 made at the AAFC, LRC in Lethbridge. The final cross was made in 1987. Norstar is a CWRW wheat cultivar developed at the LRC from the cross Winalta/Alabaskaya (Grant 1980). PGR16635 is a synthetic hexaploid wheat produced at the University of Saskatchewan Crop Development Centre (D. B. Fowler, personal communication, University of Saskatchewan, Saskatoon, SK) and obtained from Plant Gene Resources of Canada, with the parentage *Triticum tauschii* [(Coss.) Schmalh.] CI 4/Novomichurinka; it is the source of *Cmc1*, a single dominant gene for resistance to colonization by the WCM (Thomas and Conner 1986). Norwin is a hard red winter wheat cultivar developed by Montana State University and registered as a CWRW wheat in 1986. It was derived from the cross Froid/Winoka//MT6928/Trader (Taylor et al. 1986). UT125512 is an experimental line developed by Utah State University with the pedigree: Delmar/3/Delmar/PI173438//Columbia/4/McCall/5/Hansel (D. Hole, personal communication, Utah State University, Logan, UT).

Following greenhouse increase of the F_1 seed, the F_2 to F_4 generations were grown as field bulks. Head selections were taken from the F_4 bulk and screened for freezing tolerance, WCM resistance, and kernel appearance. Surviving F_4-derived F_5 families were grown as F_6 hills and F_7 rows in Lethbridge. Head selections were taken from desirable F_7 rows based on screening for plant type, straw strength, protein content, test weight, and kernel appearance. The criteria for selection and harvest of the F_8 rows were similar to those in the previous generation. In 1995, an F_7-derived F_9 line designated APB4AK7J was evaluated in preliminary agronomic trials and subsequently confirmed as wheat curl mite resistant. Three years of favourable agronomic performance and promising end-use quality attributes in replicated trials across Alberta and western Saskatchewan prompted entry into the Western Winter Wheat Cooperative (WWWC) registration trials. Tested as W337, merit assessment took place from 1997/1998 (1998) to 1999/2000 (2000) under the auspices of the Prairie Registration Recommending Committee for Grain: Wheat, Rye and Triticale Subcommittee.

Evaluation of suitability for registration in the WWWC trials was relative to Norstar, CDC Osprey (Fowler 1997), AC Tempest (Thomas and Graf 2012), and AC Bellatrix (Thomas et al. 2012). Agronomic trials were grown in Alberta (Beaverlodge, Lacombe, Lethbridge "dry land", Lethbridge "irrigated", Olds, Vegreville Vulcan, Warner), Saskatchewan (Indian Head, Melfort, Saskatoon, Swift Current), and Manitoba (Carman) through the collaborative efforts of AAFC, Alberta Agriculture and Rural Development, the University of Saskatchewan, the University of Manitoba, and the Alberta Research Council. Disease and pest resistance was measured by AAFC, the University of Manitoba, and the agronomic trial collaborators when differential reactions for various pathogens were observed. End-use quality analysis was performed by the Canadian Grain Commission. MINITAB was used for the combined mixed model statistical analysis, in which the effects of environment were considered random and genotypes were fixed (MINITAB Inc. 2007).

During the 3 yr of registration testing, resistance to the major diseases of economic importance to winter wheat in both the western and eastern prairies was assessed. Adult plant reactions to stem rust (*Puccinia graminis* Pers.: Pers. f. sp. *tritici* Eriks. & E. Henn.) and leaf rust (*P. triticina* Eriks.) were determined in inoculated field nurseries conducted by the University of Manitoba in Winnipeg, MB. The composite of stem rust races used for 1 or more years included: QTHST (C25), RHTSK (C20), RKQSR (C63), RTHJT (C57), TMRTF (C95), TMRTK (C10) and TPMKR (C53) (Roelfs and Martens 1988; Fetch 2005). Each year, the leaf rust races used for inoculation were a representative mixture collected in western Canada during the previous field season (Kolmer 1999, 2001; McCallum and Seto-Goh 2002). Reaction to common bunt [*Tilletia tritici* (Bjerk.) G. Wint. in Rabenh. and *T. laevis* Kühn in Rabenh.] was estimated in a nursery conducted by AAFC, LRC staff by inoculating seed with a composite of races that included L1, L16, T1, T6, T13, and T19 (Hoffman and Metzger 1976; Gaudet and Puchalski 1989) and planting into cold soil in October. Characterization of the WCM reaction was conducted using non-viruliferous mites under controlled environment conditions at the AAFC, LRC as described by Thomas and Conner (1986). Two replicates of 12 plants each were rated for the typical symptoms of pronounced leaf rolling and trapping of subsequent leaves following 14 to 21 d of WCM exposure. The reactions to powdery mildew [*Blumeria graminis* (DC.) E. O. Speer] and unspecified leaf spotting pathogens were recorded by trial collaborators at naturally infected test sites expressing differential symptoms.

End-use quality was evaluated at the Canadian Grain Commission, Grain Research Laboratory, following protocols of the American Association of Cereal Chemists. The grain used for these analyses was a composite sample consisting of unequal quantities of grain from those test sites where the check cultivars met top grades and produced a mean protein concentration of approximately 12.5%, which is a desired target for marketing of the CWRW wheat crop. Grain from test sites with serious down-grading factors was not included in the quality composite. Kernel visual distinguish ability attributes from each test site were examined by the Canadian Grain Commission, Grain Inspection Division, to determine eligibility into the CWRW wheat class.

Performance

Grain yield and agronomic trait data for Radiant are reported from replicated tests conducted over 8 yr (1998 to 2005) in the WWWC registration trials, in which the first 3 yr of data were used to determine the merit for registration, with the latter 5 yr of data collected as part of the test check data. The reporting of the additional data following the recommendation for registration was facilitated by the stable complement of check cultivars in the registration trial, providing a longer term indication of agronomic performance.

Based on 65 site-years (1998 to 2005) of grain yield data, Radiant yielded 8% higher than Norstar and 4% higher than AC Tempest ($P \leq 0.05$) (Table 1). It was 1% higher yielding than CDC Osprey, and based on 57 sites of data (1999 to 2005) was similar in yield to AC Bellatrix. On a regional basis, Radiant exhibited a yield advantage over all of the check cultivars in Zone 1 (southern Alberta), where it was 14% higher than Norstar ($P \leq 0.05$), 4% higher than AC Bellatrix, 3% higher than CDC Osprey, and 2% higher than AC Tempest.

Radiant exhibited very good winter survival, being similar to Norstar and CDC Osprey, and significantly better than AC Bellatrix and AC Tempest (Table 2). On average, Radiant matured 3.5 d, 1.8 d and 1.5 d later than CDC Osprey, Norstar and AC Bellatrix, respectively. It was 0.7 d earlier maturing than AC Tempest. The grain filling period, defined as the time from heading to maturity, was also longer for Radiant than all of the checks except AC Tempest. Radiant was similar in height to all of the checks except Norstar, which was 17.5 cm taller. Straw strength, as indicated by the lodging score, was better than all of the checks except AC Tempest.

Radiant was susceptible to stem rust, leaf rust and common bunt (Table 3). The reaction to powdery mildew infection was similar to the best checks, but

Table 1. Grain yield (t ha^{-1}) of Radiant compared with the check cultivars, Western Winter Wheat Cooperative registration trials (1998–2005)

					Mean[z]	
Cultivar	Zone 1[yx]	Zone 2	Zone 3	Zone 4	1999–2005	1998–2005
Norstar	3.910	4.150	3.137	4.592	4.147	4.210
AC Tempest	4.372	4.170	3.564	4.731	4.367	4.366
CDC Osprey	4.338	4.139	3.921	5.031	4.436	4.489
AC Bellatrix[w]	4.298	4.432	3.584	5.061	4.520	–
Radiant	4.475	4.229	3.402	5.055	4.503	4.551
LSD ($P \leq 0.05$)[v]	0.282	0.234	0.780	0.406	0.168	0.166
No. of tests	20	20	2	15	57	65

[z]All means are weighted by the number of tests.
[y]All zone means are for the 1999–2005 period.
[x]Zone 1: Southern Alberta sites (Lethbridge "dry land", Lethbridge "irrigated", Vulcan, Warner).
Zone 2: Parkland sites (Beaverlodge, Lacombe, Melfort, Olds, Vegreville).
Zone 3: Semi-arid prairie site (Swift Current).
Zone 4: Eastern prairie rust hazard sites (Carman, Indian Head, Saskatoon).
[w]AC Bellatrix was not included in the 1998 trials.
[v]Least significant difference includes variation from the genotype by environment interaction.

Table 2. Agronomic performance of Radiant compared with the check cultivars, Western Winter Wheat Cooperative registration trials (1999–2005)

Cultivar	Winter Survival (%)	Heading[z] (d)	Maturity[z] (d)	Height (cm)	Lodging[y] (1–9)
Norstar	91.6	176.5	220.9	105.3	4.7
AC Tempest	79.9	174.2	223.4	86.6	1.6
CDC Osprey	87.9	173.8	219.6	87.1	2.9
AC Bellatrix	81.8	175.5	221.2	86.9	2.9
Radiant	87.4	174.1	222.7	87.8	2.0
LSD ($P \leq 0.05$)[w]	4.5	0.5	0.8	1.6	0.5
No. of tests	33	42	43	50	29

[z]Days to heading and maturity expressed as day of year.
[y]Lodging scale: 1 = all plants vertical, 9 = all plants horizontal.
[x]Least significant difference includes variation from the genotype by environment interaction.

tended to be similar to or worse than the checks for leaf spotting diseases. Good resistance to the WCM was shown through the absence of typical leaf rolling and trapping of subsequent leaves as compared to susceptible check cultivars. In 2006, a severe epidemic of stripe rust (*Puccinia striiformis* Westend.) in Alberta and much of the Canadian prairies (McCallum et al. 2007) demonstrated that Radiant had good resistance to the prevalent races. Molecular analysis later identified the presence of the 1100 bp DNA fragment from the *Yr10* resistance gene (Frick et al. 1998). Further pedigree expansion of UT125512 revealed that PI178383 was a parent of Hansel (Dewey 1975) and is the likely contributor of *Yr10* (Metzger and Silbaugh 1970).

During the 3 yr of evaluation for registration, CDC Osprey and AC Tempest were used as the end-use quality checks. The data for seed characteristics were therefore only collected for these checks. The test weight of Radiant was significantly higher than CDC Osprey but significantly lower than AC Tempest (Table 4). Kernel mass was significantly higher than CDC Osprey and similar to AC Tempest. Radiant had a grain protein content and protein yield per hectare similar to CDC Osprey, but significantly lower than AC Tempest.

Radiant was rated as equal to the check cultivars in end-use quality, exhibiting acceptable grain protein concentration, milling properties, dough functionality and baking performance (Table 5). It is eligible for

Table 3. Disease reactions of Radiant compared with the check cultivars, Western Winter Wheat Cooperative registration trials (1998–2000; 2006 for stripe rust)

	Year	Norstar[z]	AC Tempest	CDC Osprey	AC Bellatrix[z]	Radiant
Stem rust[y]	1998	70 S	30 S	40 MS-S	–	30 S
	1999	50 VS	50 VS	30 S	60 VS	50 S-VS
	2000	40 S	80 S-VS	60 S	60 S	80 S
Leaf rust[y]	1998	40 S	30 S	60 MS-S	–	50 S
	1999	70–80 S	60 S	60–80 S	60–70 S	60 S
	2000	15–20 S	20–30 S	20–30 S	10 MS-S	10–15 MS-S
Common bunt[y]	1998	64 VS	33 S	69 VS	–	52 VS
	1999	83 VS	54 S	78 VS	9 R	76 VS
	2000	–	58 S	74 S	25 I	75 S
Powdery mildew[b]	1998	2.3	3.1	3.7	–	3.3
	1999	3.4	2.8	4.0	3.4	2.4
	2000	2.5	2.8	3.1	2.2	2.1
Leaf spots[xw]	1998	3.1	3.1	3.8	–	2.8
	1999	3.6	2.9	3.8	3.4	3.5
	2000	2.5	2.6	3.0	2.8	3.7
Wheat curl mite	1998	S	S	S	–	R
	1999	S	S	S	S	R
	2000	S	S	S	S	R
Stripe rust[x]	2006	–	2.6	3.3	7.1	2.1

[z]Norstar was not included in the 2006 trials; AC Bellatrix was not included in the 1998 trials.
[y]Percent infection and type of reaction: R = resistant, MR = moderately resistant, I = intermediate, MS = moderately susceptible, S = susceptible, VS = very susceptible.
[x]Rated using a 1–9 scale: 1 = disease free, 9 = very severe symptoms.
[w]Specific leaf spotting pathogens were not determined.

Table 4. Seed characteristics of Radiant compared with the check cultivars, Western Winter Wheat Cooperative registration trials (1998–2005)

Cultivar[y]	Test weight (kg hL^{-1})	Kernel mass (mg)	Grain protein[z] (%)	Protein yield (kg ha^{-1})
AC Tempest	79.7	35.9	13.8	628
CDC Osprey	78.4	30.4	12.3	579
Radiant	79.3	35.5	12.3	586
LSD ($P \leq 0.05$)[x]	0.4	0.7	0.2	20
No. of tests	54	55	53	52

[z]Grain protein content determined using whole grain NIR analysis.
[y]Norstar and AC Bellatrix seed characteristics were not determined in all years and are therefore not reported.
[x]Least significant difference includes variation from the genotype by environment interaction.

all grades of CWRW wheat and is one of the check cultivars in the WWWC registration trials. Certified seed of Radiant became commercially available to producers in fall 2004 and by 2006 it had become the predominant CWRW wheat cultivar in Alberta (Canadian Wheat Board 2006). In 2009, it was the predominant cultivar in western Canada, planted on 27.1% of the CWRW wheat acreage; in 2010, Radiant accounted for 61.8% of the CWRW wheat acreage in Alberta (Canadian Wheat Board 2010).

The continued development and use of lodging resistant, intermediate height cultivars is an important consideration in managing sustainable agricultural systems. Blackshaw (1994) showed that planting taller, more competitive winter wheat cultivars resulted in higher crop yields and less downy brome seed for weed establishment in subsequent crops. In a further study, it was shown that at a row spacing of 23 cm, seeding rates of 300 and 450 seeds m^{-2} versus a higher seeding rate of 600 seeds m^{-2} maximized yield for Radiant and several other winter wheat cultivars (Beres et al. 2010). The higher plant densities helped to preserve adequate and competitive spring stands for all cultivars in the study. Total weed biomass was reduced at the higher plant densities, particularly for Radiant, which is intermediate in height with an erect plant type and excellent straw strength. This was in contrast to shorter cultivars, which were less competitive with weeds and did not reduce weed biomass, a result of greater light penetration into the crop canopy (Blackshaw 1994; Beres et al. 2010).

Other Characteristics

Seedling Characteristics

Coleoptile anthocyanin colouration: absent (green).
Intensity of anthocyanin colouration: absent.
Juvenile growth habit: prostrate.
Pubescence of lower leaf sheath: glabrous.
Pubescence of lower leaf blades: glabrous.
Colour of lower leaf blade: medium green.
Tillering capacity (at low densities): medium-plus.

Plant Characteristics at Booting

Growth habit: erect to semi-erect.
Flag leaf colour: medium green.
Pubescence of flag leaf blade: glabrous.
Waxiness of lower side of flag leaf blade: slight.
Waxy bloom of flag leaf sheath: medium to strong.
Pubescence of flag leaf sheath: glabrous.
Flag leaf width: medium-narrow.
Flag leaf length: medium-long.
Flag leaf attitude: intermediate.
Anthocyanin colouration of flag leaf auricles: absent or very weak.
Pubescence of flag leaf auricle margins: moderate.

Plant Characteristics after Heading

Shape of culm neck: straight.
Waxiness of culm upper internode: weak to medium-weak.
Pubescence of culm upper internode: glabrous.
Pubescence of rachis margins: very strong.
Anthocyanin colouration of straw at maturity: absent.
Pith in cross-section of straw (at middle of internode below the neck): hollow.
Stem colour at maturity: light yellow.

Spike Characteristics

Shape: tapering.
Attitude at maturity: somewhat inclined.
Density: medium to medium-dense.
Length: medium long.
Waxy bloom: medium.
Colour at maturity: brown.
Awnedness: awned.
Length of awns at tip of spike: shorter than spike.
Awn colour: brown.
Awn attitude: very slightly spreading.
Supernumary spikelets: absent.

Lower Glume Characteristics

Width: medium-narrow.
Length: medium-long.
Pubescence: pubescent on glume margins, otherwise glabrous.
Shape of shoulder: sloping to slightly sloping.
Shoulder width: narrow.
Shape of beak: slightly curved.
Beak length: medium-long.
Lower glume – internal imprint: absent.
Colour at maturity: dark brown.

Kernel Characteristics

Class eligibility: CWRW Wheat.
Type: hard red.
Colour: medium red.

Table 5. Mean end-use quality characteristics[z] of Radiant and check cultivars, Western Winter Wheat Cooperative registration trials (1998–2000)

Cultivar	Wheat protein (%)	Flour protein (%)	Protein loss (%)	Hagberg falling no. (s)	Amylograph peak viscosity (B.U.)	Flour yield (%)	Flour ash (%)	Flour colour (Agtron)	Starch damage (%)
AC Tempest	13.5	12.8	0.6	395	663	73.6	0.37	73.7	5.4
CDC Osprey	12.5	11.7	0.7	385	663	75.9	0.39	76.7	4.8
Radiant	12.4	11.4	1.0	398	732	75.1	0.39	76.3	5.3
SD[y]	0.1	0.1	0.1	15	5	0.3	0.01	0.9	0.1

	Farinograph				Baking					
					Remix-to-peak (1998–1999)			Canadian short process (2000)		
Cultivar	Absorption (%)	Dough development time (min)	Stability (min)	Mixing tolerance index (B.U.)	Absorption (%)	Peak time (min)	Loaf volume (cm^3)	Absorption (%)	Peak time (min)	Loaf volume (cm^3)
AC Tempest	66.2	6.6	11.0	18.0	65.0	2.1	860	65.0	7.0	965
CDC Osprey	59.0	6.7	9.1	34.0	60.5	2.4	893	58.0	8.0	950
Radiant	60.6	6.9	9.8	25.3	62.0	2.9	883	58.0	8.9	935
SD[y]	0.2	0.4	1.4	2.6	0.0	0.1	14	0.0	0.3	23

[z]American Association of Cereal Chemists methods were followed by the CGC, GRL for determining the various end-use quality characteristics on a composite of several locations per year.
[y]Standard deviation is based on repeated testing of Allis mill check samples and standard bake flour samples with replicate tests performed over an extended period of time each year. Values provided by the CGC, GRL.

Size: medium.
Length: medium.
Width: medium.
Shape: elliptical.
Cheek shape: rounded.
Length of brush hairs: mid-long.
Size of brush: medium.
Germ shape: oval.
Germ size: mid-size.
Crease width: mid-wide.
Crease depth: mid-deep.

Maintenance and Distribution of Breeder Seed

Breeder Seed production was initiated by randomly selecting approximately 200 plants from a rogued F_7-derived F_{13} increase plot grown in 1999. Seed from each plant was grown in a 3 m long row, with a small amount of seed retained to confirm resistance to WCM colonization. Following the harvest of WCM resistant, morphologically similar rows in 2000, grain protein content and sodium dodecyl sulphate sedimentation volume were determined for each plant progeny row. Rows that were greater than one standard deviation below the mean for both of these quality parameters were discarded. In fall 2000, 165 lines were planted under isolation as individual plots in two randomized replicates. After removal of lines that revealed off-type plants or contamination, 135 Breeder Seed lines were inspected and then composited in equal proportions to generate 750 kg of Breeder Seed. The AAFC Seed Increase Unit at Indian Head, SK will maintain the Breeder Seed of Radiant. All other classes of seed will be multiplied and distributed by Canterra Seeds Ltd., 201–1475 Chevrier Blvd., Winnipeg, MB, Canada R3T 1Y7.

Sincere appreciation is expressed to the AAFC LRC staff members who assisted in the development of Radiant winter wheat, in particular: David Quinn, Martin Fast, James Prus, Tara Vucurevich, Allan Kuzyk and Byron Puchalski. The authors also acknowledge all of the scientific and technical support provided by AAFC staff, particularly at the research centres in Lethbridge, Swift Current and Winnipeg, and all contributors to the Western Winter Wheat Cooperative registration trials. Financial support from the producer check-off on wheat collected by the Canadian Wheat Board and administered by the Western Grains Research Foundation is gratefully recognized.

Atkinson, T. G. and Grant, M. N. 1967. An evaluation of streak mosaic losses in winter wheat. Phytopathology **57**: 188–192.

Beres, B. L., Clayton, G. W., Harker, K. N., Stevenson, F. C., Blackshaw, R. E. and Graf, R. J. 2010. A sustainable management package to improve winter wheat production and competition with weeds. Agron. J. **102**: 649–657.

Blackshaw, R. E. 1994. Differential competitive ability of winter wheat cultivars against downy brome. Agron. J. **86**: 649–654.

Canadian Wheat Board. 2006. Variety survey. [Online] Available: http://www.cwb.ca/public/en/farmers/surveys/variety/archive/pdf/2006/2006_variety_survey.pdf.

Canadian Wheat Board. 2010. Variety survey. [Online] Available: http://www.cwb.ca/public/en/farmers/surveys/variety/10-11/pdf/1011results.pdf.

Christian, M. L. and Willis, W. G. 1993. Survival of wheat streak mosaic virus in grass hosts in Kansas from wheat harvest to fall wheat emergence. Plant Dis. **77**: 239–242.

Dewey, W. G. 1975. Registration of 'Hansel' wheat. Crop Sci. **15**: 888.

Fetch, T. G. 2005. Races of *Puccinia graminis* on wheat, barley, and oat in Canada, in 2002 and 2003. Can. J. Plant Pathol. **27**: 572–580.

Fowler, D. B. 1997. CDC Osprey winter wheat. Can. J. Plant Sci. **77**: 665–667.

Frick, M. M., Huel, R., Nykiforuk, C. L., Conner, R. L., Kuzyk, A. and Laroche, A. 1998. Molecular characterization of a wheat stripe rust resistance gene in Moro wheat. Proc. 9th Intern. Wheat Genetics Symp., Saskatoon, SK. Vol. **3**: 181–182.

Gaudet, D. A. and Puchalski, B. L. 1989. Races of common bunt (*Tilletia caries* and *T. foetida*) in western Canada. Can. J. Plant Pathol. **11**: 415–418.

Grant, M. N. 1980. Registration of Norstar wheat. Crop Sci. **20**: 552.

Harvey, T. L., Martin, T. J. and Seifers, D. L. 1994. Importance of plant resistance to insect and mite vectors in controlling virus diseases of plants: Resistance to the wheat curl mite (Acari: Eriophyidae). J. Agric. Entomol. **11**: 271–277.

Harvey, T. L., Martin, T. J. and Seifers, D. L. 1995a. Survival of five wheat curl mite, *Aceria tosichella* Keifer (Acari: Eriophyidae) strains on mite resistant wheat. Exp. Appl. Acarol. **19**: 459–463.

Harvey, T. L., Martin, T. J., Seifers, D. L. and Sloderbeck P. E. 1995b. Adaptation of wheat curl mite (Acari: Eriophyidae) to resistant wheat in Kansas. J. Agric. Entomol. **12**: 119–125.

Harvey, T. L., Martin, T. J., Seifers, D. L. and Sloderbeck P. E. 1997. Change in virulence of wheat curl mite detected on TAM 107 wheat. Crop Sci. **37**: 624–625.

Harvey, T. L., Seifers, D. L., Martin, T. J., Brown-Guedira, G. and Gill, B. S. 1999. Survival of wheat curl mites on different sources of resistance in wheat. Crop Sci. **39**: 1887–1889.

Hoffman, J. A. and Metzger, R. J. 1976. Current status of virulence genes and pathogenic races of the wheat bunt fungi in the northwestern USA. Phytopathology **66**: 657–660.

Kolmer, J. A. 1999. Physiologic specialization of *Puccinia triticina* in Canada in 1997. Plant Dis. **83**: 194–197.

Kolmer, J. A. 2001. Physiologic specialization of *Puccinia triticina* in Canada in 1998. Plant Dis. **85**: 155–158.

Mahmood, T., Hein, G. L. and Jensen, S. G. 1998. Mixed infection of hard red winter wheat with high plains virus and wheat streak mosaic virus from wheat curl mites in Nebraska. Plant Dis. **82**: 311–315.

McCallum, B. D., Pearse, P. G., Fetch, T., Gaudet, D., Tekauz, A., Seto-Goh, P., Xi, K. and Turkington, T. K. 2007. Stripe rust of wheat and barley in Manitoba, Saskatchewan and Alberta in 2006. Can. Plant Dis. Surv. **87**: 66.

McCallum, B. D. and Seto-Goh, P. 2002. Physiologic specialization of wheat leaf rust (*Puccinia triticina*) in Canada in 1999. Can. J. Plant Pathol. **24**: 205–210.

Metzger, R. J. and Silbaugh, B. A. 1970. Inheritance of resistance to stripe rust and its association with brown glume colour in *Triticum aestivum* L. 'PI 178383'. Crop Sci. **10**: 567–568.

MINITAB Inc. 2007. MINITAB statistical software. Release 15.1.30.0. MINITAB Inc., State College PA.

Roelfs, A. P. and Martens, J. W. 1988. An international system of nomenclature for *Puccinia graminis* f. sp. *tritici*. Phytopathology **78**: 526–533.

Seifers, D. L., Harvey, T. L., Martin, T. J. and Jensen, S. G. 1997. Identification of the wheat curl mite as the vector of the high plains virus of corn and wheat. Plant Dis. **81**: 1161–1166.

Seifers, D. L., Martin, T. J., Harvey, T. L., Fellers, J. P. and Michaud, J. P. 2009. Identification of the wheat curl mite as the vector of *Triticum* mosaic virus. Plant Dis. **93**: 25–29.

Slykhuis, J. T. 1955. *Aceria tulipae* Keifer (Acarina: Eriophyidae) in relation to the spread of wheat streak mosaic. Phytopathology **45**: 116–128.

Slykhuis, J. T. 1956. Wheat spot mosaic, caused by a mite-transmitted virus associated with wheat streak mosaic. Phytopathology **46**: 682–687.

Slykhuis, J. T., Andrews, J. E. and Pittman, U. J. 1957. Relation of date of seeding winter wheat in southern Alberta to losses from wheat streak mosaic, root rot and rust. Can. J. Plant Sci. **37**: 113–127.

Taylor, G. A., Spitler, G. H., McGuire, C. F., Bergman, J. W., Dubbs, A. L., Carlson, G., Stallknecht, G. F. and Stewart, V. R. 1986. Registration of 'Norwin' wheat. Crop Sci. **26**: 1086–1087.

Thomas, J. B. and Conner, R. L. 1986. Resistance to colonization by the wheat curl mite in *Aegilops squarrosa* and its inheritance after transfer to common wheat. Crop Sci. **26**: 527–530.

Thomas, J. B. and Graf, R. J. 2012. AC Readymade and AC Tempest, selections from Redwin hard red winter wheat. Can. J. Plant Sci. **92**: (in press).

Thomas, J. B., Conner, R. L. and Graf, R. J. 2004. Comparison of different sources of vector resistance for controlling wheat streak mosaic in winter wheat. Crop Sci. **44**: 125–130.

Thomas, J. B., Gaudet, D. A. and Graf, R. J. 2012. AC Bellatrix hard red winter wheat. Can. J. Plant Sci. **92:** 163–168.