INVESTIGATIONS IN WHEAT (*Triticum aestivum* L. em Thell) USING MOLECULAR AND CONVENTIONAL BREEDING TECHNIQUES FOR ABIOTIC AND BIOTIC STRESS

By

LATHA J. REDDY

A dissertation submitted in partial fulfillment of
the requirements for the degree of

DOCTOR OF PHILOSOPHY

WASHINGTON STATE UNIVERSITY
Department of Crop and Soil Sciences

May 2006

To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of LATHA J. REDDY find it satisfactory and recommend that it be accepted.

Chair

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to my advisor and committee chair Dr. Kimberly A Garland-Campbell for her guidance, encouragement, support and kindness throughout my graduate study at WSU. I would like to express my gratitude and appreciation to my committee members Dr. Stephen Jones, Dr. Fred Muehlbauer, Dr. Xianming Chen and Dr. Lee Hadwiger for their suggestions during my study and for their insightful comments to this dissertation.

Thanks to the USDA-ARS Wheat Genetics, Quality, Physiology and Disease Research unit and Department of Crop and Soil Sciences, Washington State University for the research facilities to help me pursue my degree. I would like to thank the staff members of the Crop and Soil Sciences for their timely help. I like to express my appreciation to Dan Dreesmann, Mary Moore, Dave Wood and Laura Penman for their help with the greenhouse experiments.

I would like to thank all the members of my lab: Alicia, Richard, Jip, Tiffany, Steve, Dipak, Paul, Sandro, Carl and Meenakshi for their help and friendship while working in the lab. Thanks to Eric Weir for helping with the cold tolerance studies in the greenhouse and Lynn Little for keeping us organized and helping to conduct the field and greenhouse experiments. Special thanks to Patsy Wood, Secretary, USDA-ARS Wheat Genetics, Quality, Physiology and Disease Research unit for helping me with the resources for day to day work in the lab. Heartfelt thanks to all my friends who are a part of my life.

I would like to acknowledge the funding agencies: the Washington Wheat Commission The project “Identification of genetic factors conferring cold tolerance in winter wheat” (USDA-CSREES competitive grant 2004-01783) and the USDA-ARS Project:CWU:5348-21000-019-00D. for providing financial assistance throughout my Ph.D. program.

I am indebted to my parents, brother, sister, brother-in-law, nephew, niece, and in-laws for their love, constant support and encouragement. Finally I wish to acknowledge the love, support and patience of my husband and thank my daughter for being my inspiration.

INVESTIGATIONS IN WHEAT (*Triticum aestivum* L. em Thell) USING MOLECULAR AND CONVENTIONAL BREEDING TECHNIQUES FOR ABIOTIC AND BIOTIC STRESS

ABSTRACT

by Latha J Reddy, Ph.D
Washington State University
May 2006

Chair: Kimberly A Garland Campbell

Cold temperature is an important abiotic stress causing cold injury in winter wheat. 70% of the yield from winter wheat was lost due to cold injury in the state of Washington in 1991. There has been significant cold injury during 1999, 2004 and 2005 in Washington. Cold tolerance is a difficult trait to breed and select for in the field because it is influenced by the developmental regulators vernalization and photoperiod and by environmental variations. The objective of the first part of this research was to determine the ability of molecular markers for alleles at the major vernalization (VRN) loci in wheat, *Vrn-A1*, *Vrn-B1* and *Vrn-D1,* to predict growth habit and cold tolerance phenotypes of near isogenic lines (NILs) varying at the vernalization loci.

Two sets of 32 NILs each were developed with winter wheat cultivars Daws and Wanser as recurrent parents and Triple Dirk NILs as donor parents for the individual VRN alleles at the three orthologous *Vrn* loci. There were significant differences in cold tolerance between Daws spring and winter NILs at the *Vrn-A1* locus but did not at the *Vrn-B1* and *Vrn-D1* loci. Wanser NILs for spring and winter habit differed significantly for cold tolerance at the *Vrn-A1*, *Vrn-B1* and for one genotype at the *Vrn-D1* locus, indicating that *Vrn-B1* and *Vrn-D1* loci are also

important for regulating cold tolerance. Polymorphisms at the VA1-F/VA1-R Cleavage Amplified Polymorphic Sequence (CAPS) marker were associated with the *Vrn-A1* alleles and differences in growth habit and cold hardiness. The marker for *Vrn-A1* can be used to screen germplasm for growth habit and cold tolerance. The markers specific for *Vrn-B1* and *Vrn-D1* alleles did not consistently show any relationship to the growth habit and cold tolerance and hence need further evaluation.

The second objective of the research was to map QTLs for cold temperature tolerance in two winter wheat crosses. This study is the first to report the use of winter x winter wheat crosses to identify QTLs for cold tolerance, which will eliminate the pleiotropic effect of major genes for vernalization and photoperiod on cold tolerance. The Centurk78/Norstar population comprised 86 F_8 Recombinant Inbred Lines (RILs) and the Z0031/2*Karl population comprised 69 genotypes advanced as RILs. Three QTLs were identified in the Centurk78/Norstar population; on 5A (P= 0.0026), 5D (P= 0.0008) and 6B (P= 0.0115) chromosomes of wheat each explaining 10.7%, 14.0% and 7.5% of the phenotypic variation for cold tolerance respectively. In the Z0031/2*Karl two putative QTLs, on chromosome 4B and 5A were identified, the QTL on 4B (P=0.003) explained 14.4% variation and the QTL on 5A (P= 0.0148) explained 9.8% variation. These QTLs will be confirmed after the RIL population genomes are further saturated with molecular markers.

Stripe rust disease of wheat caused by the fungus *Puccinia* s*triiformis* Westend f.sp.*tritici* Eriks is one of the most important biotic stresses affecting the U.S. Pacific Northwest. Stripe rust affected 485,000 acres of wheat with a yield loss of 363,568 metric tons during 2002 in the state of Washington. The stripe rust pathogen is continuously evolving and therefore, continued new resistant cultivars or germplasm must be identified. The third objective was to characterize

stripe rust resistance of two soft white winter wheat populations WA7697 x A9622 and WA7697 x A96330. The parents and F_1s were evaluated for all-stage resistance in the greenhouse using 21 races of stripe rust. The parent WA7697 was resistant to 16 of the 21 races, used to screen for seedling resistance. WA7697 was susceptible to only two races, PST-23 and PST-37, and had intermediate reaction to three races. The two other parents, A9622 and A96330, were resistant to 21 and 17 races, respectively. A96330 had an intermediate reaction to four races. Based on the segregation for resistance to the races PST-23 and PST-37 in the WA7697 x A9622 population, either three or four genes operate to provide resistance in this population. In experiments conducted in Pullman and Central Ferry, WA in 2002 and 2003 all progeny from the two populations were either resistant or had intermediate resistance but none were susceptible. At Mt. Vernon, WA in 2003 five susceptible progenies were identified in the WA7697 x A9622 and 14 susceptible progenies were identified in WA7697 x A96330 population.

Ninety three selections that are highly resistant to new races of stripe rust that have been prevalent in the US since 2001, have been identified in this study. After further characterization for agronomic qualities these progenies can be used as a source of stripe rust resistance.

.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

Chapter 1

Chapter 3

LIST OF FIGURES

Page

Chapter 2

Chapter 3

This work is dedicated to my beloved parents

Jayarama Reddy and Jayalakshmi,

my husband, Raj Reddy

and my daughter, Supriya

FOREWORD

INTRODUCTION

Wheat (*Triticum aestivum* L. em. Thell) is the third most important crop grown in the US after corn (*Zea mays*) (11.8 billion bu) and soybeans (*Glycine max*) (3.14 billion bu) with production of 2.16 billion bushels of spring and winter wheat in 2004, winter wheat contributing 1.50 billion bushels. In 2004 wheat was planted on an area of 59,674, 000 acres with an average of 43.2 bu/ac yield with a value of 7.20 billion dollars. Pacific Northwest states (Washington, Idaho and Oregon) contribute 301 million bushels to the total production of wheat in the US (http://www.nass.usda.gov/).

Polyploidy, Evolution and Origin

Cultivated wheat evolved through ancient polyploidization and is an allohexaploid consisting of three sub genomes named A, B and D. Each of these genomes has seven pairs of homoeologous chromosomes (Kimber, 1987; Morris, 1967). Wheat belongs to Family: Poaceae, Tribe: Triticeae and species *Triticum* with several subspecies. *Triticum turgidum* L. var *durum* is the only tetraploid wheat cultivated today. Occurrence of polyploidy in plants is widespread. The estimated frequency in angiosperms is between 30 and 80% (Masterson, 1994). There is strong genetic evidence suggesting *T. aestivum* to have evolved from the hybridization of *Triticum monococcum* (AA) with one or more species related to section *sitopsis* of *Triticum* resulting in the tetraploid *Triticum turgidum* (AABB) (Kimber, 1987). *T. turgidum* then hybridized with diploid *Aegilops tauschii* Coss. (genome DD) (Kihara, 1944; McFadden, 1946). The exact B genome donor has not been identified because the diploid species in the Triticeae that are currently known to have the B genome failed to pair with *T. aestivum* chromosomes.

Wheat is considered to have probably originated in Transcaucasia based on the regions of distribution of *A. tauschii* one of the progenitors of bread wheat. The Southeast Caspian region of Iran is also considered a center of origin of wheat based on the prevalence of the alpha-amylase isozyme profile of the *A. tauschii* collections from this region in the present day cultivated wheat (Nishikawa, 1980) suggesting that hexaploid wheat probably originated twice in Transcaucasia and Caspian region of Iran.

Chromosome structure and genetics

Wheat has a large genome with 16 x 10^6 kb DNA, 35 times larger than rice (*Oryza sativa* L.) and six times larger than maize (*zea mays*) (Arumuganathan and Earle, 1991). Based on the renaturation kinetics of repeated and non-repeated sequences, only 25% of the wheat genome is made of non-repeated DNA and 50-65% of the genome consists of repeated sequence DNA (Flavell, 1976). As a polyploid, wheat can tolerate structural and numerical variations in the chromosome number for many generations. This has led to the development of several widely used sophisticated cytogenetic stocks such as the nulli-tetrasomics, ditelosomics and deletion lines that were created using the wheat genotype "Chinese Spring" as a recurrent parent (Endo and Gill, 1996; Sears, 1954). These cytogenetic stocks can be used for locating loci to specific chromosome arms and are used for physical mapping of loci.

Mapping resources

Genetic maps have been developed in wheat using the genetic stocks and, more recently, molecular markers. The resources for mapping are many and include some of the commonly used DNA markers such as Restriction Fragment Length Polymorphisms (RFLP), Simple

Sequence Repeats (SSR), Expressed Sequence Tags (ESTs), Amplified Fragment Length Polymorphisms (AFLP), Random Amplified Polymorphic DNA (RAPD), Sequence Tagged Sites (STS), Resistance Gene Analog Polymorphisms (RGAP), Cleavage Amplified Polymorphic Sequence (CAPS), Target Region Amplified Polymorphic Sequence(TRAPs) and Single Nucleotide Polymorphisms (SNPs).

RFLPs are based on variations in DNA sequence at the restriction site for a restriction enzyme. On digestion of the plant genomic DNA with appropriate restriction enzyme differentially sized fragments are observed and detected using Southern hybridization (Paterson, 1996). RFLPs were the first molecular markers to be used for creating genetic maps in wheat (Marino et al., 1996; Nelson et al., 1995a; Nelson et al., 1995b), but they have a lower rate of polymorphism compared to most of the PCR based markers more commonly used in wheat. RFLPs were used to create a backbone linkage map (Marino et al., 1996; Nelson et al., 1995a; Nelson et al., 1995b), for phylogenetic studies (Monte et al., 1993), to move a gene from wild species to cultivated species (Delibes et al., 1993) and to tag genes/QTLs (Groos et al., 2002) (the *Eps* locus on 3A of bread wheat is associated with an RFLP marker Xcdo549) (Shah et al., 1999).

SSRs are the most commonly used mapping resource in wheat because of their higher rates of polymorphism relative to RFLPs and ease of use. These are tandem repeats or multiple tandem repeats of short sequence motifs (no more than six bases long) flanked by unique and often conserved DNA sequences. Most wheat SSRs are two base pair repeats. PCR amplification of the SSRs using primers specific for the flanking sequence will result in polymorphisms which can be visualized using polyacrylamide gels. The SSRs most useful for mapping are specific to one genome (Roder et al., 1998). A consensus map for microsatellite markers including WMC (Wheat Microsatellite Consortium), GWM (Gatersleben Wheat Microsatellite), GDM (Gatesleben D genome Microsatellite), CFA (Clermont-Ferrand A genome), CFD (Clermont-Ferrand D genome) and BARC (Beltsville Agriculture Research Center) SSR marker sets and totalling 1,235 markers has been developed (Somers et al., 2004). There are several SSRs identified as linked to traits of interest. A few examples are the powdery mildew [*Erysiphe graminis* DM *f.sp. tritici* (Em. Marchal)] resistance gene *Pm5e* in common wheat on chromosome 7BL linked to two markers *Xgwm*783 and *Xgwm*1267 (Huang et al., 2003) and also *Pm16* on short arm of 5B linked to the marker *Xgwm*159 (Chen et al., 2005) and the marker *Xgwm*538 on chromosome 4B that is associated with karnal bunt (*Tilletia indica* Mitra) resistance (Sukhwinder et al., 2003) (www.maswheat.ucdavis.edu). SSR's linked to quality traits have also been identified and include a QTL for test weight, thousand kernel weight and milling quality in durum wheat (Elouafi and Nachit, 2004) and QTLs for preharvest sprouting, 1000 kernel weight, kernel number per spike (Groos et al., 2002).

EST-based SSRs are simple sequence repeats designed based on the Expressed Sequence Tags that have been identified in the wheat genome. The polymorphisms in random SSRs are generated from the whole genome sequence including the coding and non coding regions where as the EST SSRs are specific to the expressed sequence of the DNA and therefore may be more representative of actual genes. A QTL for resistance to leaf rust resistance and leaf tip necrosis, QLrP.sfr-7DS, in the winter wheat cultivar Forno has been tagged with EST markers Xsfr.BF473324 and Xsfr.BE493812 and SSR marker *Xgwm*1220 (Schnurbusch et al., 2004). EST SSRs are also used for assessing genetic variation in durum wheat (Eujayl et al., 2002).

AFLPs are based on selective PCR amplification of restriction fragment from a genomic DNA digest. These are more resource consuming than other PCR based markers like the SSRs and may not be as reproducible as SSRs and RFLPs but have higher polymorphism rates. AFLPs have been used to tag a major QTL for scab resistance on 7B chromosome of wheat from the cross Ning 7840 x Clark, which was located between the markers AAC/CGAC3 and GCTG/CGAC1, the leaf rust resistance gene *Lr19* and other agronomic traits in wheat (Bai et al., 1999; Groos et al., 2002; Prins et al., 2001), in addition to determining genetic diversity among wheat cultivars (Barrett and Kidwell, 1998).

Sequence Tagged Sites (STS) are developed from known sequences in the genome. Previously developed RFLP clones, sequenced AFLP fragments or cloned genes are good sources for developing STS markers. Specific primers are designed for the sequence and amplified through polymerase chain reaction and the polymorphism is detected as a size difference in the amplified product. STS markers have been used to tag *Lr10*, *Lr19* wheat leaf rust resistance genes, powdery mildew resistance gene *Pm1*, the Hessian fly resistance gene *H6*, and stripe rust resistance gene *YrMoro* (Dweikat et al., 2002; Hu et al., 1997; Prins et al., 2001; Schachermayr et al., 1997; Smith et al., 2002)

RGAPs are based on conserved sequences of disease resistance genes. The genomic DNA is amplified using degenerate primers designed from the conserved sequences of the disease resistance genes such as the Nucleolar Binding Site (NBS)-Leucine Rich Repeat (LRR), and Kinase (KIN). The size difference of the amplified DNA sequences provide the polymorphism for mapping. Several RGAP markers have been reported to be linked to stripe rust resistance genes *Yr9* (Shi et al., 2001) *Yr5* (Yan et al., 2003a), *Yr15* (Chen, 2002) and three QTLs for high temperature adult plant stripe rust resistance (Chen, 2000).

CAPS are PCR based markers where the monomorphic PCR products are digested with a restriction endonuclease to produce polymorphism due to differences at the cleavage site for the enzyme. They need more resources than SSRs, but have been useful when used to identify polymorphisms in specific regions of the genome near known major genes. The *Vrn-A1* gene, a major vernalization locus associated with growth habit of wheat is tagged with a CAPS marker amplified by the primer VA1F/VA1R (Sherman et al. 2004). The leaf rust gene *Lr51* is linked to a CAPS marker amplified by the primers S30-13L and AGA7-759R and the leaf rust gene *Lr47* can be identified with CAPS marker amplified by primer PS10R and PS10L2 in lines prescreened with primers PS10L –PS10R (Helguera et al., 2000; Helguera et al., 2005) and Fusarium Head Blight resistance in hexaploid wheat – *Lophopyrum* substitution lines is linked to a CAPS marker *Xpsr*129 (Shen et al., 2004).

Target Region Amplification Polymorphism is a marker system that is based on sequence information available around candidate gene sequences (Hu and Vick, 2003). They are PCR based, one primer is designed from the sequence of interest in the EST database and the second primer is an arbitrary primer. The genomic DNA is amplified resulting in several polymorphic bands that are visualized on a polyacrylamide gel. They have been used effectively for identification of disease resistance and quality traits in wheat (Liu et al., 2005). Single Nucleotide Polymorphisms (SNP) are another type of markers just arriving on the horizon in wheat though these are being used widely in other crops like maize and soybean. SNP is a single base mutation in a DNA sequence that can be identified by comparing sequences of DNA in germplasm or EST databases. Primers are designed based on the SNP sequence and the visualization is through processes like microarray technique and Taqman assay and the genotype data is obtained. (http://snp.cshl.org/).

COLD TEMPARATURE AN IMPORTANT ABIOTIC STRESS IN WHEAT

Cold temperature is an important abiotic stress in regions where winter wheat is cultivated. On average, crop loss due to cold injury occurs every 5-10 years in a growing region with severe winters. There was a 70% loss of wheat yield in 1991 in the state of Washington (Allan et.al. 1992) with significant cold injury occurring again in 1999, 2004 and 2005. The different types of freezing injuries that occur in a wide range of plant species include fracture jump lesions which are deviations in the plasma membrane fracture plane, hexagonal II phase in plasma membrane, electrolyte leakage, expansion induced lysis, loss of osmotic responsiveness and dehydration. All this leads to loss of cell function and cell death (Uemura et al., 1995; Webb and Steponkus, 1993; Webb et al., 1994).

Biochemical factors affecting cold temperature tolerance

The tolerance or susceptibility of a plant to freezing is influenced by the biochemical processes that occur in the plant during exposure to cold temperature. Differential accumulation of dehydrins and water soluble carbohydrates such as sucrose, starch, glucose, fructose, fructans and malate have been reported in grass species (Crecelius et al., 2003; Hurry et al., 1995; Kerepesi et al., 2004; Stupnikova et al., 2002). The accumulation of water soluble carbohydrates is probably genetically controlled (Vagujfalvi et al., 1999). Water soluble carbohydrates protect the cell structures and protoplasm and affect the enzymes involved in photosynthesis like sucrose-p-synthase and fructose-1,6-biphosphatases. Fructose-1,6-biphosphatase accumulation is higher in winter wheat as compared to spring wheat (Hurry et al., 1995) when exposed to cold. Fructan protects the cells from sugar induced feedback inhibition of photosynthesis by regulating the sucrose concentration in the vacuole (Pollock, 1986). The enzymes in malate metabolism: NADP-malate dehydrogenase, NAD-malate dehydrogenase, NADP-malic enzyme and phosphoenolpyruvate carboxylase also increase in cold hardened leaves of winter rye (Crecelius et al., 2003).

Membranes play a major role in protecting the cells from cold injury. Membrane function is critical for survival of plants and cold induces several changes in the membrane lipids. In several plant species the polyunsaturated acyl and polyunsaturated lysophopholipid species increased and the saturated lipids decreased during cold acclimation for most species. In Arabidopsis, similar reactions were observed when plants were subjected to -8^{o}C for an hour. Lipolytic activity is favorable to plants to maintain the bilayer structure of the membrane through changes in the ratio of phospholipids to galactolipids during cold treatment (Cyril et al., 2002; Palta et al., 1993; Ruelland et al., 2002; Welti et al., 2002). Dehydrins in maize bind to the lipid vesicles with acidic phospholipids to keep the membrane functional (Koag et al., 2003). In wheat, phospholipase D, Phospholipase C and phospholipaseA2 and lysophosphatidylcholine increase in response to cold (Skinner et al., 2005).

Physiological factors

Physiological changes in the plant that result in cold injury can be due to extracellular and intracelluar freezing. Extracellular freezing is the presence of ice exclusively in the regions of the tissue outside the cell. This process leads to an increase in the solute concentration and a decrease in the vapor pressure of the unfrozen solute inside the cell due to the freeze concentration of the solutes. The disequilibrium in the chemical potential of water within the cell and outside the cell and the faster decline of vapor pressure of ice compared to the liquid water will result in the movement of water from inside the cell to the outside resulting in formation of extra-cellular ice crystals (Guy 1990). This process will result in the dehydration of the cell and results in cell death if the cold temperatures continue after the cell dehydration.

In contrast to extracellular freezing, intracellular freezing is lethal to the plant. Extracellular ice growth and the accumulation of carbohydrates in the cells can slow the process of intracellular freezing (Goldstein and Nobel, 1991; Goldstein and Nobel, 1994; Yamada et al., 2002). When prolonged exposure to cold occurs in sensitive plants, the plasma membrane and cell wall do not provide resistance to the spread of extracellular ice to the intracellular spaces. In resistant plants, the cell wall and plasma membrane act as barriers for the spread of extracellular ice and prevent intracellular freezing which reduces the freezing injury. Cells with disrupted plasma membranes will respond by forming intracellular freezing and freeze damage will occur (Yamada et al., 2002).

Genetic and environmental factors

Cold acclimation is the process of increasing the freezing tolerance of plant species by exposing plants to low non-freezing temperatures. This serves two main purposes, one is to allow the plant to adjust the basic cellular function and metabolism to the low temperature stress and the second is the induction of freezing tolerance (Guy 1990).

Cold Hardiness in Arabidopsis

In Arabidopsis (*Arabidopsis thaliana*), the Cold regulated (COR) genes are an essential part of the cold hardening processes. The COR genes are regulated by a family of transcription factors known as CRT (C-repeat)/DRE (dehydration responsive element) binding factors (CBF). There are 3 members in the CBF family in Arabidopsis. The CBF1 responds to water deficit and low temperature (Jaglo-Ottosen et al., 1998), CBF2 and CBF3 bring about multiple biochemical changes (Gilmour et al., 2000). The COR genes and CBF are involved in a cold response pathway referred to as the CBF cold acclimation pathway involving a hypothesized CBF regulon that provides cold tolerance.

In the proposed CBF cold acclimation pathway a regulatory protein referred to as Inducer of CBF Expression (ICE) is thought to be the first receptor of a cold signal when plants are exposed to cold. This rapidly induces the CBF genes and in turn results in the expression of the CBF regulon. The CBF regulon includes the COR, Early Dehydration- inducible (ERD) and other unknown genes that could be cold regulated. The action of the CBF regulon provides increased freezing tolerance to the plants (Gilmour et al., 1998). Two other proteins from Sensitive to Freezing gene (SFR6) and High expression of Osmotically responsive genes (HOS1) are also proposed to be acting in the CBF Cold Acclimation Pathway (Knight et al., 1999).

Later studies on the Arabidopsis transcriptome revealed the probable existence of multiple low-temperature regulatory pathways in addition to the CBF cold response pathway (Fowler and Thomashow, 2002). 306 gene transcripts were detected that respond to cold; 218 were up-regulated when exposed to cold and 88 were down-regulated in response to cold. 64 of the up-regulated genes had long term expression and 156 genes expressed transiently. In case of the down-regulated genes, 42 had long term expression and 46 of the 88 expressed transiently. Only 12% of the genes were members of the CBF regulon and at least 28% of those were not regulated by the CBF transcription factors, suggesting that those genes were from different low-temperature regulons that are currently unknown. This implies that there could be several pathways providing cold tolerance in Arabidopsis (Fowler and Thomashow, 2002).

Cold hardiness in wheat

In wheat the different groups of *COR* genes that have been identified are *WCS19*, *WCS66*, *WCS120*, *WCOR80*, *WCOR726*, *COR39* and *COR410* in the group *COR47* and *COR14*. *COR14b* is well studied in wheat and barley and it is mapped to the long chromosome arm of 2A of *T. monococcum*. Hexaploid wheat has two loci, *Rcg1* (regulator of *COR14b* gene) and *Rcg2* located on chromosome 5A, that regulate the expression of *COR14b* mRNA accumulation (Vagujfalvi et al., 2000). *COR14b* is differentially expressed, probably due to the allelic variation at X*Cbf3* locus. The X*Cbf3* locus is homologous to the barley gene *Cbf3* which was detected because of its homology to the Arabidopsis CBF genes (Vagujfalvi et al., 2003). The *WCS 120* gene family in wheat is regulated by vernalization or the requirement for a period of exposure to cold temperature prior to the transition from vegetative to reproductive growth. The *WCS 120* mRNA accumulation follows the lethal temperature 50 (LT50 = the lethal temperature at which 50% of the plants are dead due to cold injury) values of spring and winter wheat cultivars closely, resulting in an increased accumulation during cold temperatures and decline in *WCS 120* proteins once the plant reaches vernalization saturation (Fowler et al., 1996).

Cold hardiness is influenced by developmental genes on different wheat chromosomes that regulate vegetative to reproductive transition namely, the group 2, the group 5 and chromosome 7B of wheat. A major frost tolerance gene *Fr-1* (*Fr-A1*) (Galiba et al., 1995) and QTL, *Fr-A2*, have been mapped on to the long arm of chromosome 5A (Vagujfalvi et al., 2003). *Qfr.jic*-5D, another QTL, is on 5D (Snape, 1997). 7B has a vernalization locus (Law, 1966). Major genes affecting photoperiod response *Ppd-A1*, *Ppd-B1* and *Ppd-D1* are on the group 2 chromosomes (Scarth, 1983; Welsh, 1973).

Effect of vernalization and photoperiod on regulation of low temperature tolerance in wheat

Allelic variations in the photoperiod and vernalization genes contribute to the wide adaptation of wheat worldwide. The vernalization gene, *Vrn-A1* located on 5AL, has two orthologous loci, *Vrn-B1* and *Vrn-D1*, located on the long arms of chromosomes 5B and 5D respectively (Pugsley, 1971; Pugsley, 1972). These three loci, collectively known as *Vrn-1*, each have a dominant *Vrn-1a* allele that confers spring habit and lacks response to vernalization and a recessive *Vrn-1b* allele that results in a near-absolute requirement for vernalization to transition from a vegetative to reproductive state (Pugsley, 1971; Pugsley, 1972). The orthologous *Vrn-*A^{m}*1* gene responsible for vernalization response in diploid wheat has been cloned out of *Triticum monococcum*, a progenitor of the wheat A genome. The vernalization gene, *Vrn-A1*, on chromosome 5A is closely linked to the Frost Resistance gene, *Fr1* (Galiba et al., 1995). The *Vrn-A1-Fr1* interval has been reported to have a significant effect on cold hardiness differences between spring and winter wheat genotypes based on the results from artificial freezing tests of Near Isogenic Lines (NILs) in ′Suweon 185′ and ′Chugoku 81′ (Storlie et al., 1998). The exact location of *Fr1* is not clear, different researchers have placed it proximal and distal to *Vrn-A1* (Galiba et al., 1995; Sutka et al., 1999).

Photoperiod and vernalization influence low temperature tolerance through developmental regulation. Alleles of the vernalization gene *Vrn-A1* regulate the expression of Cold Regulated (*COR*) genes (Danyluk et al., 2003; Fowler et al., 1996). Limin and Fowler, (2002) compared NILs of ‘Norstar’ (winter wheat) and ‘Manitou’ (spring wheat) and reported that the *Vrn-A1b* allele, conferring a response to vernalization and therefore, winter habit, will keep *COR* genes in an up regulated state if the plant is in the vegetative stage. Once the plants enter the reproductive stage, they are more sensitive to cold and the expression of *COR* genes is down-regulated (Danyluk et al., 2003). Winter wheat remains in the vegetative stage until the need for vernalization is satisfied and are, in general, more tolerant to cold (Fowler et al. 1996). In the case of barley, the low temperature induced *WCS* and *WCOR* gene expression was regulated by photoperiod. The *WCS* and *WCOR* gene expression was also dependent on the low temperature acclimation of the plants. In case of short day exposure there was longer and higher expression of the *WCS* and *WCOR* proteins due to the extended vegetative stage of the plant. In contrast plants exposed to long days expressed the *WCS* and *WCOR* genes for a very short period and the level of expression was reduced since the plants entered reproductive phase quickly under long day length conditions. This implies that the photoperiod and vernalization genes interact with environment and regulate the flowering time so that the plant flowers only during non-stress conditions. This influences the length of the life cycle of wheat plants (Snape et al., 2001) and their ability to withstand cold.

Cultural practices

In order to accommodate the photoperiod and vernalization requirements the winter wheat crop is usually sown during fall so that the plants can germinate and develop a strong crown and root system prior to cold temperature exposure. The colder temperatures in late fall expose plants to non-freezing temperatures, or cold acclimation. This leads to the activation of all the regulatory elements involved in cold tolerance resulting in survival of the crop over winter. If a severe or long winter occurs, the plants ability to tolerate cold towards the end of winter is low, since the plants would have reached vernalization saturation after a 4 to 8 week period depending on the cultivar grown. The cold response genes will be down regulated, with a decrease in the ability of the plants to tolerate cold. Prolonged cold or sudden temperature drops result in cold injury and economic loss (Fowler et al., 1996; Fowler et al., 2001). Spring wheat is sown during spring and the requirement for cold tolerance is less than for winter wheat but spring wheat can still suffer cold injury due to late spring frost damage.

BREEDING FOR STRIPE RUST RESISTANCE

Stripe rust (*Puccinia striiformis* f.sp. *tritici*), also known as yellow rust, is one of the most important diseases of wheat in the Pacific Northwest. Stripe rust occurs in cooler climates. The combination of resistant cultivars with application of fungicides can give higher yields even if the inoculum is prevalent in the region (Powelson and Halsey, 1982). Some fungicides can be phytotoxic when used several times at higher dosage (Rakotondradona and Line, 1984). Because fungicides do not provide a long term economical solution to the disease, resistant cultivar is the best long term solution.

Pathogen:

The fungal pathogen *Puccinia striiformis* f.sp.*tritici* is an obligate parasite and does not have known alternate hosts. *Puccinia striiformis* infects rye, barley and over 18 genera of grasses in addition to wheat. Many perennial grasses act as reservoirs. Grasses in and around wheat fields harbor the spores and the pathogen oversummers (Line, 1976; Shaner and Powelson, 1973). This is one of the sources of urediospores for the fall crop. Windborne spores from distant hosts is another important source of infection (Wiese, 1987). Stripe rust appears earlier in the field than leaf and stem rust and infection can occur throughout autumn and winter since the mycelium can remain viable at $-5^{o}C$.

Wheat rusts have as many as five spore stages. Urediospores, produced in great numbers in the spring and summer, are important epidemiologically. They are dispersed by wind to other plants, where they generate new infections and secondary urediospores in intervals as short as seven days (Wiese, 1987).

Urediospores are nutrient-independent and germinate in contact with water films. Germ tubes penetrate stomata directly. They form substomatal vesicles and intercellular hyphae with globose or lobed haustoria that establish physiologic contact with host cell membranes to complete the infection process (Wiese, 1987).

Chemical Control:

Fungicides can be an effective means of control depending on the time, rate and number of applications (Chen, 2004a; Line et al., 1983; Padgett, 2004). During 2002 stripe rust affected 70% of spring wheat crop and 2.5% of winter wheat crop, with an yield loss of 363,568 metric tons (2.3%) in the state of Washington (Chen, 2005). Low dose seed treatment combined with with high temperature adult plant (HTAP) resistance and or foliar spray to plants was more effective than fungicide application at the onset of disease (Rakotondradona and Line, 1984). Tilt® (propiconazole), Quadris® (azixtstrobin), Stratego ™ (propiconazole + trifloxystrobin), Headline™ (strobilurin) and Quilt™ (azoxystrobin + propiconazole) are the fungicides used for stripe rust control of wheat in the US (Chen, 2005)

Host Plant Resistance:

Two forms of resistance, seedling or all stage and High Temperature Adult Plant (HTAP), have been useful in stripe rust resistance breeding. Seedling resistance tends to be race specific, characterized by low infection types during all plant growth stages and is effective under wide range of temperatures (Chen 2005). If cultivars with a single source of seedling resistance are used widely, new pathogen races can evolve within 3-4 years rendering the cultivar susceptible to stripe rust (Line and Chen, 1995).

Plants with HTAP resistance alone have high resistance at higher temperature as they grow older and are susceptible during the seedling stage and when grown at low temperatures (Chen, 2005). HTAP forms a wide range of infection types, and infection types can shift based on the temperature, the stage of plant growth (Line and Chen, 1995) and the amount of inoculum present. HTAP is nonspecific, durable and has remained effective for more than two decades in cultivar 'Stephens' (Qayoum and Line, 1985).

Cultivars with a combination of HTAP and seedling resistance will be ideal for durable and higher level stripe rust resistance (Chen and Line, 1995b). The heritability of HTAP resistance derived from the cultivars Druchamp and Stephens has been reported to be high. The broad sense heritability in an F_5 population was 96.8% and 95.3% respectively for Druchamp and Stephens-derived HTAP resistance. Narrow sense heritability, which forms the main component inherited to the next generation, was calculated from the F_2, was 95.4% for Stephens and 86.1 to 89.1% for Druchamp (Chen and Line, 1995b). Seedling resistance and HTAP together have a low and variable narrow sense heritability (19.6-60.2%) but high broad sense heritability of 85.2 to 98.7% (Chen and Line, 1995b).

Additive gene action is major contributor for HTAP resistance (Chen and Line, 1995a; Chen and Line, 1995b; Henriksen and Pope, 1971; Lewellen and Sharp, 1968; Milus and Line, 1986a; Milus and Line, 1986b; Sharp et al., 1976). Chen and Line, (1993) observed that the resistance gene expression was influenced by maternal cytoplasm. Milus and Line, (1986a) studied maternal inheritance for resistance and observed that there was no maternal inheritance for resistance in the cultivars they studied.

The available literature suggests the importance of studying cold tolerance and stripe rust resistance in wheat in the Pacific Northwest due to the significant impact of these stresses on crop production. This dissertation is based upon a series of experiments designed to develop an understanding of cold tolerance in wheat and to identify stripe rust resistance for HTAP and seedling resistance. Chapter two reports the relationship between the vernalization genes and cold tolerance. Chapter three reports the status of a molecular map developed for cold tolerance in two RIL populations of wheat and Chapter four reports the breeding for high temperature adult plant stripe rust resistance.

References:

Arumuganathan, K., and E.D. Earle. 1991. Nuclear DNA content of some important plant species. Plant Molecular Biology Reporter 9:208-218.

Brule-Babel, A.L., and D.B. Fowler. 1989. Use of controlled environments for winter cereal cold hardiness evaluation: controlled freeze tests and tissue water content as prediction tests. Canadian Journal of Plant Science = Revue Canadienne de Phytotechnie 69:355-366.

Bai, G., F.L. Kolb, G. Shaner, and L.L. Domier. 1999. Amplified fragment length polymorphism markers linked to a major quantitative trait locus controlling scab resistance in wheat. Phytopathology 89:343-348.

Barrett, B.A., and K.K. Kidwell. 1998. AFLP-based genetic diversity assessment among wheat cultivars from the Pacific Northwest. Crop Science 38:1261-1271.

Pollock, C.J. 1986. Fructans and the metabolism of sucrose in vascular plants. New Phytologist 104:1-24.

Campbell, K.G., P.L. Finney, C.J. Bergman, D.G. Gualberto, J.A. Anderson, M.J. Giroux, D. Siritunga, J. Zhu, F. Gendre, C. Roue, A. Verel, and M.E. Sorrells. 2001. Quantitative trait loci associated with milling and baking quality in a soft x hard wheat cross. Crop Science 41:1275-1285.

Chen, X.M and Wood., D.A. 2004. Control of stripe rust of winter wheat with foliar fungicides. Fungicide and Nematicide Tests (online.) Report 60:CF027 http://www.apsnet.org/online/FNtests/

Chen, X.M. 2005. Epidemiology and control of stripe rust [*Puccinia striiformis f. sp. tritici*] on wheat. Canadian Journal of Plant Pathology = Revue Canadienne de Phytopathologie 27: 314-37.

Chen, X.M., and R.F. Line. 1993. Inheritance of stripe rust resistance in wheat cultivars postulated to have resistance genes at Yr3 and Yr4 loci. Phytopathology 83:382-388.

Chen, X.M., and R.F. Line. 1995a. Gene action in wheat cultivars for durable high-temperature adult-plant resistance and interactions with race-specific, seedling resistance to stripe rust caused by *Puccinia striiformis*. Phytopathology 85:382-388.

Chen, X.M., and R.F. Line. 1995b. Gene number and heritability of wheat cultivars with durable, high-temperature, adult-plant resistance and race specific resistance to *Puccinia striiformis* . Phytopathology 85:573-578.

Chen, X.M., Y.H. Luo, X.C. Xia, L.Q. Xia, X. Chen, Z.L. Ren, Z.H. He, and J.Z. Jia. 2005. Chromosomal location of powdery mildew resistance gene PM16 in wheat using SSR marker analysis. Plant Breeding = Zeitschrift für Pflanzenzuchtung 124:225-228.

Chen, X.M., and R.F. Line 2000. VIII International Plant and Animal Genome Conference, Town and Country Hotel, San Diego, Calif. 9-12 January 2000.

Chen, X.M. and G.P.Yan. 2002. Development of RGAP markers for stripe rust resistance gene *Yr15* and use of the markers to detect the gene in breeding lines. Phytopathology 92:S14.

Crecelius, F., P. Streb, and J. Feierabend. 2003. Malate metabolism and reactions of oxidoreduction in cold-hardened winter rye (*Secale cereale* L.) leaves. Journal of Experimental Botany 54:1075-1083.

Cyril, J., G.L. Powell, R.R. Duncan, and W.V. Baird. 2002. Changes in membrane polar lipid fatty acids of seashore paspalum in response to low temperature exposure. Crop Science 42:2031-2037.

Danyluk, J., N.A. Kane, G. Breton, A.E. Limin, D.B. Fowler, and F. Sarhan. 2003. TaVRT-1, a putative transcription factor associated with vegetative to reproductive transition in cereals. Plant Physiology 132:1849-1860.

Delibes, A., D. Romero, S. Aguaded, A. Duce, M. Mena, I. Lopez-Brana, M.F. Andres, J.A. Martin Sanchez, and F. Garcia-Olmedo. 1993. Resistance to the cereal cyst nematode (*Heterodera avenae* Woll.) transferred from the wild grass *Aegilops ventricosa* to hexaploid wheat by a "stepping stone" procedure. Theoretical and Applied Genetics 87:402-408.

Dweikat, I., W. Zhang, and H. Ohm. 2002. Development of STS markers linked to Hessian fly resistance gene H6 in wheat. Theoretical Applied Genetics 105:766-770.

Elouafi, I., and M.M. Nachit. 2004. A genetic linkage map of the Durum x *Triticum dicoccoides* backcross population based on SSRs and AFLP markers, and QTL analysis for milling traits. Theoretical and Applied Genetics 108:401-413.

Endo, T.R., and B.S. Gill. 1996. The deletion stocks of common wheat. The Journal of Heredity 87:295-307.

Eujayl, I., M.E. Sorrells, M. Baum, P. Wolters, and W. Powell. 2002. Isolation of EST-derived microsatellite markers for genotyping the A and B genomes of wheat. Theoretical and Applied Genetics 104:399-407.

Flavell, R.B. and D.B. Smith. 1976. Nucleotide sequence organisation in the wheat genome. Heredity : an International Journal of Genetics 37:231-252.

Fowler, D.B., L.P. Chauvin, A.E. Limin, and F. Sarhan. 1996. The regulatory role of vernalization in the expression of low-temperature-induced genes in wheat and rye. Theoretical and Applied Genetics 93:554-559.

Fowler, D.B., G. Breton, A.E. Limin, S. Mahfoozi, and F. Sarhan. 2001. Photoperiod and temperature interactions regulate low-temperature-induced gene expression in barley. Plant physiology 127:1676-1681.

Fowler, S., and M.F. Thomashow. 2002. Arabidopsis transcriptome profiling indicates that multiple regulatory pathways are activated during cold acclimation in addition to the CBF cold response pathway. The Plant Cell 14:1675-1690.

Galiba, G., S.A. Quarrie, J. Sutka, A. Morounov, and J.W. Snape. 1995. RFLP mapping of the vernalization (*Vrn1*) and frost resistance (*Fr1*) genes on chromosome 5A of wheat. Theoretical and Applied Genetics 90:1174-1179.

Gilmour, S.J., A.M. Sebolt, M.P. Salazar, J.D. Everard, and M.F. Thomashow. 2000. Overexpression of the Arabidopsis CBF3 tanscriptional activator mimics multiple biochemical changes associated with cold acclimation. Plant Physiology 124:1854-1865.

Gilmour, S.J., D.G. Zarka, E.J. Stockinger, M.P. Salazar, J.M. Houghton, and M.F. Thomashow. 1998. Low temperature regulation of the Arabidopsis CBF family of AP2 transcriptional activators as an early step in cold-induced COR gene expression. The Plant Journal : for Cell and Molecular Biology 16:433-442.

Goldstein, G., and P.S. Nobel. 1991. Changes in osmotic pressure and mucilage during low-temperature acclimation of *Opuntia ficus-indica*. Plant Physiology 97:954-961.

Goldstein, G., and P.S. Nobel. 1994. Water relations and low-temperature acclimation for cactus species varying in freezing tolerance. Plant Physiology 104:675-681.

Groos, C., G. Gay, M.R. Perretant, L. Gervais, M. Bernard, F. Dedryver, and G. Charmet. 2002. Study of the relationship between pre-harvest sprouting and grain color by quantitative trait loci analysis in a white x red grain bread-wheat cross. Theoretical and Applied Genetics 104:39-47.

Helguera, M., I.A. Khan, and J. Dubcovsky. 2000. Development of PCR markers for the wheat leaf rust resistance gene *Lr47*. Theoretical and Applied Genetics 100:1137-1143.

Helguera, M., L. Vanzetti, M. Soria, I.A. Khan, J. Kolmer, and J. Dubcovsky. 2005. PCR Markers for *Triticum speltoides* Leaf Rust Resistance Gene *Lr51* and Their Use to Develop Isogenic Hard Red Spring Wheat Lines. Crop Science 45:728-734.

Henriksen, G.B., and W.K. Pope. 1971. Additive resistance to stripe rust in wheat. [*Puccinia Striiformis*]. Crop Science 11:825-827.

Hu, J., and B.A. Vick. 2003. Target region amplification polymorphism: a novel marker technique for plant genotyping. Plant Molecular Biology Reporter 21:289-294.

Hu, X.Y., H.W. Ohm, and I. Dweikat. 1997. Identification of RAPD markers linked to the gene *PM1* for resistance to powdery mildew in wheat. Theoretical and Applied Genetics 94:832-840.

Huang, X.Q., L.X. Wang, M.X. Xu, and M.S. Roder. 2003. Microsatellite mapping of the powdery mildew resistance gene *Pm5e* in common wheat (*Triticum aestivum* L.). Theoretical and Applied Genetics 106:858-865.

Hurry, V.M., A. Strand, M. Tobiaeson, P. Gardestrom, and G. Oquist. 1995. Cold hardening of spring and winter wheat and rape results in differential effects on growth, carbon metabolism, and carbohydrate content. Plant Physiology 109:697-706.

Jaglo-Ottosen, K.R., S.J. Gilmour, D.G. Zarka, O. Schabenberger, and M.F. Thomashow. 1998. Arabidopsis CBF1 overexpression induces COR genes and enhances freezing tolerance. Science 280:104-106.

Kerepesi, I., E. Banyai-Stefanovits, and G. Galiba. 2004. Cold acclimation and abscisic acid induced alterations in carbohydrate content in calli of wheat genotypes differing in frost tolerance. Journal of Plant Physiology 161:131-133.

Kihara, H. 1944. Discovery of the DD-analyser, one of the ancestors of *Triticum vulgare* (in Japanese). Agric. Hortic 19:13-14.

Kimber, G. and M. Feldman. 1987. Wild Wheat. University of Missouri Press, Columbia.

Knight, H., E.L. Veale, G.J. Warren, and M.R. Knight. 1999. The *sfr6* mutation in Arabidopsis suppresses low-temperature induction of genes dependent on the CRT/DRE sequence motif. [Erratum: 2004 Sept., v. 16, no. 9, p. 2541.]. Plant Cell 11:875-886.

Koag, M.C., R.D. Fenton, S. Wilkens, and T.J. Close. 2003. The binding of maize DHN1 to lipid vesicles. Gain of structure and lipid specificity. Plant Physiology 131:309-316.

Law, C.N. 1966. The location of genetic factore affecting a quantitative character in wheat. Genetics 53:487-498.

Lewellen, R.T., and E.L. Sharp. 1968. Inheritance of minor reaction gene combinations in wheat to *Puccinia striiformis* at two temperature profiles. Canadian Journal of Botany 46:21-26.

Limin, A.E., and D.B. Fowler. 2002. Developmental traits affecting low-temperature tolerance response in near-isogenic lines for the vernalization locus *Vrn-A1* in wheat (*Triticum aestivum* L. em Thell). Annals of Botany 89:579-585.

Line, R.F. 1976. Factors contributing to an epidemic of stripe rust [*Puccinia striiformis*] on Wheat in the Sacramento Valley of California in 1974. Plant Disease Reporter 60:312-316.

Line, R.F., and X. Chen. 1995. Successes in breeding for and managing durable resistance to wheat rusts. Plant Disease 79:1254-1255.

Line, R.F., R.B. Scott, and E.B. Adams. 1983. Control of stripe rust in western Washington, 1982 [*Puccinia striiformis* on wheat, *Triticum aestivum*]. Fungicide and Nematicide Tests : results - American Phytopathological Society 30:40-41

Liu, Z.H., J.A. Anderson, J. Hu, T.L. Friesen, J.B. Rasmussen, and J.D. Faris. 2005. A wheat intervarietal genetic linkage map based on microsatellite and target region amplified polymorphism markers and its utility for detecting quantitative trait loci. Theoretical and Applied Genetics 111:782-794.

Marino, C.L., J.C. Nelson, Y.H. Lu, M.E. Sorrells, P. Leroy, N.A. Tuleen, C.R. Lopes, and G.E. Hart. 1996. Molecular genetic maps of the group 6 chromosomes of hexaploid wheat (*Triticum aestivum* L. em. Thell.). Genome 39:359-366.

Masterson, J. 1994. Stomatal size in fossil plants: evidence for polyploidy in majority of angiosperms. Science 264:421-23.

McFadden, E.S. and E.R. Sears., 1946. The origin of *Triticum spelta* and its free-threshing hexaploid relatives. Journal of Heredity 37:81-89, 107-116.

Milus, E.A., and R.F. Line. 1986a. Gene action for inheritance of durable, high-temperature, adult-plant resistance to stripe rust in wheat. Phytopathology 76:435-441.

Milus, E.A., and R.F. Line. 1986b. Number of genes controlling high-temperature, adult-plant resistance to stripe rust in wheat. Phytopathology 76:93-96.

Monte, J.V., C.L. McIntyre, and J.P. Gustafson. 1993. Analysis of phylogenetic relationships in the Triticeae tribe using RFLPs. Theoretical and Applied Genetics 86:649-655.

Morris, R., and Sears, E.R., (ed.) 1967. The cytogenetics of wheat and its relatives., Wheat and Wheat Improvement pp. 19-87. American Society of Agronomy, Madison.

Nelson, J.C., A.E. Van Deynze, E. Autrique, M.E. Sorrells, Y.H. Lu, S. Negre, M. Bernard, and P. Leroy. 1995a. Molecular mapping of wheat. Homoeologous group 3. Genome 38:525-533.

Nelson, J.C., A.E. Van Deynze, E. Autrique, M.E. Sorrells, Y.H. Lu, M. Merlino, M. Atkinson, and P. Leroy. 1995b. Molecular mapping of wheat. Homoeologous group 2. Genome 38:516-524.

Nishikawa, K., Furuta, Y., and T. Wada 1980. Genetic studies on alpha-amylase isozymes in wheat. III Intraspecific variation in *Aegilops Squarrosa* and birthplace of hexaploid wheat. Japanese Journal of Genetics 55:325-336.

Padgett, G.B., Garber, B.W. and M.A. Purvis 2004. Evaluation of selected fungicide rates and application timings for managing stripe rust of wheat 2004. Fungicide and Nematicide Tests (online.) Report 60:CF004 http://www.apsnet.org/online/FNtests/.

Palta, J.P., B.D. Whitaker, and L.S. Weiss. 1993. Plasma membrane lipids associated with genetic variability in freezing tolerance and cold acclimation of Solanum species. Plant Physiology 103:793-803.

Paterson, A.H. 1996 Making genetic maps. In Genome Mapping in Plants, Academic Press Limited, London, United Kingdom. pp 25.

Powelson, R.L., and M.E. Halsey. 1982. Control of stripe rust of wheat with fungicides, [*Puccinia striiformis*, *Triticum aestivum*]. Fungicide and nematicide tests : results - American Phytopathological Society 38:62.

Prins, R., J.Z. Groenewald, G.F. Marais, J.W. Snape, and R.M.D. Koebner. 2001. AFLP and STS tagging of *Lr19*, a gene conferring resistance to leaf rust in wheat. Theoretical and Applied Genetics 103:618-624.

Pugsley, A.T. 1971. A Genetic Analysis of the Spring-Winter Habit of Growth in Wheat. Australian J Agriculture Research 22:21-31.

Pugsley, A.T. 1972. Additional Genes Inhibiting Winter Habit in Wheat. Euphytica 21:547-552.

Qayoum, A., and R.F. Line. 1985. High-temperature, adult-plant resistance to stripe rust of wheat. Phytopathology 75:1121-1125.

Rakotondradona, R., and R.F. Line. 1984. Control of stripe rust and leaf rust of wheat with seed treatments and effects of treatments on the host [*Puccinia striformis*, *Puccinia recondita*, *Triticum aestivum*, fungicides, Washington]. Plant Disease 68:112-117.

Roder, M.S., V. Korzun, K. Wendehake, J. Plaschke, M.-H. Tixier, P. Leroy, and M.W. Ganal. 1998. A microsatellite map of wheat. Genetics 149:2007-2023.

Ruelland, E., C. Cantrel, M. Gawer, J.C. Kader, and A. Zachowski. 2002. Activation of phospholipases C and D is an early response to a cold exposure in Arabidopsis suspension cells. Plant Physiology 130:999-1007.

Scarth, R., and C.N. Law 1983. The location of the photoperiod gene *Ppd2* and an additional genetic factor for ear emergence time on chromosome 2B of wheat. Heredity 37:335-340.

Schachermayr, G., C. Feuillet, and B. Keller. 1997. Molecular markers for the detection of the wheat leaf rust resistance gene *Lr10* in diverse genetic backgrounds. Molecular Breeding : New Strategies in Plant Improvement 3:65-74.

Schnurbusch, T., E. Bossolini, M. Messmer, and B. Keller. 2004. Tagging and validation of a major quantitative trait locus for leaf rust resistance and leaf tip necrosis in winter wheat cultivar forno. Phytopathology 94:1036-1041.

Sears, E.R. 1954. The aneuploids of common wheat. Missouri Agriculture Experiment Station Research Bulletin 572.

Shah, M.M., K.S. Gill, P.S. Baenziger, Y. Yen, S.M. Kaeppler, and H.M. Ariyarathne. 1999. Molecular mapping of loci for agronomic traits on chromosome 3A of bread wheat. Crop Science 39:1728-1732.

Shaner, G., and R.L. Powelson. 1973. The oversummering and dispersal of inoculum of *Puccinia striiformis* in Oregon. [Grasses, Wheat]. Phytopathology 63:13-17.

Sharp, E.L., B.K. Sally, and G.A. Taylor. 1976. Incorporation of additive genes for stripe rust [*Puccinia striiformis*] resistance in winter wheat. Phytopathology 66:794-797.

Shen, X., L. Kong, and H. Ohm. 2004. Fusarium head blight resistance in hexaploid wheat (*Triticum aestivum*)-*Lophopyrum* genetic lines and tagging of the alien chromatin by PCR markers. Theoretical and Applied Genetics 108:808-813.

Sherman, J.D., L. Yan, L. Talbert, and J. Dubcovsky. 2004. A PCR marker for growth habit in common wheat based on allelic variation at the *VRN-A1* gene. Crop Science 44:1832-1838.

Shi, Z.X., X.M. Chen, R.F. Line, H. Leung, and C.R. Wellings. 2001. Development of resistance gene analog polymorphism markers for the *Yr9* gene resistance to wheat stripe rust. Genome 44:509-516.

Skinner, D.Z., B.S. Bellinger, S. Halls, K.-H. Baek, K. Garland-Campbell, and W.F. Siems. 2005. Phospholipid acyl chain and phospholipase dynamics during cold acclimation of winter wheat. Crop Science 45:1858-1867.

Smith, P.H., R.M.D. Koebner, and L.A. Boyd. 2002. The development of a STS marker linked to a yellow rust resistance derived from the wheat cultivar Moro. Theoretical and Applied Genetics 104:1278-1282.

Snape, J.W., K. Butterworth, E. Whitechurch, and A.J. Worland. 2001. Waiting for fine times: genetics of flowering time in wheat. Euphytica :119:185-190.

Snape, J.W. Semikhodskii, A., Fish L, Sarma R.N., Quarrie S.A., Galiba, G., and J. Sutka 1997. Mapping frost tolerance loci in wheat and comparative mapping with other cereals. Acta Agron Hung 45:268-270.

Somers, D.J., P. Isaac, and K. Edwards. 2004. A high-density microsatellite consensus map for bread wheat (*Triticum aestivum L.*). Theoretical and Applied Genetics 109:1105-1114.

Storlie, E.W., R.E. Allan, and M.K. Walker-Simmons. 1998. Effect of the *Vrn1-Fr1* interval on cold hardiness levels in near-isogenic wheat lines. Crop Science 38:483-488.

Stupnikova, I.V., G.B. Borovskii, N.V. Dorofeev, A.A. Peshkova, and V.K. Voinikov. 2002. Accumulation and disappearance of dehydrins and sugars depending on freezing tolerance of winter wheat plants at different developmental phases. Journal of Thermal Biology 27:55-60.

Sukhwinder, S., G.L. Brown-Guedira, T.S. Grewal, H.S. Dhaliwal, J.C. Nelson, H. Singh, and B.S. Gill. 2003. Mapping of resistance gene effective against Karnal bunt pathogen of wheat. Theoretical and Applied Genetics 106:287-292.

Uemura, M., R.A. Joseph, and P.L. Steponkus. 1995. Cold acclimation of Arabidopsis thaliana. Effect on plasma membrane lipid composition and freeze-induced lesions. Plant Physiology 109:15-30.

Vagujfalvi, A., G. Galiba, J. Dubcovsky, and L. Cattivelli. 2000. Two loci on wheat chromosome 5A regulate the differential cold-dependent expression of the *cor14b* gene in frost-tolerant and frost-sensitive genotypes. Molecular Genetics and Genomics 263:194-200.

Vagujfalvi, A., G. Galiba, L. Cattivelli, and J. Dubcovsky. 2003. The cold-regulated transcriptional activator Cbf3 is linked to the frost-tolerance locus *Fr-A2* on wheat chromosome 5A. Molecular Genetics Genomics : 269:60-67.

Vagujfalvi, A., I. Kerepesi, G. Galiba, T. Tischner, and J. Sutka. 1999. Frost hardiness depending on carbohydrate changes during cold acclimation in wheat. Plant Science 144:85-92.

Webb, M.S., and P.L. Steponkus. 1993. Freeze-induced membrane ultrastructural alterations in rye (*Secale cereale*) leaves. Plant Physiology 101:955-963.

Webb, M.S., M. Uemura, and P.L. Steponkus. 1994. A comparison of freezing injury in oat and rye: two cereals at the extremes of freezing tolerance. Plant Physiology. 104:467-478.

Welsh, J.R., Keim, D.L., Pirasteh, B. and R.D. Richards 1973. Genetic control of photoperiod response in wheat. International Wheat Genetic Symposium pp. 879-884, Missouri Agriculture Experiment Station, Columbia, Missouri.

Welti, R., W. Li, Y. Sang, H. Biesiada, H.E. Zhou, C.B. Rajashekar, T.D. Williams, and X. Wang. 2002. Profiling membrane lipids in plant stress responses. Role of phospholipase D (alpha) in freezing-induced lipid changes in Arabidopsis. The Journal of Biological Chemistry 277:31994-32002.

Wiese, M.V. 1987. Compendium of wheat diseases. 2nd ed. APS Press, St. Paul, Minn.

Yamada, T., K. Kuroda, Y. Jitsuyama, D. Takezawa, K. Arakawa, and S. Fujikawa. 2002. Roles of the plasma membrane and the cell wall in the responses of plant cells to freezing. Planta 215:770-778.

Yan, G.P., X.M. Chen, R.F. Line, and C.R. Wellings. 2003. Resistance gene-analog polymorphism markers co-segregating with the *Yr5* gene for resistance to wheat stripe rust. Theoretical and Applied Genetics 106:636-643.

Chapter one

Evaluation of Cold Hardiness in Two Sets of Near Isogenic Lines of wheat (*Triticum aestivum*) with Polymorphic Vernalization Alleles

Latha Reddy[1], R.E Allan[2] and K.A.G. Campbell[2*]

[1] Department of Crop and Soil Sciences, 201 Johnson Hall, Washington State University, Pullman, WA 99164-6420

[2] USDA/ARS, Wheat Genetics, Quality, Physiology, and Disease Research Unit, 209 Johnson Hall, Washington State University, Pullman, WA 99164-6420

[*]Corresponding author Email: kgcamp@wsu.edu

As Published In

Plant Breeding (in Press)

Abstract

In wheat, variation at the orthologus *Vrn-1* loci, located on each of the three genomes, A, B, and D, are responsible for vernalization response. A dominant *Vrn-1a* allele on any of the three wheat genomes results in spring habit and the presence of recessive *Vrn-1b* alleles on all three genomes results in winter habit. Two sets of Near Isogenic Lines (NILs) were evaluated for DNA polymorphisms at their *Vrn-A1*, *B1* and *D1* loci and for cold hardiness. Two winter wheat cultivars, ‘Daws’ and ‘Wanser’ were used as recurrent parents and ‘Triple Dirk’ NILs were used as donor parents for orthologous *Vrn-1* alleles. The NILs were analyzed using molecular markers specific for each allele. Only 26 of 32 ‘Daws’ NILs and 25 of 32 ‘Wanser’ NILs had a plant growth habit that corresponded to the marker genotype for the markers used. Freezing tests were conducted in growth chambers programmed to cool to -21.5°C. Relative Area Under Death Progress Curve (AUDPC), with a maximum value of 100 was used as a measure of death due to freezing. The average relative AUDPC of the spring habit Daws *Vrn-A1a* NILs was 86.15; significantly greater than the corresponding winter habit Daws *Vrn-A1b* NILs (42.98). In contrast, all the Daws *Vrn-A1bVrn-B1aVrn-D1b* and *Vrn-A1bVrn-B1bVrn-D1a* NILs (spring habit) had relative AUDPC values equal to those of their Daws sister genotypes with *Vrn-A1bVrn-B1bVrn-D1b* NILs (winter habit). The average AUDPC of spring and winter habit Wanser NILs differed at all three *Vrn-A1*, *Vrn-B1* and *Vrn-D1* locus comparisons. We conclude that Daws and Wanser have different background genetic interactions with the *Vrn-1* loci influencing cold hardiness. The marker for *Vrn-A1* is diagnostic for growth habit and cold hardiness but there is no relationship between the *Vrn-B1* and *Vrn-D1* markers and the cold tolerance of the NILs used in this study.

Key words: Winter wheat – cold hardiness – vernalization – near isogenic lines – *Vrn-1* intron 1 deletion markers

Introduction

Winter wheat is sown during the fall and is harvested the following summer and needs exposure to low temperature, or vernalization, to transition from the vegetative to reproductive stage. Vernalization is essential for winter wheat to complete its lifecycle during a regular crop season but if plants are exposed to extreme low temperatures, cold injury can occur resulting in economic losses. In the US, the winter wheat crop is significantly reduced due to cold injury every 5-10 years. In the state of Washington 70% of winter wheat was lost during the winter of 1991 due to cold injury (Allan, 1992).

Genes affecting vernalization response as well as cold tolerance have been mapped to chromosome 5AL. The Frost Resistance gene, *Fr1*, has been reported to be closely linked to the Vernalization gene, *Vrn-A1*, on chromosome 5A (Galiba et al., 1995). The *Vrn-A1-Fr1* interval has a significant effect on cold hardiness differences between spring and winter wheat genotypes based on the results from artificial freezing tests of Near Isogenic Lines (NILs) in derived from the cultivars ′Suweon 185′ and ′Chugoku 81′ (Storlie et al., 1998). In wheat, in addition to *Fr-A1*(*Fr1*) (Galiba et al., 1995), two QTLs for frost resistance, *QFr.jic*-5D (Snape, 1997) and *Fr-A2*, have been identified (Vagujfalvi et al., 2003). *Fr-A1* (*Fr1*) and *Fr-A2* have been mapped to the wheat chromosome 5A and *QFr.jic*-5D has been mapped to wheat chromosome 5D.

Alleles of the vernalization gene *Vrn-A1* regulate the expression of Cold Regulated (*COR*) genes (Danyluk et al., 2003; Fowler et al., 1996). Limin and Fowler, 2002 compared NILs of cultivars ‘Norstar’ and ‘Manitou’ and reported that the *Vrn-A1b* allele, conferring a response to vernalization and therefore, winter habit, will keep *COR* genes in an upregulated state if the plant is in the vegetative stage. Once the plants enter the reproductive stage, they are more sensitive to cold and the expression of *COR* genes is down-regulated (Danyluk et al., 2003). Winter wheat remains in the vegetative stage until the need for vernalization is satisfied and are, in general, more tolerant to cold (Fowler et al. 1996).

Vrn-A1 has two orthologous loci, *Vrn-B1* and *Vrn-D1*, located on the long arms of chromosomes 5B and 5D respectively (Pugsley, 1971; Pugsley, 1972). These three loci collectively known as *Vrn-1*, each have a dominant *Vrn-1a* allele that confers spring habit and lacks response to vernalization and a recessive *Vrn-1b* allele that results in a near-absolute requirement for vernalization to transition from a vegetative to reproductive state (Pugsley, 1971; Pugsley, 1972). The orthologous $Vrn\text{-}A^{m}1$ gene has been cloned out of *Triticum monococcum*, a progenitor of the wheat A genome. $Vrn\text{-}A^{m}1$ is similar to the Arabidopsis flowering gene *APETALA 1* (*AP1*), a regulator of transition from vegetative to reproductive growth (Yan et al., 2003b).

A large deletion is present in the first intron of *Vrn-1* in spring habit wheat that possess the dominant *Vrn-A1a*, *Vrn-B1a* or *Vrn-D1a* alleles (Fu, 2005). In contrast, the winter habit cultivar 'Triple Dirk C', possessing recessive *Vrn-1b* alleles at all three orthologous loci, has no intron1 deletions. Fu et al. (2005) hypothesized that the deletion contained a regulatory element important for vernalization that differentiates the winter and spring habit wheat genotypes. PCR primers specific for the Intron1 deletions have been developed (Fu, 2005). A Cleavage Amplification Polymorphic Sequence (CAPS) marker specific for the *Vrn-A1* locus also has been developed (Sherman et al., 2004).

‘Triple Dirk’ is a spring wheat with the dominant *Vrn-A1a* and *Vrn-B1a* alleles and the recessive *Vrn-D1b* allele. Triple Dirk does not have any response to vernalization treatment. Pugsley (1971) developed Vernalization (Vrn) NILs in the Triple Dirk background and studied their response to vernalization. Triple Dirk B and Triple Dirk F possess the dominant allele *Vrn-B1a* on chromosome 5B, and the recessive alleles *Vrn-A1b* on chromosome 5A and *Vrn-D1b* on 5D and have little response to vernalization. Triple Dirk D and Triple Dirk E are also spring habit wheats that do not respond to vernalization. Triple Dirk D has only the dominant *Vrn-A1a* allele while Triple Dirk E has only the *Vrn-D1a* dominant allele. Triple Dirk C is a winter habit wheat possessing recessive *Vrn-1b* alleles at all three loci with a large response to vernalization (Pugsley 1971).

Molecular markers have been used to identify the effect of vernalization genes on cold hardiness (Brule-Babel and Fowler, 1988; Galiba et al., 1995; Storlie et al., 1998). PCR based markers for the promoter region of *Vrn-A1* and for the intronic regions of the different *Vrn* alleles have been used effectively to determine the different vernalization alleles in several accessions (Fu, 2005; Sherman et al., 2004). These direct markers for the different vernalization alleles can be used to evaluate the NILs and the results from the cold hardiness tests for these NILs can be compared to see if any particular vernalization allele significantly affects cold hardiness. Near isogenic lines for vernalization alleles are a good resource to study the effect of individual alleles on cold hardiness.

The objective of this study was to apply the *Vrn-A1*, *Vrn-B1*, and *Vrn-D1* specific markers to study the relationship of the marker genotypes with the phenotypes for vernalization response and cold hardiness in wheat Vrn-NILs.

Materials and Methods

Population development: Two Vrn-NIL sets were used for this research. Daws, a soft white winter wheat (Peterson et al., 1977) and Wanser, a hard red winter wheat (Nelson and Nagamitsu, 1972) were used as recurrent parents. Each set used the Triple Dirk NILs developed by Pugsley as *Vrn-1a* allele donors (Pugsley, 1971) (Table1). When these crosses were initiated, Triple Dirk B and Triple Dirk F were thought to have different dominant Vrn alleles so a set of Vrn-NILs was developed using each of Triple Dirk D, Triple Dirk B, Triple Dirk F and Triple Dirk E as donor parents. Within the progeny of each of four BC_7 families per cross, a winter and a spring sibling was identified. Each sibling was self pollinated and the growth habit of its progeny was checked in both greenhouse and field environments during 1999 and 2000. Spring habit NILs were retained only if they were homozygous for spring habit as determined by these progeny tests. Thus each Vrn-NIL set comprised four orthologous *Vrn-1* loci as four families possessing both a winter and a spring sib for a total of 32 Vrn-NILs per recurrent parent. The Vrn-NILs have been deposited in the US National Plant Germplasm Information Network (GRIN: http://www.ars-grin.gov). The Daws Vrn-NILs used in this experiment have the numbers PI 639058 to PI 639096 and the Wanser Vrn-NILs were assigned PI 638621 to PI 638656. Theoretically, Triple Dirk alleles make up 0.37% of the genome of each Vrn-NIL, thus the effects of individual *Vrn-1* loci and alleles can be determined in two genetic backgrounds. We no longer had the original Triple Dirk donors that were used to develop our Vrn-NIL sets so Triple Dirk B, Triple Dirk D, Triple Dirk E, and Triple Dirk F were obtained from the Australian Winter Cereals Collection, Tamworth, New South Wales, Australia and were included as checks to confirm the presence or absence of specific *Vrn-1* alleles.

DNA tests: Genomic DNA was isolated using the protocol described by Dellaporta et al., (1983). The PCR conditions used were as described by Fu et al. (2005) for the primer pairs Intr1/B/F-Intr1/B/R3, Intr1/B/F-Intr1/B/R4 which are specific for the B genome; and for the primer pairs Intr1/D/F-Intr1/D/R3 and Intr1/D/F-Intr1/D/R4, which are specific for the D genome. The conditions specified by Sherman et al. (2004) were used for the primer pair VA1-F/VA1-R which is specific for the A genome. VA1-F/VA1-R is a CAPS marker. Digestion of the PCR product of this primer with *Aci*I gives a 532 bp band associated with winter habit and 456 bp band associated with spring habit (Sherman et al., 2004). The Intr1/B/F-Intr1/B/R3 primer pair was designed to detect the intron1 deletions in the dominant *Vrn-B1a* allele. Fu et al. 2005 reported that if an intron1 deletion had occurred in the dominant *Vrn-B1a* allele, a 709 bp PCR amplification product resulted from amplification with the Intr1/B/F-Intr1/B/R3 primer pair. The Intr1B/F-Intr1/B/R4 primers are specific for absence of the intron1 deletion in the dominant

Vrn-B1a allele, so genotypes with no intron1 deletion, or genotypes with recessive *Vrn-B1b,* produce an 1149 bp band and the genotypes with the *Vrn-B1a* have no PCR product with this primer pair. The Intr1/D/F-Intr1/D/R3 primer pair results in amplification of intron1 in the dominant *Vrn-D1a* allele associated with spring habit resulting in a 1671 bp band indicating a deletion is present (Fu, 2005). The Intr1/D/F-Intr1/D/R4 primer pair are specific for the absence of the intron1 deletion in the dominant *Vrn-D1a* allele, resulting in no PCR product for genotypes having the *Vrn-D1a* allele or amplification of the recessive *Vrn-D1b* allele producing a 997bp band (Fu, 2005).

The PCR products were resolved on a 2% Agarose gel and sized using the 100bp Gene Ruler ladder from MBI Fermentas (Fermentas Inc. Hanover, MD, USA). Nullitetrasomic lines of

Triticum aestivum cv. ‘Chinese Spring’, N5AT5D, N5BT5D and N5DT5B, ‘Chinese Spring’, Triple Dirk B, Triple Dirk D, Triple Dirk E, Triple Dirk F, and ‘Norstar’ winter wheat were used as checks in all PCR amplifications. The entire experiment was replicated three times.

Artificial Freeze test: Freezing tests were used to evaluate cold temperature tolerance under controlled environmental conditions. Artificial freezing test results have good correlation to the field survivability index under natural conditions (Brule-Babel and Fowler, 1989b). Plants were grown in SunShine mix LC1 (Sun Gro Horticulture, Bellevue, WA, USA) in cell pack ′1020′ inserts packed into ′1020 flats′ (The Blackmore company, Belleville, MI, USA) of 27.62cm(W) x 53.98cm(L) x 5.72cm(H) dimension that contained drainage holes. Each tray contained 96 seedlings and 36 trays were used for an entire experiment. Because of space limitations, the Wanser and Daws Vrn-NIL sets were evaluated in separate experiments. Each replication included each of the 32 Vrn-NILs within a recurrent parent set, plus Wanser, Daws and commercial spring and winter wheat checks for a total of 38 genotypes. There were a total of 9 genotypes evaluated as “recurrent parents”. These included Daws, Wanser and the following checks: ‘Alpowa’, ‘Burt’ and ‘Scarlet’ as spring habit checks and ‘Centurk78’, ‘Eltan’, Norstar and ‘Stephens’ as winter habit checks. The spring and winter habit checks were included in all replications but the exact spring and winter genotypes varied across replications. Daws was included in all replications. Wanser was included in all replications where Wanser derived Vrn-NILs were evaluated. Other checks were repeated in two to six replications.

Each genotype was represented by 10 seedlings, randomized within a test temperature. Each set of 38 genotypes was evaluated at each of eight test temperatures for a total of 80 seedlings per genotype. Immediately after planting, germination time was synchronized by placing seeded, watered trays in a cold room at 4^{o}C for three days and then moving them to a greenhouse at 24°C and 16 hour day length. Macro and micro nutrients (Peter's All Purpose, Scotts-Sierra, Marysville, OH, USA) at a final dilution of 100ppm were applied through a watering system once per day to saturation. At about the three leaf stage, plants were vernalized for 5 weeks in a 2.25m^2 growth chamber (Conviron Inc, Ashville, NC, USA) with lighting at 200µmol m^{-2}s^{-1} was supplied by fluorescent and incandescent bulbs, with a 16/8 hour light/dark cycle; and temperature maintained at a constant 4°C.

After the vernalization period, plants were saturated with water to equalize water content throughout trays. The tops of the plants were removed to approximately 2cm above the soil surface. The artificial freeze test was conducted by reducing the growth chamber temperature from 4°C to -10°C over a period of 8 hours. Then the temperature was decreased for 12 more hours at the rate of 1.5°C every 1.5 hours until the lowest test temperature (-20.5°C) was reached. A full set of 38 genotypes, 10 plants per genotype, was removed at each of 8 temperatures (-10, -11.5, -13, -14.5, -16, -17.5, -19 and –20.5°C). After freezing, seedlings were placed in a growth chamber at 4°C in the dark. The temperature of the growth chamber was increased over 24 hours to 13°C. Plants were then placed in the greenhouse at 24°C for regrowth. Regrowth was rated 5 weeks after the freeze test as 1=alive and 0=dead.

Experimental design: The freeze tests were designed as randomized complete blocks with four blocks, conducted over time. Percent survival was calculated from the ten plants per genotype for each temperature within a replication. Previous researchers have used this percent survival data to calculate LT_{50} values for survival using logistic regression (Brule-Bable and Fowler, 1989, Storlie et al. 1998). In our case, however, the diagnostics for goodness of fit to a logistic regression model were poor because of the high rates of death for the spring habit NILs. Therefore, we analyzed and presented survival data in the manner that is standard in plant disease assessment, as relative Area Under the Death Progress Curve (AUDPC) for each genotype, calculated as relative Area Under the Disease Progress Curve (AUDPC) (Shaner and Finney, 1977). The AUDPC data were analyzed by ANOVA using the PROC GLM (General Linear Models) procedure of SAS (SAS Inst. Inc., Cary, NC, USA) with all effects except block considered fixed. Prior to analysis, in order to improve normality and correct for heterogeneous variances, data were transformed by adding and subtracting 0.001 to relative AUDPC values of 0 and 1, respectively, then calculating an arcsin square root transformation. A genotype within recurrent parent model, $Y_{ijk} = \mu + RP_i + B_k(RP_i) + G_j(RP_i) + E_{ijk}$ where $Yijk$=relative AUDPC value for a given genotype, μ =overall mean, RP_i = recurrent parent, B_k =Block within recurrent parent, G=Genotype within recurrent parent and E_{ijk} = experimental error, was used to obtain the least square means and 95% confidence intervals for the transformed relative AUDPC values for each genotype. For clarity, least square means and confidence intervals were back transformed and multiplied by 100 in tables presented in the results.

RESULTS

Molecular marker data: The Triple Dirk NILs, Nullitetrasomics and Chinese Spring showed the expected bands in nearly all cases (Table 2). The only exceptions occurred with Triple Dirk D and Chinese Spring, with the CAPS marker VA1-F/VA1-R, specific for the *Vrn-A1a* allele where both the 456 and 532bp bands were observed (Table 2). Chinese Spring has a dominant *Vrn-D1a* allele conditioning spring habit and the VA1-F/VA1-R primer should amplify 532bp band for recessive allele at the *Vrn-A1* locus.

The Daws spring-habit Vrn-NILs with *Vrn-A1a* PI 639058, PI 639059, PI 639060 and

PI 639061, showed the 456bp VA1-F/VA1-R band as expected and also had very little cold tolerance (Table 3). These Vrn-NILs all had the 1149bp band from the Intr1/B/F - Intr1/B/R4, amplification indicating the presence of the recessive *Vrn-B1b* allele, and amplification with Intr1/D/F - Intr1/D/R4 primers indicated presence of the recessive *Vrn-D1b* allele as expected (Table 3).

The Daws spring habit PI 639068, PI 639069, PI 639070, PI 639071, PI 639088, PI 639089, PI 639090 and PI 639091 (Table 3), had the 709bp band when amplified with Intr1/B/F & Intr1/B/R3 primer pair indicating the presence of intron1 deletions diagnostic for the dominant *Vrn-B1a* allele. In addition the 997bp band for the recessive *Vrn-D1b* allele was observed when amplified with the Intr1/D/F - Intr1/D/R4 primer pair, indicating the spring habit was conditioned only by the *Vrn-B1* locus. These lines all had much more cold tolerance than the lines in which the spring habit was conditioned by the *Vrn-A1* locus (Table 3).

The Daws spring habit Vrn-NILs with the *VrnD1a* allele, PI 639078, PI 639079, PI 639080 and PI 639081, had the recessive *Vrn-B1b* alleles for the B genome. Of the four lines, PI 639078 was the only line with the expected 1671bp band diagnostic of the *Vrn-D1a* allele. No product was obtained for three Vrn-NILs, PI 639079, PI 639080 and PI 639081, for the *Vrn-D1* alleles using the Intr1/D/F - Intr1/D/R3 and Intr1/D/F - Intr1/D/R4 primers. These Vrn-NILs, were of spring growth habit and all the NILs had similar cold tolerance values.

Most of the Daws winter habit Vrn-NILs had the recessive alleles for all the *Vrn-1* loci correlating with their phenotype and pedigree, but a few exceptions were seen. The recurrent parent, Daws, had the expected 1149bp band for the *Vrn-B1b* allele with the Intr1/B/F and Intr1/B/R4 marker, a 532bp diagnostic band for *Vrn-A1b* with the VA1F-VA1R and a 997bp band for *Vrn-D1b* when amplified with the Intr1/D/F-Intr1/D/R4. The winter habit Vrn-NILs PI

639073 and PI 639075, did not show the expected 1149bp band for *Vrn-B1b* with the Intr1/B/F and Intr1/B/R4 primer.

The Wanser spring habit Vrn-NILs , PI 638622, PI 638623, PI 638624 and PI 638621, had the 456bp band for *Vrn-A1a* allele based on the CAPS marker VA1-F/VA1-R amplification, the 1149bp band for recessive *Vrn-B1* allele with the primer pair Intr1/B/F-Intr1/B/R4 and 997bp band when amplified with Intr1/D/F - Intr1/D/R4 primer pair for *Vrn-D1b* allele, the marker genotype and the growth habit phenotype were as expected for all the loci. The spring habit Vrn-NILs, PI 638630, PI 638631, PI 638648 and PI 638649, when amplified with the Intr1/B/F - Intr1/B/R3 primer pair, produced a 709bp band diagnostic for *Vrn-B1a*. In contrast, the spring habit Vrn-NILs PI 638632, PI 638633, PI 638650 and PI 638651 did not have the 709bp band for the *Vrn-B1a*, this marker genotype is not the same as their expected marker phenotype which reflects their spring growth habit (Table 3). PI 638650 yielded a band of 1149bp with the Intr1/B/F-Intr1/B/R4 primer pair, diagnostic for *Vrn-B1b.* This result suggested PI 638650 carried the winter – conditioning allele, but it was of spring growth habit. All these NILs had the recessive allele for *Vrn-A1* and *Vrn-D1*. The Wanser spring Vrn-NILs PI 638640 and PI 638642 had the expected band of 1671bp for *Vrn-D1a* allele when amplified with Intr1/D/F-Intr1/D/R3. The *Vrn-B1b* and *Vrn-A1b* recessive allele was present in the spring habit Vrn-NIL PI 638642. In contrast, the recessive *Vrn-B1* allele was absent in case of PI 638640 as implied by the Intr1/B/F-Intr1/B/R4 primer pair which was not expected. The spring habit Vrn-NIL PI 638639 had the 997bp band when amplified with Intr1/D/F-Intr1/D/R4 which was diagnostic for the recessive *Vrn-D1a* allele but did not amplify the 1671bp band as expected for the *Vrn-D1a* allele. The AUDPC value was higher (less cold tolerance) compared to the other three genotypes with the *Vrn-D1b* allele. This NIL had a recessive *Vrn-A1* allele but did not amplify any product with the primer pairs for B genome. We observed a recessive *Vrn-A1* allele for the spring habit NIL PI 638641 but did not detect any allele from the B genome nor from the D genome but the growth habit confirms the presence of the dominant *Vrn-D1*. The cold tolerance value of PI 638641 is similar to PI 638640 and PI 638642 (Table 3).

Most of the Wanser winter habit Vrn-NILs, when amplified with primers specific for the *Vrn-1* winter alleles, showed the expected products, except for the winter habit Vrn-NIL, PI 638638, which did not yield any PCR product for the *Vrn-B1b* allele using the Intr1/B/F-Intr1/B/R4 primer pair. It is necessary for this genotype to have the *Vrn-A1*, *Vrn-B1* and *Vrn-D1* alleles in the recessive state since the growth habit was confirmed to be winter.

Freeze Testing: Statistical analysis revealed that genotypes and replications varied significantly for death due to freezing (Table 4). The R^2 value for the statistical model with replications and genotypes within sets in the model was 0.902. All effects in the ANOVA and the contrasts examined were highly significant (Table 4). The variation for replications was due to the slight variation in the growth chamber conditions from one test to the next. Genotype effects were highly significant and series of single degree of freedom contrasts were calculated in order to examine the genotypic effects more closely (Table 4). Significant differences existed between spring and winter habit genotypes. Those differences were present within each of the Daws and Wanser NIL sets indicating that, across all three *Vrn-1* loci, dominant and recessive vernalization alleles significantly affected the cold hardiness levels of the genotypes.

Relative AUDPC means: Relative AUDPC is a measure of death due to freezing. Higher values indicate more death and lower values indicate greater survival where a relative AUDPC of 100 is equal to complete death of all plants at all tested temperatures and a relative AUDPC of 0 indicates complete survival of all plants at all temperatures. The spring habit checks ‘Alpowa’ and ‘Scarlet’ had high relative AUDPC values with Alpowa having slightly greater survival (Table 5). Of the winter habit checks, Norstar was the most tolerant to cold, and Stephens was the least cold hardy. The relative AUDPC of Daws, Wanser, and other winter habit checks was significantly different from that of the spring check cultivars. In these experiments, Daws and Wanser had similar relative AUDPC values.

Relative AUDPC for Daws NILs: In the discussion that follows and in Table 5, the spring habit genotypes are paired in rows with their sister winter habit genotypes that were originally derived from the same cross. The winter habit genotypes in the Daws NIL set all had the same genotype at *Vrn-1* loci and there were no significant differences among the winter habit NILs for freezing survival. The range for relative AUDPC for spring habit Daws NILs was 50.5 to 90.4 and for winter habit Daws NILs the range was 35.3 to 52 (Table 5). The average relative AUDPC over all spring habit Daws NILs was 68.6 as compared with 43.51 for the winter habit Daws NILs (Table 5). All four spring habit genotypes with *Vrn-A1a* had similar cold hardiness values (average relative AUDPC of 86.2), but differed significantly from the four sister winter habit genotypes with *Vrn-A1b* (average relative AUDPC of 43) indicating that *Vrn-A1* region had a role in the cold hardiness differences observed in the Daws NIL set.

The average relative AUDPC for the eight spring habit genotypes in the Daws NIL set with *Vrn-B1a* was 62.7 (Table 5), but they were not significantly ($p<0.05$) less cold hardy than the eight sister winter habit genotypes with *Vrn-B1b* (average relative AUDPC = 42.6). The average relative AUDPC values over the four spring habit genotypes in the Daws NIL set with *Vrn-D1a* was 62.9, but they also were not significantly ($p<0.05$) less cold hardy than the four sister winter habit genotypes with *Vrn-D1b* (average relative AUDPC = 45.8). Significant differences ($p<0.05$) in cold hardiness were also observed for the spring habit genotypes with *Vrn-A1a* as compared to the spring habit genotypes with either *Vrn-B1a* or *Vrn-D1a*.

Relative AUDPC LS means for Wanser NILS: As above, the winter habit genotypes in the Wanser Vrn-NIL set all had the same penotype at *Vrn-1* loci but two genotypes, PI 638626 and PI 638628 were less cold hardy than other winter habit genotypes. The overall ranges and average relative AUDPC values for the Wanser Vrn-NIL set were similar to those for the Daws Vrn-NIL set. The range for relative AUDPC for the spring habit Wanser Vrn-NILs was 36.5 to 93.6 while the winter habit Wanser Vrn-NILs ranged from 28.6 to 78.6. The average AUDPC over all spring habit Wanser Vrn-NILs was 87.9 as compared with 42.4 for the winter habit Wanser Vrn-NILs. Significant differences in cold hardiness existed between the spring and winter habit Vrn-NILs at all of the *Vrn-1* loci.

The average relative AUDPC for genotypes possessing *Vrn-A1a* was 99, contrasted with their sister genotypes possessing *Vrn-A1b* (average relative AUDPC = 53.5) (Table 6). Significant differences also existed for the spring habit genotypes with *Vrn-B1a* in the Wanser Vrn-NIL set (average relative AUDPC = 94.9) as compared with their sister winter habit genotypes possessing *Vrn-B1b* (average relative AUDPC = 37). The genotypes with *Vrn-D1a* were more cold hardy than other spring habit genotypes in the Wanser Vrn-NIL set with an average relative AUDPC of 62.3 as compared to their sister winter habit genotypes with *Vrn-D1b* (average relative AUDPC of 42). The PI 638639 genotype was the only line possessing *Vrn-D1a* that was significantly less cold hardy than its winter counterpart, PI 638643 with *Vrn-D1b*. Two of the winter habit Vrn-NILs with *Vrn-A1b* were less cold hardy than other winter NILs but equal to Stephens, a winter check with less winter hardiness than other winter checks we evaluated.

Discussion

Vernalization genes regulate the expression of cold hardiness (Fowler et al., 1996) in the Daws and Wanser lines. In the case of the Daws *Vrn-A1* NILs and most of the Wanser NILs there was significant difference between the spring and winter habit genotypes. There were a few exceptions in all the genomes.

Molecular marker data: Alleles for the spring growth habit are associated with deletions in the intron1 region in the A, B and D genome of common wheat. All the donor parents of the spring alleles in this study had large deletions in the first intron (Fu, 2005). The phenotype for growth habit of all the Vrn-NILs was evaluated each generation and for two years after the NILs were developed. From our marker evaluations of the Vrn-NILs we confirmed that the expected alleles were present and the phenotype for vernalization requirement (spring or winter growth habit) matched with the genotypes most of the time. The CAPS marker associated with the spring growth habit in the Daws and Wanser Vrn-NILs can be used as a marker to determine the Vrn phenotype. The Intron1 deletion markers cannot be used to predict the requirement for vernalization because of their inconsistency in both the Daws and Wanser Vrn-NILs.

We can attribute the few cases where phenotype and pedigree did not match marker results to a variety of reasons: (1) a recombination might have occurred within the gene (Dooner and Martinez-Ferez, 1997; Fridman et al., 2000) resulting in the loss of intron with the marker (2) base change(s) might have occurred in the primer binding site (3) the gene may be linked in repulsion phase allowing random assortment of the marker away from the gene, (4) the molecular markers may be lost due to non-mendelian inheritance of extra-genomic information (Lolle et al., 2005) (5) the DNA variants used in the development of the CAPS marker may not be the only reason for the differences in growth habit (Sherman et al., 2004) of the different genotypes used for this study. Because only four genotypes were evaluated per recurrent parent for each *Vrn-1* allele group, our ability to confirm the possibilities is limited. These primers should be evaluated on additional Vrn-NILs and in a wider array of germplasm.

Freeze Test: The differences in cold hardiness observed for the Vrn-NILs are mainly due to interaction between specific *Vrn-1* alleles and genetic effects from the recurrent parents. For the Daws Vrn-NILs, only the *Vrn-A1* allele differed significantly for cold hardiness. This confirms that the *Vrn-A1* locus, and perhaps the linked *Fr-1* locus provides improved cold hardiness to winter NILs with *Vrn-A1b* and is a major factor in determining vernalization requirement and freezing tolerance of wheat (Brule-Babel and Fowler, 1988; Galiba et al., 1995; Storlie et al., 1998).

The interaction of the Daws genetic background with *Vrn-B1* and *Vrn-D1* loci resulted in similar levels of cold tolerance regardless of the allele, implying that the spring NILs with additional genes from the Daws background can have cold hardiness similar to winter wheat with the incorporation of *Vrn-B1a* or *Vrn-D1a* alleles (Koemel et al., 2004). In the case of the Wanser Vrn-NILs the AUDPC values for the spring habit Vrn-NILs are significantly different from the winter habit NILs for the *Vrn-A1* and *Vrn-B1* loci, and one line with *Vrn-D1a* allele indicating that the Wanser genetic background interacts with the *Vrn-1* loci in a different way than that of the Daws genetic background. The Wanser NILs have a wider range of AUDPC values as compared to the Daws NILs.

Storlie et al. (1998) observed a background genetic effect on cold hardiness in the two sets of NILs derived by backcrossing a spring wheat ′Marfed′ as recurrent parent to two winter wheat donor parents ′Suweon 185′ and ′Chugoku 81′ used in their experiment. The different levels of cold tolerance observed may also be due to the interaction of the different *Vrn* alleles with different cold tolerance genes present on other chromosomes of wheat (Cahalan and Law, 1979).

Our results indicate that the specific vernalization alleles affect cold hardiness of fully vernalized spring and winter wheat (Koemel et al., 2004). This proves the presence of background genetic interaction with the *Vrn-1* loci influencing cold hardiness (Cahalan and Law, 1979). This also implies that the *Vrn-1* Intron1 deletion phenotype markers used in this experiment are not absolutely associated with the expected vernalization phenotype and need to be further evaluated to determine the exact nature of inconsistency. The Daws and Wanser Vrn-NILs, plus a similar set that we developed in Stephens wheat, can be used as a resource for further study of the relationship between the vernalization alleles and cold hardiness in wheat.

Acknowledgements

We thank Dr. Dan Skinner for critical review of the manuscript, Dr. Kim Kidwell for kindly providing the primers published by Fu et al. (2005) and Sherman et al. (2004). Financial support for this work came from the Washington Wheat Commission, The project “Identification of genetic factors conferring cold tolerance in winter wheat” (USDA-CSREES competitive grant 2004-01783) and the USDA-ARS Project:CWU:5348-21000-019-00D.

References

Allan, R. E., J.A. Pritchett, and L.M. Little, 1992: Cold injury observations. Annual Wheat Newsletter **38**, 281.

Brule-Babel, A. L., and D.B. Fowler, 1988: Genetic control of cold hardiness and vernalization requirement in winter wheat. Crop sci. **28**, 879-884.

Brule-Babel, A. L., and D.B. Fowler, 1989: Genetic control of cold hardiness and vernalization requirement in rye. Genome **32**, 19-23.

Cahalan, C., and C.N. Law, 1979: The genetical control of cold resistance and vernalisation requirement in wheat. Heredity **42** 125-132.

Danyluk, J., N.A. Kane, G. Breton, A.E. Limin, D.B. Fowler, and F. Sarhan, 2003: Tavrt-1, a putative transcription factor associated with vegetative to reproductive transition in cereals. Plant Physiology **132**, 1849-1860.

Dellaporta, J. S., J. Wood, and J.B. Hicks, 1983: A plant DNA minipreparation: Version II. Plant Mol. Biol. Rep **1**, 19-21.

Dooner, H. K., and I.M. Martinez-Ferez, 1997: Recombination occurs uniformly within the bronze gene, a meiotic recombination hotspot in the maize genome. The Plant cell **9**, 1633-1646.

Fowler, D. B., L.P. Chauvin, A.E. Limin, and F. Sarhan, 1996: The regulatory role of vernalization in the expression of low-temperature-induced genes in wheat and rye. Theor. Appl. Genet. **93**, 554-559.

Fridman, E., T. Pleban, and D Zamir, 2000: A recombination hotspot delimits a wild-species quantitative trait locus for tomato sugar content to 484 bp within an invertase gene. Proc. Natl. Acad. Sci. USA **97**, 4718-4723.

Fu, D., Péter Szűcs, L. Yan, M. Helguera, J. S. Skinner, Jarislav von Zitzewitz, P. M. Hayes, J. Dubcovsky, 2005: Large deletions within the first intron in *Vrn-1* are associated with spring growth habit in barley and wheat. Mol. Gen. Genet. **273**, 54-65.

Galiba, G., S.A. Quarrie, J. Sutka, A. Morounov, and J.W. Snape, 1995: RFLP mapping of the vernalization (*Vrn1*) and frost resistance (*Fr1*) genes on chromosome 5A of wheat. Theor. Appl. Genet. **90**, 1174-1179.

Koemel, J. E., A.C. Guenzi,. J.A. Anderson, and E.L. Smith, 2004: Cold hardiness of wheat near-isogenic lines differing in vernalization alleles. Theor. Appl. Genet. **109**, 839-846.

Limin, A. E., and D.B.Fowler, 2002: Developmental traits affecting low-temperature tolerance response in near-isogenic lines for the vernalization locus *Vrn-A1* in wheat (*Triticum aestivum* l. Em thell). Ann. Bot. **89**, 579-585.

Lolle, S. J., J.L. Victor, J.M. Young, and R.E. Pruitt, 2005: Genome-wide non-mendelian inheritance of extra-genomic information in arabidopsis. Nature **434**, 505-509.

Nelson, W. L., and M. Nagamitsu, 1972: Registration of Wanser wheat. Crop Sci. **12**, 718.

Peterson, C. J. J., O.A. Vogel, D.W. George, G.L. Rubenthaler, and R.E. Allan, 1977: Registraton of Daws wheat [cultivars]. Crop Sci. **17**, 674-675.

Pugsley, A. T., 1971: A genetic analysis of the spring-winter habit of growth in wheat. Australian J Agr Res **22**, 21-31.

Pugsley, A. T., 1972: Additional genes inhibiting winter habit in wheat. Euphytica **21**, 547-552.

Shaner, G., and R.E. Finney, 1977: The effect of nitrogen fertilization on the expression of slow-mildewing resistance in knox wheat [cultivars, *Erysiphe graminis*]. Phytopathology **67**, 1051-1056.

Sherman, J. D., L. Yan, L.Talbert, and J. Dubcovsky, 2004: A PCR marker for growth habit in common wheat based on allelic variation at the *Vrn-A1* gene. Crop Sci. **44**, 1832-1838.

Snape, J. W. A. Semikhodskii, L. Fish, R. N. Sarma, S. A. Quarrie, G. Galiba, and J. Sutka, 1997: Mapping frost tolerance loci in wheat and comparative mapping with other cereals. Acta Agron. Hung. **45**, 268-270.

Storlie, E. W., R.E. Allan, and M.K. Walker-Simmons, 1998: Effect of the *Vrn1-Fr1* interval on cold hardiness levels in near-isogenic wheat lines. Crop Sci. **38**, 483-488.

Vagujfalvi, A., G. Galiba, L. Cattivelli, and J. Dubcovsky, 2003: The cold-regulated transcriptional activator *Cbf3* is linked to the frost-tolerance locus *Fr-A2* on wheat chromosome 5A. Mol. Genet. Gen. **269**, 60-67.

Yan, L., A. Loukoianov, G. Tranquilli, M. Helguera, T. Fahima, and J. Dubcovsky, 2003: Positional cloning of the wheat vernalization gene *vrn1*. Proc. Natl. Acad. Sci.USA **100**, 6263-6268.

Table 1**:** Allelic details of the genotypes and primers used to amplify the *Vrn-1* in the experiment

Spring allele	**Winter allele**	**Donor parent**	**Donor Parent Genotype**	**Primer for spring allele**	**Expected band size**	**Primer for winter allele**	**Expected band size**
Vrn-A1a	*Vrn-A1b*	Triple Dirk D	*Vrn-A1a Vrn-B1b Vrn-D1b*	VA1F/VA1R	456bp	VA1F/VA1R	532bp
Vrn-B1a (*Vrn2*)	**Vrn-B1b* (*Vrn2*)	Triple Dirk B	*Vrn-A1b Vrn-B1a Vrn-D1b*	Intr1/B/F-Intr1/B/R3	709bp	Intr1/B/F-Intr1/B/R4	1149bp
Vrn-B1a (*Vrn4*)	**Vrn-B1b* (*Vrn4*)	Triple Dirk F	*Vrn-A1b Vrn-B1a Vrn-D1b*	Intr1/B/F-Intr1/B/R3	709bp	Intr1/B/F-Intr1/B/R4	1149bp
Vrn-D1a	*Vrn-D1b*	Triple Dirk E	*Vrn-A1b Vrn-B1b Vrn-D1a*	Intr1/D/F-Intr1/D/R3	1671bp	Intr1/D/F-Intr1/D/R4	997bp

Footnote: Recurrent parent genotype: Daws: *Vrn-A1b Vrn-B1b Vrn-D1b*, Wanser: *Vrn-A1b Vrn-B1b Vrn-D1b*.

* The alleles denoted by Triple Dirk B and Triple Dirk F have been determined to be either identical or allelic. Dominant *Vrn-1* alleles are designated with the locus name followed by an *a* and the recessive alleles are designated with a *b*.

Table 2**:** Molecular Marker data for the checks showing the bands observed and expected for the primers used for *Vrn-A1* gene and its orthologues on B and D genomes

Marker Data										
	Vrn-A1		***Vrn-B1***				***Vrn-D1***			
	VA1-F		Intr1/B/F		Intr1/B/F		Intr1/D/F		Intr1/D/F	
	VA1-R		Intr1/B/R3		Intr1/B/R4		Intr1/D/R3		Intr1/D/R4	
CHECKS	observed	expected	observed	expected	observed	expected	observed	expected	observed	expected
TripleDirk D	456/532	456	np	np	1149	1149	np	np	997	997
TripleDirk B			709	709	np	np	np	np	997	997
TripleDirk F			709	709	np	np	np	np	997	997
TripleDirk E			np	np	1149	1149	1671	1671	np	np
Chinese Spring	456/532	np	np	np	1149	1149	1671	1671	np	np
Nullitetra 5A	np	np	np	np	1149	1149	1671	1671	np	np
Nullitetra 5B	*		np	np	np	np	1671	1671	np	np
Nullitetra 5D	*		np	np	1149	1149	np	np	np	np
Norstar (winter check)	532	532	np	np	1149	1149	np	np	997	997

Foot note: np= no PCR product, All the bands reported here are in bp

These checks were used as controls for the marker experiments for Daws and Wanser NILs.

* checks not tested for the primer

VA1-F/VA1-R = specific to A genome, Digestion of the PCR product with *AciI* gives a 532bp band for winter habit genotypes and 456bp band for spring habit genotypes.

Intr1/B/F-Intr1/B/R3 = When intron deletion is present in the dominant *Vrn-B1a* allele a 709bp amplification product seen.

Intr1B/F-Intr1/B/R4 = Absence of intron deletion in the dominant *Vrn-B1a* allele or genotypes with recessive *Vrn-B1b* allele produce 1149bp band as PCR product.

Intr1/D/F-Intr1/D/R3 = If intron deletion is present in dominant *Vrn-D1a* allele a 1671bp band is amplified through PCR.

Intr1/D/F-Intr1/D/R4 = Absence of intron deletion in the dominant *Vrn-D1a* allele or lines with recessive *Vrn-D1b* allele produced a 997bp band on PCR amplification

Table3: Daws and Wanser spring NILs with their expected marker phenotype and observed growth habit.(Expected marker phenotype matched observed except in cases indicated)

Accessions	**Donor Parent**	**Expected Marker Genotype at the locus**			**Growth Habit Phenotype**
Daws Spring NILs		**Vrn-A1**	**Vrn-B1**	**Vrn-D1**	
PI 639058 (*Vrn-A1a*)	*Triple Dirk D*	spring	winter	winter	spring
PI 639059 (*Vrn-A1a*)	*Triple Dirk D*	spring	winter	winter	spring
PI 639060 (*Vrn-A1a*)	*Triple Dirk D*	spring	winter	winter	spring
PI 639061 (*Vrn-A1a*)	*Triple Dirk D*	spring	winter	winter	spring
PI 639068 (*Vrn-B1a*)	*Triple Dirk B*	winter	spring	winter	spring
PI 639069 (*Vrn-B1a*)	*Triple Dirk B*	winter	spring	winter	spring
PI 639070 (*Vrn-B1a*)	*Triple Dirk B*	winter	spring	winter	spring
PI 639071 (*Vrn-B1a*)	*Triple Dirk B*	winter	spring	winter	spring
PI 639088 (*Vrn-B1a*)	*Triple Dirk F*	winter	spring	winter	spring
PI 639089 (*Vrn-B1a*)	*Triple Dirk F*	winter	spring	winter	spring
PI 639090 (*Vrn-B1a*)	*Triple Dirk F*	winter	spring	winter	spring
PI 639091 (*Vrn-B1a*)	*Triple Dirk F*	winter	spring	winter	spring
PI 639078 (*Vrn-D1a*)	*Triple Dirk E*	winter	winter	spring	spring
PI 639079 (*Vrn-D1a*)	*Triple Dirk E*	winter	winter	spring[a]	spring
PI 639080 (*Vrn-D1a*)	*Triple Dirk E*	winter	winter[a]	spring[a]	spring
PI 639081 (*Vrn-D1a*)	*Triple Dirk E*	winter	winter	spring[a]	spring
Wanser Spring NILs					
PI 638622 (*Vrn-A1a*)	*Triple Dirk D*	spring	winter	winter	spring
PI 638623 (*Vrn-A1a*)	*Triple Dirk D*	spring	winter	winter	spring
PI 638624 (*Vrn-A1a*)	*Triple Dirk D*	spring	winter	winter	spring
PI 638621 (*Vrn-A1a*)	*Triple Dirk D*	spring	winter	winter	spring
PI 638630 (*Vrn-B1a*)	*Triple Dirk B*	winter	spring	winter	spring
PI 638631 (*Vrn-B1a*)	*Triple Dirk B*	winter	spring	winter	spring
PI 638632 (*Vrn-B1a*)	*Triple Dirk B*	winter	spring[a]	winter	spring
PI 638633 (*Vrn-B1a*)	*Triple Dirk B*	winter	spring[a]	winter	spring
PI 638648 (*Vrn-B1a*)	*Triple Dirk F*	winter	spring	winter	spring
PI 638649 (*Vrn-B1a*)	*Triple Dirk F*	winter	spring	winter	spring
PI 638650 (*Vrn-B1a*)	*Triple Dirk F*	winter	spring[ab]	winter	spring
PI 638651 (*Vrn-B1a*)	*Triple Dirk F*	winter	spring[a]	winter	spring
PI 638639 (*Vrn-D1a*)	*Triple Dirk E*	winter	winter[a]	spring[a]	spring
PI 638640 (*Vrn-D1a*)	*Triple Dirk E*	winter	winter[a]	spring	spring
PI 638641 (*Vrn-D1a*)	*Triple Dirk E*	winter	winter[a]	spring[a]	spring
PI 638642 (*Vrn-D1a*)	*Triple Dirk E*	winter	winter	spring	spring

Foot Note: All the winter accessions have recessive alleles at the 3 loci hence have a winter habit when grown in the field and are expected to have a marker phenotype indicating winter habit.

[a] the presence of these expected alleles were not confirmed by diagnostic PCR tests suggesting unstable alleles in the corresponding genomes.

[b] PI638650 appeared to have the winter allele *Vrn-B1b* based on diagnostic PCR tests.

Table 4**:** Analysis of variance for Area Under the Death Progress Curve (AUDPC) from artificial freeze tests conducted on two NIL sets of wheat plus commercial checks possessing allelic differences at the orthologous *Vrn-1* loci

Source	**Degrees of Freedom**	**Mean Squares**	**Probability of F**
Recurrent Parent	8	0.47	<0.0001
Replications within Recurrent Parent	33	0.28	<0.0001
Genotypes within Recurrent Parent	64	0.31	<0.0001
Single Degree of Freedom Contrasts for genotypes:			
Spring habit vs. winter habit	1	9.79	<0.0001
Spring habit vs. winter habit within Daws NILs	1	3.13	<0.0001
Spring habit vs. winter habit within Wanser NILs	1	7.02	<0.0001
Spring habit vs. winter habit within *Vrn-A1*	1	6.87	<0.0001
Spring habit vs. winter habit within *Vrn-A1* for Daws NILs	1	4.90	<0.0001
Spring habit vs. winter habit within *Vrn-A1* for Wanser NILs	1	2.23	<0.0001
Spring habit vs winter habit within *Vrn-B1*	1	4.39	<0.0001
Spring habit vs winter habit within *Vrn-B1* for Daws NILs	1	0.43	<0.0001
Spring habit vs winter habit within *Vrn-B1* for Wanser NILs	1	5.24	<0.0001
Spring habit vs winter habit within *Vrn-D1*	1	0.45	<0.0001
Spring habit vs winter habit within *Vrn-D1* for Daws NILs	1	0.15	<0.0053
Spring habit vs winter habit within *Vrn-D1* for Wanser NILs	1	0.32	<0.0001

R^2=0.9024 **CV**= 16.66

Footnote 1: Because replications were considered to be random effects, the error term used for the F test of significance of Recurrent Parent effects was 0.1889*MS(replication within recurrent parent)+0.8111*MS(Error) or 0.046 with 52.065 degrees of freedom.

Footnote 2: The check cultivars were included in the recurrent parent effects. This increased the degrees of freedom for all effects.

Table 5**:** Average Relative Area Under the Death Progress Curve (AUDPC) and 95% confidence intervals for Near Isogenic Lines (NILs) differing for alleles at the orthologous *Vrn-1* loci in wheat using Daws winter wheat as the recurrent parent.

Daws NILs							
Spring				**Winter**			
PI Number	**Donor Parent**	**Relative AUDPC**	**Confidence Limits (95%)**	**PI Number**	**Relative AUDPC**	**Confidence Limits (95%)**	**Prob > F**
PI 639058 (*Vrn-A1a*)	*Triple Dirk D*	88.0	+/- 20.8	PI 639063 (*Vrn-A1b*)	43.8	+/- 18.0	*<0.05
PI 639059 (*Vrn-A1a*)	*Triple Dirk D*	79.9	+/- 27.0	PI 639064 (*Vrn-A1b*)	36.0	+/- 16.9	*<0.05
PI 639060 (*Vrn-A1a*)	*Triple Dirk D*	86.3	+/- 22.3	PI 639065 (*Vrn-A1b*)	46.1	+/- 18.2	*<0.05
PI 639061 (*Vrn-A1a*)	*Triple Dirk D*	90.4	+/- 18.7	PI 639066 (*Vrn-A1b*)	46.0	+/- 18.2	*<0.05
PI 639068 (*Vrn-B1a*)	*Triple Dirk B*	51.8	+/- 18.7	PI 639073 (*Vrn-B1b*)	45.9	+/- 18.2	NS
PI 639069 (*Vrn-B1a*)	*Triple Dirk B*	65.5	+/- 18.7	PI 639074 (*Vrn-B1b*)	42.8	+/- 17.9	NS
PI 639070 (*Vrn-B1a*)	*Triple Dirk B*	55.7	+/- 18.8	PI 639075 (*Vrn-B1b*)	47.1	+/- 18.3	NS
PI 639071 (*Vrn-B1a*)	*Triple Dirk B*	78.1	+/- 17.1	PI 639076 (*Vrn-B1b*)	45.3	+/- 18.1	NS
PI 639088 (*Vrn-B1a*)	*Triple Dirk F*	71.9	+/- 18.2	PI 639093 (*Vrn-B1b*)	42.2	+/- 17.8	NS
PI 639089 (*Vrn-B1a*)	*Triple Dirk F*	69.6	+/- 18.4	PI 639094 (*Vrn-B1b*)	43.6	+/- 18.0	NS
PI 639090 (*Vrn-B1a*)	*Triple Dirk F*	53.4	+/- 18.8	PI 639095 (*Vrn-B1b*)	39.0	+/- 17.4	NS
PI 639091 (*Vrn-B1a*)	*Triple Dirk F*	55.8	+/- 15.4	PI 639096 (*Vrn-B1b*)	35.3	+/- 13.6	NS
PI 639078 (*Vrn-D1a*)	*Triple Dirk E*	50.5	+/- 18.6	PI 639083 (*Vrn-D1b*)	44.4	+/- 18.0	NS
PI 639079 (*Vrn-D1a*)	*Triple Dirk E*	67.8	+/- 18.6	PI 639084 (*Vrn-D1b*)	41.8	+/- 17.7	NS
PI 639080 (*Vrn-D1a*)	*Triple Dirk E*	64.4	+/- 18.8	PI 639085 (*Vrn-D1b*)	44.8	+/- 18.1	NS
PI 639081 (*Vrn-D1a*)	*Triple Dirk E*	68.8	+/- 18.5	PI 639086 (*Vrn-D1b*)	52.0	+/- 18.7	NS
PI 566596 (ALPOWA)		99.6	+/- 2.0	CItr 17419 (DAWS)	37.3	+/- 10.8	*<0.05
PI 601814 (SCARLET)		96.8	+/- 7.7	PI 536994 (ELTAN)	39.3	+/- 13.9	*<0.05
				CItr 17735 (NORSTAR)	8.3	+/- 10.8	*<0.05
				CItr 17596 (STEPHENS)	77.4	+/- 13.9	*<0.05
				CItr 13844 (WANSER)	24.5	+/- 11.5	*<0.05
				CItr 12696 (BURT)	26.4	+/- 15.2	*<0.05
				CItr 17724 (CENTURK78)	25.0	+/- 18.1	*<0.05

Footnote: for Prob diff.<0.05column: * significant difference between dominant (spring habit) and recessive (winter habit) *Vrn-1* alleles.

Vrn loci for the winter genotype for all the NILs are *Vrn-A1bVrn 1bVrn-D1b*

NS = non significant

Table 6**:** Average Relative Area Under the Death Progress Curve (AUDPC) and 95% confidence intervals for Near Isogenic Lines (NILs) differing for alleles at the orthologous *Vrn-1* loci in wheat using Wanser winter wheat as the recurrent parent

Wanser NILs							
Spring				**Winter**			
PI Number	**Donor Parent**	**Relative AUDPC**	**Confidence Limits (95%)**	**PI Number**	**Relative AUDPC**	**Confidence Limits (95%)**	**Prob > F**
PI 638622 (*Vrn-A1a*)	*Triple Dirk D*	100.0	+/- 0.6	PI 638626 (*Vrn-A1b*)	78.6	+/- 16.6	*<0.05
PI 638623 (*Vrn-A1a*)	*Triple Dirk D*	98.0	+/- 8.4	PI 638627 (*Vrn-A1b*)	31.1	+/- 15.5	*<0.05
PI 638624 (*Vrn-A1a*)	*Triple Dirk D*	98.9	+/- 6.4	PI 638628 (*Vrn-A1b*)	74.6	+/- 17.3	*<0.05
PI 638621 (*Vrn-A1a*)	*Triple Dirk D*	99.1	+/- 3.8	PI 638629 (*Vrn-A1b*)	29.8	+/- 15.2	*<0.05
PI 638630 (*Vrn-B1a*)	*Triple Dirk B*	61.8	+/- 18.3	PI 638635 (*Vrn-B1b*)	29.7	+/- 15.2	*<0.05
PI 638631 (*Vrn-B1a*)	*Triple Dirk B*	99.6	+/- 2.4	PI 638636 (*Vrn-B1b*)	28.6	+/- 15.0	*<0.05
PI 638632 (*Vrn-B1a*)	*Triple Dirk B*	100.0	+/- 0.2	PI 638637 (*Vrn-B1b*)	39.0	+/- 16.8	*<0.05
PI 638633 (*Vrn-B1a*)	*Triple Dirk B*	100.0	+/- 0.1	PI 638638 (*Vrn-B1b*)	35.4	+/- 16.3	*<0.05
PI 638648 (*Vrn-B1a*)	*Triple Dirk F*	99.6	+/- 4.1	PI 638653 (*Vrn-B1b*)	50.0	+/- 18.0	*<0.05
PI 638649 (*Vrn-B1a*)	*Triple Dirk F*	99.7	+/- 1.8	PI 638654 (*Vrn-B1b*)	31.9	+/- 15.6	*<0.05
PI 638650 (*Vrn-B1a*)	*Triple Dirk F*	98.7	+/- 4.7	PI 638655 (*Vrn-B1b*)	48.1	+/- 17.9	*<0.05
PI 638651 (*Vrn-B1a*)	*Triple Dirk F*	100.0	+/- 1.8	PI 638656 (*Vrn-B1b*)	33.3	+/- 15.9	*<0.05
PI 638639 (*Vrn-D1a*)	*Triple Dirk E*	96.7	+/- 7.7	PI 638643 (*Vrn-D1b*)	31.9	+/- 15.6	*<0.05
PI 638640 (*Vrn-D1a*)	*Triple Dirk E*	63.9	+/- 18.3	PI 638644 (*Vrn-D1b*)	32.7	+/- 15.8	NS
PI 638641 (*Vrn-D1a*)	*Triple Dirk E*	64.0	+/- 18.3	PI 638645 (*Vrn-D1b*)	46.5	+/- 17.7	NS
PI 638642 (*Vrn-D1a*)	*Triple Dirk E*	36.5	+/- 16.5	PI 638647 (*Vrn-D1b*)	56.9	+/- 18.3	NS
PI 566596 (ALPOWA)		99.6	+/- 2.0	CItr 17419 (DAWS)	37.3	+/- 10.8	*<0.05
PI 601814 (SCARLET)		96.8	+/- 7.7	PI 536994 (ELTAN)	39.3	+/- 13.9	*<0.05
				CItr 17735 (NORSTAR)	8.3	+/- 10.8	*<0.05
				CItr 17596 (STEPHENS)	77.4	+/- 13.9	*<0.05
				CItr 13844 (WANSER)	24.5	+/- 11.5	*<0.05
				CItr 12696 (BURT)	26.4	+/- 15.2	*<0.05
				CItr 17724 (CENTURK78)	25.0	+/- 18.1	*<0.05

Footnote: for Prob diff. <0.05column: *significant difference between dominant (spring habit) and recessive (winter habit) *Vrn-1* alleles.

Vrn loci for the winter genotype for all the NILs are *Vrn-A1bVrn-B1bVrn-D1b*

NS= non significant

Chapter Two

Mapping of Cold Temperature Tolerance Genes in Two Populations of Wheat (*Triticum aestivum* L. em Thell)

Latha Reddy[1], Qijian Song[2], Jose Costa[3], Perry Cregan[4] James A Anderson[5] and Kimberly A Garland Campbell[6]

1. Washington State University, #201 Johnson Hall, Pullman WA99164
2. USDA-ARS BARC, USDA/ARS Soybean Research Laboratory, Beltsville, MD 20705
3. University of Maryland, 2102 Plant Sciences Bldg., Dept. of Natural Resource Sciences and Landscape Architecture, College Park, MD20742-4452
4. USDA-ARS BARC, USDA/ARS Soyb Gen. Imprv. Lab, Beltsville, MD20705-2350
5. University of Minnesota, Agronomy/Plant Genetics, 308 Hayes Hall, 1509 Gortner Avenue, St. Paul, MN 55108
6. USDA-ARS, Wheat Genetics, Quality, Physiology and Disease Research Unit #209 Johnson Hall Pullman WA

Abstract

Winter wheat production suffers economic losses due to cold and freezing injury every five years on average in winter wheat growing regions with severe winters. The objectives of our research were to identify quantitative trait loci (QTLs) associated with resistance to cold in two winter wheat recombinant inbred line (RILs) populations. RIL populations of Centurk78/Norstar (86 lines) and Z0031/2*Karl (69 lines) were used to map QTLs for cold tolerance. Parental polymorphism screens of 1510 wheat SSR primers of the gwm and barc series identified 197 polymorphic primers for the Centurk78/Norstar population and 137 polymorphic primers for the Z0031/2*Karl population. Three putative QTL were identified in the Centurk78/Norstar population the first QTL between barc117 and gwm205 is on chromosome 5A with LOD of 2.0 (P= 0.0026) and R^2 of 10.7%, second putative QTL is between gwm626 and gwm508 on 6B with LOD of 1.4 (P= 0.0115) and R^2 of 7.5% and the third putative QTL is on chromosome 5D near gdm138 with LOD of 2.5 (P= 0.0008) and R^2 of 14.0%. Two putative QTLs were identified in the Z0031/2*Karl population, one on chromosome 4B between barc193 and barc218 with a LOD of 2.0 (P=0.003) and R^2 of 14.4% and the second putative QTL was on 5A between barc117 and barc197 with LOD of 1.4 (P= 0.0148) and R^2 of 9.8%. These QTLs will be verified after the genome is further saturated.

Introduction

Cold temperature is a major problem for winter wheat (*Triticum aestivum*) production in temperate regions with severe winters. To decrease yield losses due to cold injury in regions with severe winters we need cold tolerant cultivars (Fowler et al., 1981). Genetic differences in cold tolerance have been measured in winter wheat both in field and under aritificial conditions (Brule-Babel and Fowler, 1989a) but the genetic mechanisms and inheritance controlling these differences are not well studied, primarily due to the difficulty of assessing genotypic differences in cold hardiness.

Regulatory genes controlling cold tolerance have been well studied in the model plant Arabidopsis (*Arabidopsis thaliana*) (Thomashow, 1998; Thomashow, 2001). Transcriptome analysis in Arabidopsis has indicated a total of 306 cold responsive genes of which 218 are upregulated by cold and 88 are down regulated by cold (Fowler and Thomashow, 2002). Transcriptome profiling elucidated the presence of multiple regulatory pathways (Fowler and Thomashow, 2002). The C-repeat Binding Factor (CBF) cold response pathway for cold acclimation in Arabidopsis has received the most attention. There are three main regulatory elements called the C-repeat binding factors (CBF1-3) with a major role in providing cold tolerance in the CBF cold response pathway (Thomashow, 2001).

In barley (*Hordeum vulgare* L.) and wheat, populations developed from crosses between winter and spring habit genotypes have been used to identify quantitative trait loci for cold tolerance and expression studies have been conducted for *Cbf* and cold regulated genes (*Cor*) (Choi et al., 2002; Francia et al., 2004; Hayes et al., 1993; Limin et al., 1997; Vagujfalvi et al., 2003). In wheat, the frost tolerance gene *Fr-A1*, was mapped to chromosome 5A in a population of single chromosome recombinant lines (Galiba et al., 1995). The exact location of *Fr-A1* is unclear since it is placed proximal and distal to *Vrn-A1* (Galiba et al., 1995 Sukta et al., 1999). Two QTLs, *Fr-A2* on 5A chromosome of wheat in F_5 RILs of *T. monococcum* (Vagujfalvi et al., 2003) and *QFr.jic*-5D on chromosome 5D of wheat (Snape, 1997) have been reported . Recently 11 *Cbf* like genes from the *T. monoccocum* BAC library (Lijavetzky, 1999) were observed to map to a 0.8 cM region of the *Fr-*A^m locus (Miller et al., 2006). In barley, two QTLs *Fr-H1* and *Fr-H2* on 5H chromosome (Hayes et al., 1993; Francia et al., 2004) have been identified in populations derived from crosses between ‘Dicktoo’ x ‘Morex’ and ‘Nure’ x ‘Tremois’. Three groups of CBF genes, *HvCBF1*, *HvCBF3* and *HvCBF4*, each with additional subgroups have been identified in Dicktoo x Morex population. The alleles in each subgroup are highly conserved (Skinner et al., 2006). One or more of these CBF genes are candidate genes for *Fr-H2* in the Nure x Tremois barley population based on results from comparative mapping with common markers and BIN positions (Skinner et al., 2006). BIN is a part of a chromosome arm demarcated by specific markers and BIN position identifies the loci through associated markers in that particular region of the chromosome. All of the above research has been conducted in populations derived from winter habit x spring habit germplasm where major genes for vernalization are segregating.

Photoperiod and vernalization influence low temperature tolerance through developmental regulation. Alleles of the vernalization gene *Vrn-A1* regulate the expression of Cold Regulated (*COR*) genes (Danyluk et al., 2003; Fowler et al., 1996). When the plant is in the vegetative stage *COR* genes are in an upregulated state. Once the plants enter the reproductive stage, they are more sensitive to cold and the expression of *COR* genes is down-regulated (Danyluk et al., 2003). Winter wheats remain in the vegetative stage until the need for vernalization is satisfied and are, in general, more tolerant to cold (Fowler et al., 1996). In the case of barley, the low temperature induced *WCS* and *WCOR* gene expression was also regulated by photoperiod. There was a longer and higher expression of the *WCS* and *WCOR* proteins due to the extended vegetative stage of the plant under short days (8 h day length). In contrast plants exposed to long days (20 h day length) expressed the *WCS* and *WCOR* genes for a very short period and the level of expression was reduced once the plants entered reproductive phase quickly under long day length conditions.

Although the major photoperiod and vernalization genes have large effects on cold tolerance in cereals, the practical breeding goal is to improve cold tolerance in winter by winter wheat populations where those major genes are not segregating. In order to avoid the effect of vernalization and photoperiod the best population to map QTLs for cold tolerance is a winter x winter wheat cross. The objective of this experiment is to map QTLs for cold tolerance in two winter wheat recombinant inbred line (RIL) populations: Centur78/Norstar and Z0031/2*Karl.

Materials and Methods

Mapping populations:

Centurk78/Norstar: 86 Recombinant Inbred Lines (RILs) used in this study were developed from a cross between two hard red winter wheats: Norstar and Centurk78 (Grant, 1980; Schmidt et al., 1981). The RILs are currently in the F_8. Norstar was bred in Alberta Canada and selected for its very high level of winter hardiness but it has poor disease resistance. Centurk78 was bred in Nebraska, USA as a selection from Centurk, a moderately winter hardy wheat and used as the susceptible parent for this population.

Z0031/2*Karl (69 BC_1S_8 lines) were developed from a backcross between Karl, a high quality hard red winter wheat with good agronomic characteristics (Sears et al., 1991) and the synthetic hexaploid Z0031 (RL5263/PI404584). Z0031 was derived from cross between the winter durum (*Triticum turgidium* subsp.*Durum*) cultivar Rubezh (PI404584) and the *T. tauschii* (Coss.) accession RL5263. Karl was the resistant parent and Z0031 was the susceptible parent in this cross.

Genotyping:

DNA was extracted from 5-7 seedlings per genotype using the procedure described by (Dellaporta, 1983). Genotyping was performed using simple sequence repeat (SSR) markers from the GWM, BARC,WMC, CFA, CFD and GDM series (Roder et al., 1998; Somers et al., 2004; Song et al., 2005). The markers were synthesized to include the M-13 sequence (Oetting et al., 1995). Some of the primers were labeled with DS33 Dye to run on the ABI 3730 DNA Analyzer (Applied Biosystems, Foster City, CA). Other primers were visualized using IR800 and IR700 dyes on the Licor Global IR2 Analysis system (Li-cor Biosciences, Lincoln, Nebraska). Results were analysed using either 'GENESCAN' software for the IR2 data (Li-cor Biosciences, Lincoln, Nebraska) or GENEMAPPER V3.7 for data collected from the ABI 3730 DNA Analyzer (Applied Biosystems, Foster City, CA). The genotyping with BARC markers was done at Beltsville Agricultural Research Center, Beltsville, Maryland. Parental polymorphism for the RFLP markers *Xcdo*504, *Xpsr*426and *Xpsr*2021 that flank the *Vrn-A1* region in wheat were evaluated. All methods were as in Storlie et al., (1998).

Freeze testing under controlled conditions:

Artificial Freeze test: Artificial freezing tests were used to evaluate cold temperature tolerance under controlled environmental conditions. Artificial freezing test results have good correlation to the field survivability index under natural conditions (Brule-Babel and Fowler, 1989b). Wheat seedlings were seeded into SunShine mix LC1 (Sun Gro Horticulture, Bellevue, WA, USA) in cell pack ′1020′ inserts packed into ′1020 flats′ (The Blackmore company, Belleville, MI, USA) of 27.62cm(W) x 53.98cm(L) x 5.72cm(H) dimension that contained drainage holes. 10 plants were planted per genotype and freeze test temperature (see below) for a total of 80 plants per genotype

Because of space limitations, the experiment was conducted in sets of 32 RILS, plus the winter wheat check cultivars Stephens & Eltan (as cold susceptible and resistant checks, repectively), and the four population parents for a total of 38 genotypes per set. Checks and parents were included in each freeze test set. Each population was tested three times. Immediately after planting, germination time was synchronized by placing seeded, watered trays in a cold room at 4^{o}C for three days and then moving them to a greenhouse at 24^{o}C with a 16 hour day length. Macro and micro nutrients (Peter's All Purpose , Scotts-Sierra, Marysville, OH, USA) at a final dilution of 100 ppm were applied through a watering system once per day to saturation. At the three leaf stage, seedlings were transferred to a 2.25 m^2 growth chamber (Conviron Inc, Ashville, NC, USA) for vernalization with lighting at 200µmol $m^{-2}s^{-1}$ supplied by fluorescent and incandescent bulbs, with a 16/8 hour light/dark cycle; and temperature maintained at a constant 4^oC. Seedlings were held in vernalization for five weeks.

After the vernalization period, plants were saturated with water to equalize water content throughout trays. The tops of the plants were removed to approximately 2 cm above the soil surface. Temperature monitoring probes were place in one tray per temperature. The artificial freeze test was conducted by reducing the growth chamber temperature from 4^oC to -10^oC over a period of 8 hours. Then the temperature was decreased for 12 more hours at the rate of 1.5^oC every 1.5 hours until the lowest test temperature (-20.5^oC) was reached. A full set of 38 genotypes, 10 plants per genotype, was removed at each of 8 temperatures (-10, -11.5, -13, -14.5, -16, -17.5, -19 and $–20.5^oC$). After freezing, plants were placed in a growth chamber at 4^oC in the dark. The temperature of the growth chamber was increased over 24 hours to 13°C. Plants were then placed in the greenhouse at 24^oC for regrowth. Regrowth was rated 5 weeks after the freeze test as 1 = alive and 0 = dead.

Data Analysis:

The LT50 value was calculated using logistic regression for each genotype in each freeze test set according to (Brule-Babel and Fowler, 1989b). Data were analyzed using analysis of variance in a genotypes within sets design. The model for this design was a genotype within set model, $Y_{ijk} = \mu + S_i + B_k(S_i) + G_j\ (S_i) + E_{ijk}$ where $Yijk$ = LT50 value for a given genotype, μ = overall mean, S_i = set, B_k = Block within set, G=Genotype within set and E_{ijk} = experimental error. Linkage maps were constructed for each population using MAPMAKER (Lander et al.,

1987) with the Haldane mapping function. Due to software limitations, the Z0031/2*Karl population was analyzed as an RIL population in order to construct the linkage map and identify QTLs. Because linkage maps were not dense, QTL analysis was conducted using single marker regression of the mean LT50 scores as dependent variables and individual markers as independent variables for each population. When linkage groups had more than three markers, QTLs were also analyzed using interval analysis. The software QGENE (Nelson, 1997) was used for QTL identification. Markers were considered to be associated with LT50 if the *t*-test for the difference between marker classes was significant at $P<0.05$. Although this significance level allows for a large probability of Type 1 error, probable QTLs will later be confirmed through additional mapping experiments targeted to chromosome areas of interest.

Results:

Evaluation of morphological trait:

The LT50 values of the parents were -16.0 for Centurk78, -18.6 for Norstar, -18.2 for Karl and -12.4 for Z0031 indicating that although Centurk78 and Norstar are differentially cold tolerant in the field, they are both fairly tolerant of freezing in the artificial freezing tests. The progeny of the Centurk78/Norstar population had LT50 scores ranging from -14.0^{o}C to -21.0^{o}C with a median of -17.0^{o}C (Fig1). Similarly the Z0031/2*Karl population had LT50 values ranging from -11.0^{o}C to -19.0^{o}C with a median of -16.0^{o}C (Fig1), indicating that transgressive segregation occurred in the Centurk78/Norstar population and that the parents possessed different genes contributing to improved cold tolerance. The frequency distribution of the LT50 values for the progeny of the two populations approximated normal distributions.

Molecular marker analysis:

RFLP results: Parents were tested using the RFLP markers *Xcdo504*, *Xpsr426*, *Xpsr2021* flanking the *Vrn-A1* and *Xwg644* marker located within the *Vrn-A1* locus. All four parents had identical RFLP banding patterns for the above listed markers for the *Vrn-A1* region on chromosome 5A indicating that populations were not segregating for cold hardiness effects associated with that locus.

The two parents Centurk78 and Norstar were screened for 1510 SSR markers and 184 markers were found to be polymorphic. The polymorphic markers fit 1:1 segregation ratio (P=0.05) for recombinant inbred lines. These 184 SSR markers were used for linkage analysis and mapping of the cold tolerance trait in the Centurk78/Norstar population. 111 polymorphic markers were identified from a total of 631 SSR markers screened for Z0031 and Karl. The polymorphic markers segregated as expected for a backcross population with a 1:3 ratio at P = 0.05 (tested using chi-square test).

Linkage analysis:

From the 184 SSR markers analysed in the Centurk78/Norstar population, we identified 17 linkage groups (Fig.2) and 58 unlinked markers. The average number of markers per chromosome was 5 with an average chromosome length of 60 cM and a total length of 990 cM for the 17 linkage groups observed. The 17 linkage groups were associated with 17 different wheat chromosomes. The linkage groups were associated with wheat chromosomes based on the previously published maps for GWM markers (Roder et al., 1998) and BARC markers (Song et al., 2005) and their exact locations need to be verified.

For the Z0031/2*Karl population, 111 polymorphic markers were grouped into 14 linkage groups (Fig 3) with an average of 4 markers per chromosome and a total length of 330 cM. All the 14 linkage groups were associated with 14 wheat chromosomes based on previously published maps (Roder et al., 1998; Song et al., 2005).

QTL analysis:

Three putative QTLs were identified in the Centurk78/Norstar population. One QTL is on chromosome group 5A near barc117 and gwm205. The QTL at barc117 had a Log of Odds ratio (LOD) score of 2.0 with *P*= 0.0026 and accounted for 10.7% of phenotypic variation for LT50 values, gwm205 has a LOD of 0.71 with *P* = 0.075 and accounted for phenotypic variation of 4.1%. Another locus in the same group, gwm186, has a LOD score of 1.2 (*P*= 0.0183) and accounts for 6.8% phenotypic variation (Fig 4). Chromosome group 6B has a second putative QTL that included the markers gwm518 and barc67 (Fig 4). The marker gwm518 has a LOD score of 1.4 (*P*= 0.0115) and accounts for 7.5% of the phenotypic variation, barc67 accounts for 3.0% of the phenotypic variation. The third putative QTL is on chromosome 5D defined by the marker gdm138 which has a LOD score of 2.5 (*P*= 0.0008) and accounts for 14.0% phenotypic variation. In that same group, barc248 has a LOD score of 1.3 (*P*=0.018) and accounts for 8.4% of phenotypic variation.

In the Z0031/2*Karl population there were two putative QTLs. The first QTL was located on chromosome 4B and the second was located on chromosome 5A. The QTL on 4B was between barc193 and barc218 (Fig 5) with a LOD score of 2.0 (*P*=0.003) and an R^2 value of 13.8%. In that same group, barc229 explained 14.4% phenotypic variation with a LOD score of 1.6 (*P*= 0.0085). The second putative QTL was on chromosome 5A including barc117, barc100, barc360 and barc197 (Fig 5). At barc197, the LOD score was 1.4 (*P*= 0.0148) accounting 9.8% of the phenotypic variation. Barc100, barc117 and barc 360 accounted for 8.3%, 5.2% and 6.3% of the phenotypic variation, respectively.

The possibility of epistatic interactions was evaluated using MapManager software. None were detected for the Centurk78/Norstar population but in the case of the Z0031/2*Karl population the marker barc197 on chromosome 5A was epistatic to barc141, an unlinked marker in this population but located on chromosome 5A based on the published map.

Discussion

In this study linkage maps of SSR markers for each of two winter wheat populations segregating for cold tolerance were constructed. The use of SSR markers allowed us to compare our map with published maps. Two loci, *Fr1* (*Fr-A1*) and QTL *Fr-A2*, responsible for cold tolerance have been mapped to wheat chromosome 5A. A third locus, the QTL *QFrjic*-5D was mapped to chromosome 5D (Galiba et al., 1995; Snape, 1997; Vagujfalvi et al., 2000; Vagujfalvi et al., 2003). Although our populations did not segregate at *Vrn-A1*, on chromosome 5A we identified QTLs on chromosome 5A in both populations as well as on other chromosomes in wheat. The QTL on 5A in Centurk78/Norstar population has the marker gwm186 reported to be linked to *Fr-A2* (Vagujfalvi et al., 2003)

The Centurk78/Norstar population had a low level of polymorphism with just 12.2% of the markers differing between the two parents. Since both the parents are commercial hard winter wheat cultivars they probably have some ancestry in common. The Z0031/2*Karl population had a marginally higher rate of polymorphism (17.6%) probably because the Z0031 is a synthetic hexaploid and Karl is a hard winter wheat cultivar. In a recent survey of polymorphism rates for SSR markers, polymorphism rates varied from 2.1% to 26.8% among 23 different intervarietal crosses in US wheat. (Dr. S. Chao, personal communication). The low levels of polymorphism are probably due to low levels of recombination (Dvorak et al., 1998) in wheat.

Because over 1500 SSR markers are now available, we were able to identify 17 linkage groups in the Centurk78/Norstar population and 14 linkage groups in Z0031/2*Karl population.

We were able to associate all of those linkage groups with wheat chromosomes based on previous maps.

Even so, map coverage in these populations is still low. Only 23.6% (990 cM) and 7.9% (330 cM) of the estimated 4200 cM total map size of the hexaploid wheat genome (Messmer et al., 1999) is covered in the Centurk78/Norstar and the Z0031/2*Karl population, respectively. The phenotypic variation explained by each QTL in the two populations is between 3.0% and 14.4%, and can be improved with more accurate linkage maps and larger population sizes. The cold tolerance in the two populations could possibly be controlled by many minor QTLs as seen in case of Fusarium head blight (FHB) (Lin et al., 2004; Paillard et al., 2004).

The putative QTLs identified will need to be confirmed after the genome is further saturated with markers. In Centurk78/Norstar population, the chromosomes 1A, 1D, 3B, 3D need markers to be represented as linkage groups and all the groups need additional markers to prove the statistical significance of the putative QTLs identified in this experiment. The Z0031/2*Karl population has only 14 linkage groups with current marker saturation, groups 1A, 1D, 2A, 3B, 4D, 6D, and 7A need markers for a framework map to show up as linkage groups in this linkage analysis and all the groups need more markers to get to the total estimated map size of 4200 cM for hexaploid wheat.

Future Work:

Miller et al., 2006 have mapped 11 Cbf transcription factors to the *Fr-*A^m*2* region on 5A chromosome in *Triticum monococcum*. These Cbf genes will be used as candidate genes and mapped on to the two populations. The map will be further saturated using Diversity Arrays Technology (DArT) or Target Region Amplification Polymorphism (TRAP) markers to get full coverage. We have also begun to develop larger populations segregating in the areas of putative

QTLs that have been identified here. After confirming the QTLs identified here, they will be moved to different genotypes using marker assisted selection to breed cultivars with good cold tolerance.

References:

Brule-Babel, A.L., and D.B. Fowler. 1989a. Use of controlled environments for winter cereal cold hardiness evaluation: controlled freeze tests and tissue water content as prediction tests. Canadian Journal of Plant Science = Revue Canadienne de Phytotechnie 69:355-366.

Brule-Babel, A.L., and D.B. Fowler. 1989b. Genetic control of cold hardiness and vernalization requirement in rye. Genome 32:19-23.

Choi, D.W., E.M. Rodriguez, and T.J. Close. 2002. Barley cbf3 gene identification, expression pattern, and map location. Plant Physiology 129:1781-1787.

Danyluk, J., N.A. Kane, G. Breton, A.E. Limin, D.B. Fowler, and F. Sarhan. 2003. TaVRT-1, a putative transcription factor associated with vegetative to reproductive transition in cereals. Plant Physiology 132:1849-1860.

Dellaporta, J.S., J. Wood and J.B.Hicks. 1983. A plant DNA minipreparation: Version II. Plant Molecular Biology Reports 1:19-21.

Dvorak, J., M.-C. Luo, and Z.-L. Yang. 1998. Restriction fragment length polymorphism and divergence in the genomic regions of high and low recombination in self-fertilizing and cross-fertilizing *Aegilops* species. Genetics 148:423-434.

Fowler, D.B., L.V. Gusta, and N.J. Tyler. 1981. Selection for winterhardiness in wheat. III. Screening methods for cold resistance of cultivars. Crop Science 21:896-901.

Fowler, D.B., L.P. Chauvin, A.E. Limin, and F. Sarhan. 1996. The regulatory role of vernalization in the expression of low-temperature-induced genes in wheat and rye. Theoretical and Applied Genetics 93:554-559.

Fowler, S., and M.F. Thomashow. 2002. Arabidopsis transcriptome profiling indicates that multiple regulatory pathways are activated during cold acclimation in addition to the CBF cold response pathway. The Plant Cell 14:1675-1690.

Francia, E., F. Rizza, L. Cattivelli, A.M. Stanca, G. Galiba, B. Toth, P.M. Hayes, J.S. Skinner, and N. Pecchioni. 2004. Two loci on chromosome 5H determine low-temperataure tolerance in a 'Nure' (winter) x 'Tremois' (spring) barley map. Theoretical and Applied Genetics 108:670-680.

Galiba, G., S.A. Quarrie, J. Sutka, A. Morounov, and J.W. Snape. 1995. RFLP mapping of the vernalization (*Vrn1*) and frost resistance (*Fr1*) genes on chromosome 5A of wheat. Theoretical and Applied Genetics 90:1174-1179.

Grant, M.N. 1980. Registration of Norstar wheat cultivar. Crop Science 20:552.

Hayes, P.M., T. Blake, T.H.H. Chen, S. Tragoonrung, F. Chen, A. Pan, and B. Liu. 1993. Quantitative trait loci on barley (*Hordeum vulgare* L.) chromosome 7 associated with components of winterhardiness. Genome 36:66-71.

Lander, E.S., P. Green, J. Abrahamson, A. Barlow, M.J. Daly, and S.E. Lincoln. 1987. MAPMAKER: an interactive computer package for constructing primary genetic linkage maps of experimental and natural populations. Genomics 1:174-181.

Lijavetzky D, M.G., Wicker T, Keller B, Wing R, Dubcovsky J. 1999. Construction and characterization of a bacterial artificial chromosome (BAC) library for the A genome of wheat. Genome. 42:1176-82.

Limin, A.E., J. Danyluk, L.P. Chauvin, D.B. Fowler, and F. Sarhan. 1997. Chromosome mapping in low-temperature induced Wcs120 family genes and regulation of cold-tolerance expression in wheat. Molecular & General Genetics 253:720-727.

Lin, F., Z.X. Kong, H.L. Zhu, S.L. Xue, J.Z. Wu, D.G. Tian, J.B. Wei, C.Q. Zhang, and Z.Q. Ma. 2004. Mapping QTL associated with resistance to Fusarium head blight in the Nanda2419 x Wangshuibai population. I. Type II resistance. Theoretical and applied genetics 109:1504-1511.

Messmer, M.M., M. Keller, S. Zanetti, and B. Keller. 1999. Genetic linkage map of a wheat x spelt cross. Theoretical and Applied Genetics 98:1163-1170.

Miller, A., G. Galiba, and J. Dubcovsky. 2006. A cluster of 11 *CBF* transcription factors is located at the frost tolerance locus *Fr-*A^m*2* in *Triticum monococcum*. Molecular Genetics and Genomics 275:193-203.

Nelson, J.C. 1997. QGENE: software for marker-based genomic analysis and breeding. Molecular Breeding : New Strategies in Plant Improvement 3:239-245.

Oetting, W.S., H.K. Lee, D.J. Flanders, G.L. Wiesner, T.A. Sellers, and R.A. King. 1995. Linkage analysis with multiplexed short tandem repeat polymorphisms using infrared fluorescence and M13 tailed primers. Genomics 30:450-458.

Paillard, S., T. Schnurbusch, R. Tiwari, M. Messmer, M. Winzeler, B. Keller, and G. Schachermayr. 2004. QTL analysis of resistance to Fusarium head blight in Swiss winter wheat (*Triticum aestivum* L.). Theoretical and Applied Genetics 109:323-332.

Roder, M.S., V. Korzun, K. Wendehake, J. Plaschke, M.-H. Tixier, P. Leroy, and M.W. Ganal. 1998. A microsatellite map of wheat. Genetics 149:2007-2023.

Schmidt, J.W., V.A. Johnson, P.J. Mattern, A.F. Dreier, and D.V. McVey. 1981. Registration of Centurk 78 wheat cultivar. Crop Science 21:989.

Sears, R.G., E.G. Heyne, T.J. Martin, T.S. Cox, L.E. Browder, D.L. Wetzel, M.D. Shogren, L.C. Bolte, S.P. Curran, and J.R. Lawless. 1991. Registration of 'Karl' wheat. Crop Science 31:1386.

Skinner, J., P. Szucs, J. von Zitzewitz, L. Marquez-Cedillo, T. Filichkin, E. Stockinger, M. Thomashow, T. Chen, and P. Hayes. 2006. Mapping of barley homologs to genes that regulate low temperature tolerance in Arabidopsis. Theoretical and Applied Genetics 112:832-842.

Snape, J.W., K. Butterworth, E. Whitechurch, and A.J. Worland. 2001. Waiting for fine times: genetics of flowering time in wheat. Euphytica 119:185-190.

Snape, J.W., A. Semikhodskii, L. Fish, R.N. Sarma, S.A. Quarrie, G. Galiba, and J. Sutka 1997. Mapping frost tolerance loci in wheat and comparative mapping with other cereals. Acta Agron Hung 45:268-270.

Somers, D.J., P. Isaac, and K. Edwards. 2004. A high-density microsatellite consensus map for bread wheat (*Triticum aestivum* L.). Theoretical and Applied Genetics 109:1105-1114.

Song, Q., J. Shi, S. Singh, E. Fickus, J. Costa, J. Lewis, B. Gill, R. Ward, and P. Cregan. 2005. Development and mapping of microsatellite (SSR) markers in wheat. Theoretical and Applied Genetics 110:550-560.

Storlie, E.W., R.E. Allan, and M.K. Walker-Simmons. 1998. Effect of the *Vrn1-Fr1* interval on cold hardiness levels in near-isogenic wheat lines. Crop Science 38:483-488.

Thomashow, M.F. 1998. Role of cold-responsive genes in plant freezing tolerance. Plant Physiology 118:1-7.

Thomashow, M.F. 2001. So what's new in the field of plant cold acclimation? Lots! Plant Physiology 125:89-93.

Vagujfalvi, A., G. Galiba, J. Dubcovsky, and L. Cattivelli. 2000. Two loci on wheat chromosome 5A regulate the differential cold-dependent expression of the *cor14b* gene in frost-tolerant and frost-sensitive genotypes. Molecular and General Genetics 263:194-200.

Vagujfalvi, A., G. Galiba, L. Cattivelli, and J. Dubcovsky. 2003. The cold-regulated transcriptional activator Cbf3 is linked to the frost-tolerance locus *Fr-A2* on wheat chromosome 5A. Molecular Genetics and Genomics 269:60-67.

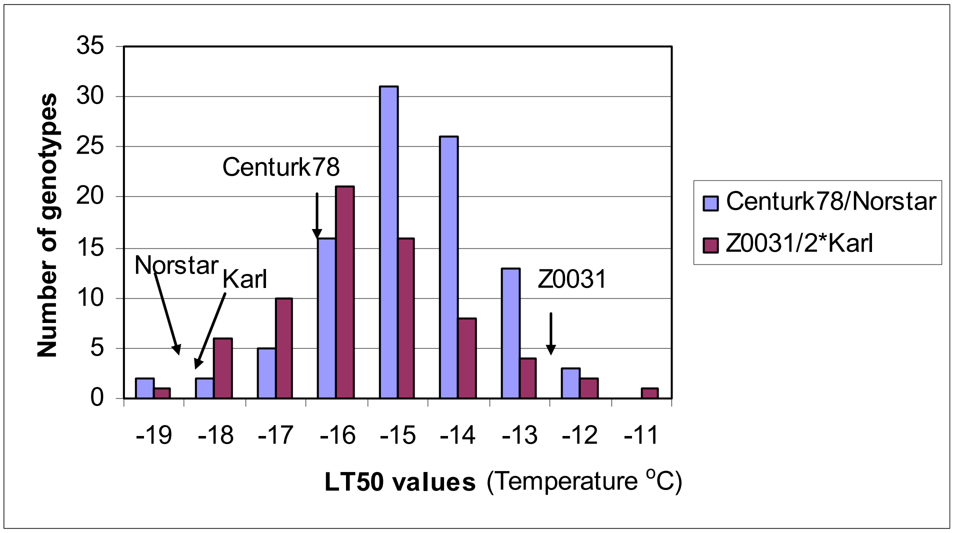


Figure 1 Frequency distribution of LT50 values for Centurk78/Norstar and Z0031/2*Karl population.

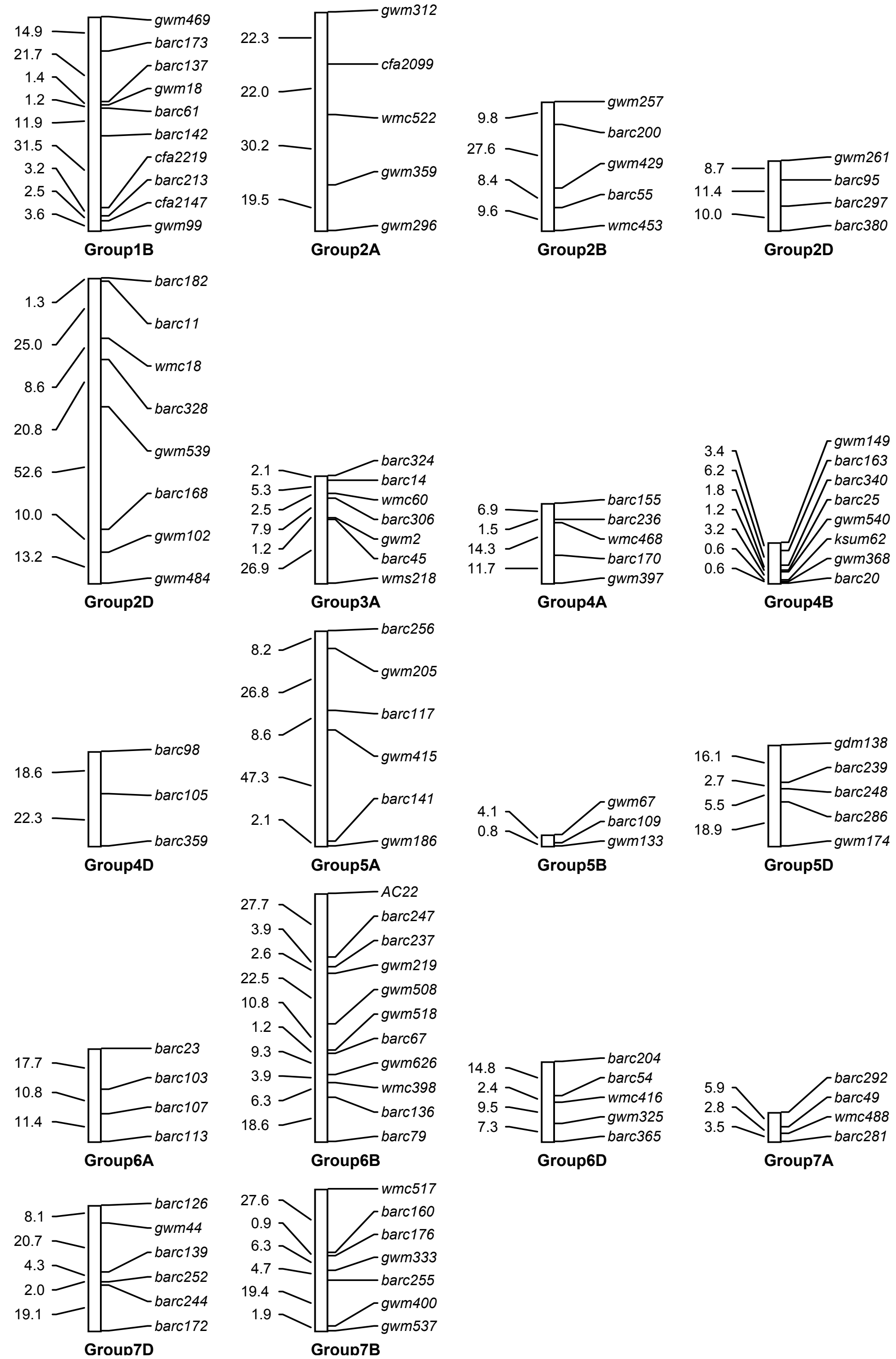


Figure 2 : 17 Linkage groups for Centurk78/Norstar population that are associated with the 17 wheat chromosome groups based on published wheat maps. Linkage among SSR markers was determined using MAPMAKER software with Haldane mapping function. Numbers to the left are map distances in cM, SSR marker names are to the right.

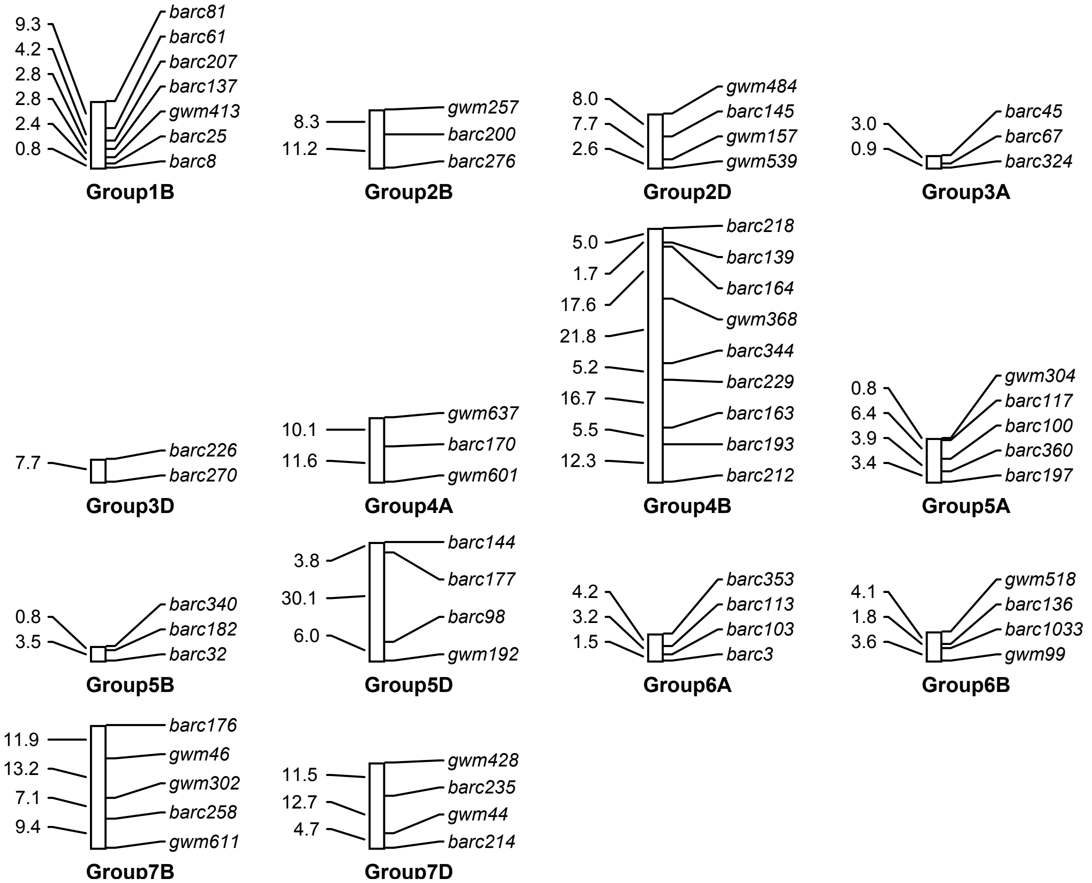


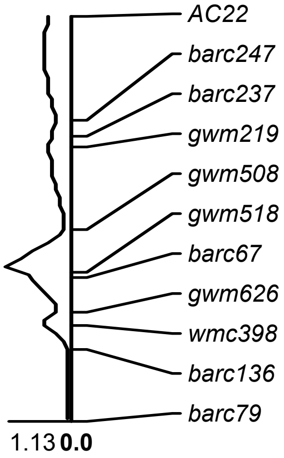
Figure 3: 14 Linkage groups for Z0031/2*Karl population associated with the 14 chromosome groups of wheat . Linkage among SSR markers was determined using MAPMAKER software with Haldane mapping function. Numbers to the left are map distances in cM, SSR marker names are to the right.

Group5D

Interval analysis for trait LT50

Group5A

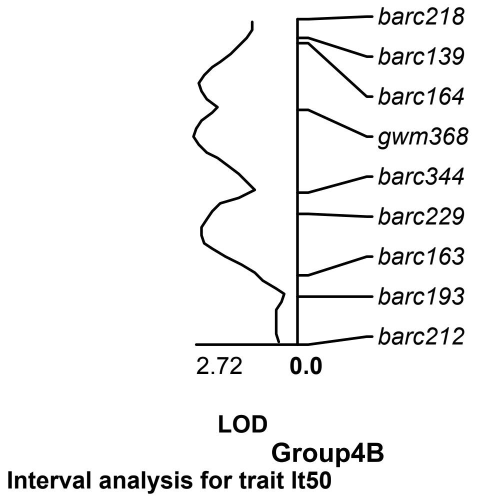
Interval analysis for trait LT50



Group6B

Interval analysis for trait LT50

Figure 4: Three putative QTLs identified for Centurk78/Norstar population on group 5A, 5D and 6B chromosome



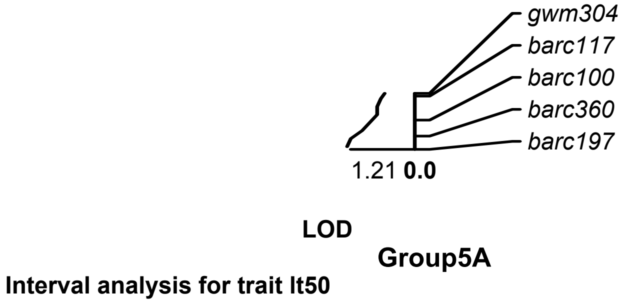


Figure 5: Two putative QTLs identified in Z0031/2*Karl population on chromosome group 4B and group 5A

Chapter Three

Breeding for High Temperature Adult Plant Resistance to Stripe Rust in Two Populations of Winter Wheat (*Triticum aestivum* L. *em* Thell)

Latha Reddy[1], Xianming Chen[2] and Kimberly Garland Campbell[2]

1.Washington State University, #201 Johnson Hall, Pullman WA99164

2. USDA-ARS, Wheat Genetics, Quality, Physiology and Disease Research Unit #209 Johnson Hall Pullman WA

Abstract

Stripe rust causes wheat yield losses every year in the Pacific Northwest. The new races of stripe rust races that have been prevalent in the US since 2000 are virulent on most known resistance genes and defeat several single resistance genes that are present in commonly cultivated varieties. The objective of this project was to assay the stripe rust resistance of two soft white winter wheat populations, WA7697 x A9622 and WA7697 x A96330 that are segregating for multiple stripe rust resistance genes. Based on their pedigree, population WA7697 x A96330 could have *Yr3a*, *YrSte*, *YrSte2, Yr17*, *Yr2*, *Yr4a* and *Yr13* stripe rust resistance genes, and the WA7697 x A9622 population could have *Yr3a*, *YrSte*, *YrSte2 YrTye*, *Yr4a*, *Yr16*, *YrTr1*, and *YrTr2* genes. In addition, both populations could have genes for high-temperature adult-plant resistance. The parent WA7697 was resistant to 16 of the 21 races used to screen for seedling or all stage resistance. WA7697 was susceptible to only two races, PST-23 and PST-37, and had an intermediate infection type (IT) for three races. The two other parents, A9622 and A96330, were resistant to 21 and 17 races respectively. A96330 had an intermediate IT to four races. The segregation for resistance to races PST-23 and PST-37 in the WA7697 x A9622 population ($F_{3:5}$) indicated that either three or four genes operate to provide resistance in this population. The two $F_{3:4}$ populations were screened in the field at WSU farms located at Pullman WA during 2002 (F_3) and 2003($F_{3:4}$) and at Central Ferry WA and Mt. Vernon WA during 2003($F_{3:4}$). At Pullman and Central Ferry all the genotypes from the two populations were either resistant or had intermediate resistance but none were susceptible. At Mt. Vernon five susceptible progenies were identified in WA7696 x A9622 and 14 were identified in WA7697 x A96330. 93 progenies that are highly resistant to predominant races of stripe rust that are causing severe epidemics in the US were identified. After further characterization for agronomic traits these progenies can be used as source of stripe rust resistance.

Introduction:

Stripe rust of wheat is caused by *Puccinia striiformis* Westend f. sp. *tritici* Eriks. This disease can cause a 100% yield loss in susceptible cultivars making stripe rust one of the most important diseases of wheat worldwide (Chen, 2005). In the United States, stripe rust has been a problem in the Pacific Northwest (PNW) and California for several decades, but since 2000 it has emerged as a threat to the south central states and the central great plains and other parts of the world (Chen, 2004).

P. striiformis f. sp. *tritici* is an obligate parasite. Urediniospores can infect wheat at any stage of the plant's growth when there is green leaf tissue for the fungi to thrive on. The disease progresses through secondary infections provided environmental conditions are favorable, with low night temperatures ranging from 7-18^{o}C and high humidity for spore germination and infection (Chen, 2005).

In wheat, resistance to stripe rust is controlled by genes that are expressed throughout all growth stages (seedling or all-stage resistance) and those that are expressed in the adult plant stage, or High Temperature Adult Plant (HTAP) genes. All seedling resistance genes identified to date are race specific (Chen and Line, 1992a; Chen and Line, 1992b; Chen and Line, 1995b; Chen, 1998) most provide high levels of resistance that put selection pressure on *P. striiformis* to evolve virulent races resulting in quick “breakdown” of resistance leading to epidemics. Genetic variation in *P. striiformis* arises mainly through mutation and somatic recombination, since a sexual stage has not been discovered. HTAP resistance genes provide resistance only at the adult plant stage at high temperatures. HTAP resistance does not totally prevent the pathogen from infecting and reproducing but reduces the rate of pathogen multiplication (Chen and Line, 1995a; Chen and Line, 1995b) so that economic yield loss is limited. Most adult plant resistance genes are not race specific.

Numerous resistance genes have been officially (*Yr1*-*Yr37*) or provisionally named (Chen, 1998; Lupton, 1962; McIntosh, 1998, Chen 2005) and incorporated into wheat (Allan et al., 1993; Allan, 1967). Most of them are seedling resistance genes and have not remained effective after deployment. One strategy to use race specific seedling resistance genes is to combine or pyramid them (Knott, 1989). Gene pyramiding can avoid the depletion of effective resistant genes even with increases in pathogen virulence. Through gene pyramiding both seedling and HTAP resistance genes can be combined resulting in durable resistance. Gene combinations that allow *P. striiformis* to cause some infection also allow pathogen survival and reduce selection pressure. The resistant cultivars with single seedling resistance gene will result in selection of the mutant pathogen that is virulent on the resistant gene over the commonly occurring pathogen race. Thus the mutant pathogen population size and distribution will increase and can be identified as a new race (Wellings and McIntosh, 1990).

Most of winter wheat cultivars have been resistant to several *P. striiformis* races in the PNW due to the stripe rust resistance genes present in the pedigrees of the cultivars currently being grown. In contrast, since 2000, new virulent races have caused serious yield losses in spring wheat, (Chen, 2005). New stable sources of resistance are required in order to reduce economic losses in spring wheat and to continue to avoid losses in winter wheat. The selection and identification of effective gene combinations that we have initiated in this study will provide new information about the combination of genes that result in stable resistance and identify new sources of resistance in agronomically adapted backgrounds.

Control of stripe rust through chemical control is effective but adds to the input costs for growers. Breeding for resistance to stripe rust is the best solution to combat the disease in wheat (Line and Chen, 1995) especially in developing countries and for farmers with low economic status.

The Objective of this study was to characterize the stripe rust resistance in two soft white wheat populations WA7697 x A9622 and WA7697 x A96330 that segregate for multiple stripe rust resistance genes.

Materials and Methods:

Plant Material:

The two crosses used in this project were WA7697 x A9622 and WA7697 x A96330. These were made to create cultivars with combined seedling and HTAP resistance to stripe rust. WA7697 is a club wheat with a pedigree Stephens/PS-279. PS-279 is a susceptible genotype and Stephens has both HTAP and seedling resistance. The probable seedling resistance genes in WA7697, derived from Stephens, are *Yr3a*, *YrSte*, *YrSte2*. Stephens also has two to three genes for HTAP resistance (Chen and Line 1995a, 1995b). A9622, the male parent, is a club wheat with the pedigree WA7665/Rulo. The pedigree of WA7665 is Tyee//Capelle Desprez/Tres. The pedigree of Rulo is Tyee//Roazon/Tres. The seedling resistance genes that could be present in A9622 are *YrTye*, *Yr4a*, *YrTr1*, *YrTr2*. The HTAP resistance gene *Yr16* may also be present. Tyee (*YrTye*) and Tres (*YrTr1*, *YrTr2*) have seedling resistance genes and Capelle Desprez has seedling resistance genes (*Yr3a*, *Yr4a*) as well as an adult plant resistance gene (*Yr16*). A96330, the male parent for the second cross, is a soft white winter wheat. The pedigree of A96330 is Madsen/WA6910. The pedigree of WA6910 is Maris Huntsman/VH74521. These ancestors may contribute *Yr17*, *Yr2*, *Yr3a*, and *Yr4a* (McIntosh, et al., 1998) seedling resistance genes and *Yr13* for adult plant resistance to the progeny population. Madsen has *Yr17* for seedling resistance and unidentified genes for HTAP resistance.

The parents were screened in the greenhouse to identify the stripe rust races that would cause susceptible reactions. The races that caused an intermediate to susceptible reaction and originated locally were used as inoculum in the field to test the two populations.

Screening for stripe rust in the greenhouse:

Screening in the greenhouse was done once. Seeds of the parents were planted in pots (approximately 10 seeds per pot). Seedlings were grown in a rust free greenhouse at a diurnal temperature cycle and 16/8 hours day/night cycle. Freshly collected spores of a total of 21 races were used to inoculate the parents (Chen and Line 1992a). The North American *P. striformis* f.sp. *tritici* races: PST-3, PST-8, PST-17, PST-20, PST-21, PST-23, PST-25, PST-29, PST-35, PST-37, PST-41, PST-43, PST-45, PST-74, PST-77, PST-78, PST-84, PST-89 PST-95, PST-96 and PST-97 were used to test the parents and F_1s of each population. The cultivar Nugaines, was included as a susceptible check for every race. Inoculation of the seedlings was done uniformly at the two leaf stage with urediospores of a specific test race, followed by incubation in a dew chamber at 10°C for 24 h in the dark. Inoculated seedlings were then placed in a growth chamber within the greenhouse at a diurnal temperature cycle that gradually changes between 4°C at 2 am and 20°C at 2 pm. The light period consisted of daylight supplemented with metal halide lights to extend the duration of light to 16h.

Infection type (IT) data were recorded 21 days after inoculation, based on a scale of 0-9 described by Line and Qayoum 1992 where 0-3 are considered resistant, 4-6 are considered intermediate and 7-9 are considered as susceptible. The plant material used for seedling resistance screening was $F_{3:5}$.

Field screening for stripe rust:

For field screening, the parents and progeny of each population were planted in replicated field trials. PS-279 was included as a susceptible disease spreader. Seeds were planted using a

Wintersteiger Plot Master Head Row Planter (Wintersteiger Inc., Salt Lake City, UT). Each plot was a 1.5 M single row. Spacing between plots was 0.3 M. The field experiment was conducted over two years. During the 2002 crop season, F_3 plant material was planted only at the WSU Crop Science Dept. Spillman Farm near Pullman WA. For the 2003 crop season the experiment was repeated at Spillman Farm and also planted at the WSU research farms in Mt. Vernon and Central Ferry, WA (only two replicates were planted at Central Ferry) using the $F_{3:4}$ material.

Races PST-29, PST-37, PST-43 and PST-45 were used for artificial inoculations at Spillman Farm during 2001-2002 to defeat the *YrTye*, *Yr4a*, *YrTr1*, *YrTr2*, *Yr17*, *Yr2* and *Yr3a* resistance genes that were thought to be present based on the pedigree of the populations used in the study. Inoculations were repeated three times with a one week interval when the weather forecast for night temperature was 7-18^{o}C, conducive for stripe rust inoculation. The races used in the field inoculation were previously present in this region. Artificial inoculations were done only at Spillman Farm. Inoculum was produced on seedlings as described above for seedling resistance screening. Spores were collected using a vacuum operated spore collectore and mixed with Talc in a 1:100gms spore: talc ratio, approximately. Inoculation was done using a hand held plant duster (Johnny's Selected Seeds, Winslow, Maine) (Chen and Line 1995). During 2002-2003, races PST-74 and PST-37, PST-95 and PST-96 were used for field inoculations since the parental screening WA7697 and A96330 had intermediate reaction to PST-95, A96330 had an intermediate reaction to PST-96. The F_1 of WA7697 x A9622 and WA7697 x A96330 had intermediate reaction to PST-95 and PST-96. Natural infections were utilized for the study at Mt.Vernon and Central Ferry locations.

The field plots were scored three times during the growing season with an interval of one week, the first reading was recorded when the symptoms appeared on the genotypes and susceptible checks. The 0-9 scale (Line and Qayoum 1992) was used to score the IT of the progeny parents and checks.

Experimental design: The experiment was designed as a randomized complete block with three replicates for each location, year,. ANOVA using the PROC GLM (General Linear Models) procedure of SAS (SAS Inst. Inc., Cary, NC, USA) was done with genotype as the main effect and standard error was obtained. Mean of three readings for each replicate was used and the mean was rounded off to the nearest whole number. The infection type data is presented as histograms.

Results:

Parent and F_1 screening of the populations WA7697xA9622 and WA7697xA96330 for resistance with different races in the greenhouse:

The parents and population F_1s were evaluated for seedling resistance using a total of 21 races of stripe rust. Nugaines consistently had an IT 8 (susceptible). Of the 21 races only PST-23 and PST-37 caused a susceptible reaction on WA7697 and a resistant to intermediate reaction on the other two parents and F_1s. The other 19 races caused resistant to intermediate reactions on the parents and F_1s (Table 1). PST-23 has virulence to ten *Yr* genes as described in table 2. We observed a susceptible reaction on WA7697 since PST-23 defeats the seedling genes from Stephens. The F_1 of WA7697 x A9622 also had a susceptible reaction.

When PST-37 was the inoculum source WA7697 was susceptible due to the virulence of PST-37 on the seedling genes from Stephens (Table 2). A9622 was resistant to PST-37 and the F_1 between WA7697 x A9622 had an intermediate reaction. The other parent, A96330 had an intermediate reaction to PST-37 but that F_1 was resistant.

The race PST-43 is virulent on twelve resistance genes (Table 2). *YrTr1* and *YrTr2* are from Tres and are present in A9622 hence A9622 was expected to have an intermediate to susceptible reaction to PST-43 but a highly resistant reaction was observed. PST-45 is virulent on the *Yr17* gene present in A96330 (Table 2). A96330 was expected to have *Yr17* and *Yr2* seedling genes based on its pedigree and we expected an intermediate to susceptible reaction with PST-45 but a resistant reaction ws observed.

For the race PST-97, the variation in infection type was probably due to the heterogeneity within the breeding line WA7697 and A96330. For the race PST-96 the parent A96330 has an intermediate reaction, while the F_1 had a resistant reaction obtained from the other parent WA7697, or from a combination of genes from both parents that resulted in higher overall resistance. Races PST-23 and PST-77 had variation in infection type for A96330 probably due to heterogeneity in the breeding line.

Seedling Evaluation of Resistance of WA7697 x A9622 to PST-23 in Greenhouse

When the progeny of WA7697 x A9622 were tested for resistance with PST-23, most progenies were resistant. 199 progeny had an IT 2 (Fig 2), 94 had IT 1, 14 had IT 3, 5 had IT 4, 24 had IT 5 and 6 were susceptible with IT 8. The progeny segregated with a ratio 344:6 resistant: susceptible. Chi-Square test was used and the ratio fit the three and four gene model.

Resistance of WA7697 x A9622 to PST-37

WA7697 was susceptible and A9622 was resistant to race PST-37, hence the WA7697 x A9622 progeny were screened for resistance to PST-37. 92% of the progenies had IT 0, 1 and 2 (Fig 1): 185 progenies had IT 2, 79 progenies had IT 0 and 63 progenies with IT 1. Of the remaining 8% most of the progenies had IT 5 with one progeny each with IT 3 and 4 and three progeny with an IT 8. The progeny segregated with a ratio 347:3 resistant: susceptible. Chi-Square test was used and the ratio fit the three and four gene model.

Evaluation of Resistance of WA7697 x A9622 in Fields

In this population 200 progenies were resistant with an IT 0 (Fig 3). 43 progenies had an IT 2, and 6 had an IT 3 at Spillman Farm during 2002. During 2003 about 216 progenies were highly resistant (Fig 3) with no symptoms of disease and four progenies each had IT 2 and 3, two progenies had IT 4 and ten progenies had IT 5. At Central Ferry during 2003 about 228 progenies were immune with an IT of 0 (Fig 4) and nine progenies had IT 2, two progenies each were observed with IT 3 and 4 and eight progenies with IT 5. At Mt. Vernon the trend was similar to Central Ferry with about 215 progenies having IT 0 (Fig 4), about 23 having a resistant reaction with IT 2, three progenies had IT 3, two progenies had IT 4, six progenies had IT 5 and five progenies had a susceptible reaction with IT 8.

Evaluation of Resistance of WA7697 x A96330 in fields

Of the 225 (F_3) plants in the WA7697 x A96330 population, 206 progenies had no symptoms of disease (Fig 3) in the three replicates planted at Spillman during 2002 and the remaining 28 lines were resistant. In 2003 the progenies ($F_{3:4}$) followed a similar trend with plants being mostly resistant (Fig 4) and two progenies with IT 2, one progeny with IT 3 and three progenies with IT 5 were observed, susceptible progenies (IT above 6) were not seen. At Central Ferry during 2003 the progenies had a wider distribution but were mostly resistant. About 184 had IT 0 (Fig 5) and of the remaining 43, 14 progenies had IT 2, four progenies had IT 3, five progenies had IT 4 and 20 progenies had IT 5. At Mt. Vernon during 2003, 163 progenies were immune (Fig 6), 18 progenies had IT 2, 7 progenies had IT 3, 6 progenies had IT 4, 27 progenies had IT 5 and 14 progenies were susceptible with IT 8.

Stripe rust samples were collected from Spillman Farm and tested in the greenhouse on the wheat differentials to determine which races were actually present in the field. PST-20 was found to be predominant in the field at Spillman during 2002, though PST-29, PST-37, PST-43 and PST-45 were used for artificial inoculation. During 2003 artificial inoculation was done using PST-37, PST-74, PST-95, and PST-96 and the stripe rust samples collected from the field were identified as predominantly PST-97, PST-100 and PST-103.

Discussion:

In both populations, we identified progenies that are highly resistant to multiple stripe rust races as seedlings. Several of these races are currently common in the Pacific Northwest and are from the new group of stripe rust races that have been prevalent in the US since 2000 (Chen, 2005).

From the seedling tests of the parents and the F_1 of both populations in the greenhouse most of the races resulted in a resistant reaction. This resistance to multiple races is either due to a low number of highly effective genes or to multiple genes within each parent that confer resistance. The analysis of segregation ratios indicates that in each population, there are three to four resistance genes that may be providing the resistance. The different races used in this study are diverse and were selected because, in combination, they defeat most currently identified single genes except *Yr5* and *Yr15* based on reactions using the wheat differential cultivars for stripe rust genes. The *Yr* genes present in the differentials are *Yr21* in ‘Lemhi’, *Yr1* in ‘Chinese 166’, *Yr2* and *YrHVII* in ‘Heines VII’, *Yr10* and *YrMor* in ‘Moro’, *YrPa1*, *YrPa2*, and *YrPa3* in ‘Paha’, *Yr3a*, *YrD*, and *YrDru* in ‘Druchamp’, *YrPr1* and *YrPr2* in ‘Paha’, *Yr2*, *Yr4a* and *YrYam* in ‘Yamhill’, *Yr3a*, *YrS*, and *YrSte* in Stephens, *Yr7*, *Yr22* and *Yr23* in ‘Lee’, *Yr6* and *Yr20* in ‘Fielder’, *YrTye* in ‘Tyee’, *YrTr1* and *YrTr2* in ‘Tres’, *Yr17* and *YrTye* in ‘Hyak’*Yr8*, *Yr9*, *Yr9* and *YrCle* in ‘Clement’ and *Yr8* and *Yr19* in ‘Compare’ (Chen, 2005).

WA7697 was susceptible to PST-23 indicating that the Stephens seedling genes were defeated. A9622 was resistant because the resistant genes hypothesized to be present were not defeated by PST-23. The F_1 of the WA7697 x A9622 was susceptible, and the F_5 progeny of the population were mostly resistant. The parents and F_1 used here were recreated using new source of seed and this could be one of the reasons for the observed results from the F_5 to be different from the expected results based on the F_1 reaction to PST-23. Testing the F_2 of the newly created F_1 used in this experiment with race PST23 will clarify the F_5 results of the population. One other probable reason for susceptibility of the F_1 is epistatic interaction. The resistance in this population may be due to recessive gene. In the other population A96330 had a resistant and intermediate reaction to PST-23 but the F_1 was resistant and hence the population was not screened for seedling resistance with PST-23.

Race PST-37 caused a susceptible reaction on WA7697 and a resistant reaction on A9622. The F_1 of WA7697 x A9622 had an intermediate IT. The progenies were skewed towards resistance due to different genes contributed from both parents. In the WA7697 x A96330 population A96330 had an intermediate reaction for PST-37 and the F_1 of this population was resistant.

Since seedling resistance is expressed at all stages, the field tests evaluated both seedling and high temperature adult plant resistance. Most of the progenies were resistant to stripe rust in the field in all environments. At the Central Ferry and Mt. Vernon locations during 2003 a susceptible reaction was observed. The environment at Mt. Vernon with cool temperatures and high humidity is considered conducive for stripe rust development and multiple cycles of infection occur during the growing season. The ratio of resistant to susceptible progenies for the populations WA7697 x A96330 and WA7697 x A9622 at Mt. Vernon was 221:14 and 249:5 respectively. Chi-square tests indicate that segregation ratio follows the four gene model with dominance at $P=0.05$. The susceptible progenies were only observed at Mt. Vernon location and we cannot confirm this ratio at the Spillman Farm and Central Ferry locations due to different races present at these locations as compared to Mt. Vernon. Larger population sizes will provide better estimates and help verify the number of genes segregating

In conclusion a total of 93 (Table3) progenies from the two populations were selected for further agronomic characterization and advancement towards cultivar development and as a germplasm source highly effective for stripe rust resistance. By combining both adult and seedling resistance genes plants will have higher level and durable resistance (Chen and Line, 1995a; Chen and Line, 1995b).

Future Work

The 93 progenies identified are an important source of stripe rust resistance. Of the identified seedling genes only *Yr5* and *Yr15* remain resistant to all currently known races of stripe rust in the US. They are currently being used in wheat breeding programs and new sources of resistance are needed. Neither of the populations used in this study carry *Yr5* and *Yr15*. The best genotypes will be identified from the 93 progenies; the selected progeny will then be crossed and backcrossed to the susceptible genotype PS-279 in order to identify the number of stripe rust resistant genes present. The genes present in the genotypes will be identified by testing the genotypes with different virulent races and by complementation tests to differentials carrying single genes present in the pedigrees of both crosses..

References:

Allan, R.E., C.J. Peterson, Jr., R.F. Line, G.L. Rubenthaler, and C.F. Morris. 1993. Registration of 'Rely' wheat multiline. Crop Science 33:213-214.

Allan, R.E. and L.H. Purdy, 1967. Single gene control of stripe rust resistance in wheat. The Plant Disease Reporter 51:1041-1043.

Chen, X.M, and R.F. Line. 1992a. Identification of stripe rust resistance genes in wheat genotypes used to differentiate North American races of *Puccinia striiformis*. Phytopathology 82:1428-1434.

Chen, X.M, and R.F. Line. 1992b. Inheritance of stripe rust resistance in wheat cultivars used to differentiate races of *Puccinia striiformis* in North America. Phytopathology 82:633-637.

Chen, X.M., and R.F. Line. 1995a. Gene action in wheat cultivars for durable high-temperature adult-plant resistance and interactions with race-specific, seedling resistance to stripe rust caused by *Puccinia striiformis*. Phytopathology 85:382-388.

Chen, X.M., and R.F. Line. 1995b. Gene number and heritability of wheat cultivars with durable, high-temperature, adult-plant resistance and race specific resistance to *Puccinia striiformi*s. Phytopathology 85:573-578.

Chen, X.M., Line, R.F., Shi, Z. X., and H. Leung, 1998. Genetics of wheat resistance to stripe rust 9th International Wheat Genetics Symposium, Saskatoon, Saskatchewan, Canada. August 2-7. University Extension Press. 3:237-239.

Chen, X.M., Milus, E.A., Long, D.L., and L.F. Jackson, 2004. Impact of wheat stripe rust and races of *Puccinia striiformis f. sp. tritici* in the United States. 11th International Cereal Rusts and Powdery Mildew Conference, Norwich, UK. July 22-26. A2.11.

Chen, X.M. 2005. Epidemiology and control of stripe rust [*Puccinia striiformis* f. sp. *tritici*] on wheat. Canadian Journal of Plant Pathology 27: 314-37.

Knott, D.R. 1989. The Wheat Rusts-breeding for resistance. Springer Verlag : Germany.

Line, R.F., and Abdul Qayoum. 1992 Virulence, Aggressiveness, evolution and distribution of races of *Puccinia striiformis* (the cause of stripe rust of wheat) in North America, 1968-87. U.S. Department of Agriculture Technical Bulletin No.1788, pp 6, 10.

Line, R.F., and X.M Chen. 1995. Successes in breeding for and managing durable resistance to wheat rusts. Plant Disease 79:1254-1255.

Lupton, F.G.H., and R.C.F. Macer 1962. Inheritance of resistance to yellow rust (*Puccinia glumarum* Erikss & Henn) in seven varieties of wheat. Transactions of British Mycological Society 45:21-45.

McIntosh, R.A., Hart G.E., Devos, K.M., Gale M.D., and W.J. Rogers, (ed.) 1998. Catalogue of gene symbols for wheat, Vol. 5, pp. 1-1-235. University Extension Press, Saskatoon, Saskatchewan, Canada.

Wellings, C.R., and R.A. McIntosh. 1990. *Puccinia striiformis* f.sp. *tritici* in Australasia: pathogenic changes during the first 10 years. Plant Pathology 39:316-325.

Table1: Infection types of parents and F_1s of test populations to diverse races of *Puccinia striiformis* f.sp. *tritici* in the greenhouse from one replicate.

Genotypes	**PST-3**	**PST-8**	**PST-17**	**PST-20**	**PST-21**	**PST-23**
WA7697	2	1	2	1	0	7
A9622	0	1	1	1	0	0
A96330	1	1	5	2	0	2,5
F1(WA7697 x A9622)	2	1	2	1	0	8
F1(WA7697 x A96330)	1	-	1	1	0	1
Nugaines	8	8	8	8	8	8
Genotypes	**PST-25**	**PST-29**	**PST-35**	**PST-37**	**PST-41**	**PST-43**
WA7697	0	0	5	8	2	0
A9622	0	0	3	1	0	0
A96330	0	0	1	5	0	0
F1(WA7697 x A9622)	4	2	3	5	2	0
F1(WA7697 x A96330)	0	0	1	2	1	0
Nugaines	8	8	8	8	8	8
Genotypes	**PST-45**	**PST-74**	**PST-77**	**PST-78**	**PST-84**	**PST-89**
WA7697	0	5	4	0	5	2
A9622	0	1	0	0	0	0
A96330	0	5	2,4	1	3	1
F1(WA7697 x A9622)	0	5	4	0	5	2
F1(WA7697 x A96330)	0	0	0	0	2	0
Nugaines	8	8	8	8	8	8
Genotypes	**PST-95**	**PST-96**	**PST-97**			
WA7697	5,2	2	1			
A9622	0	2	0			
A96330	1,4	5	1			
F1(WA7697 x A9622)	5	5	0			
F1(WA7697 x A96330)	1	2	0			
Nugaines	8	8	8			

Footnote: Disease reaction rated as infection type on a 0-9 scale (Line and Qayoum, 1992) where 0 is resistant and 9 is susceptible.

Table2: Races of *Puccinia Striiformis* f.sp.*tritici* used to evaluate seedling resistance of parents and F_1s and their virulence formula based on the wheat differentials used to differentiate the races.

Races	Virulence formula
PST-3	Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*) (1)
PST-8	Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*), Yamhill (*Yr2*,*Yr4a*, *YrYam*)
PST-17	Chinese 166 (*Yr1*), Lee (*Yr7*, *Yr22*, *Yr23*), Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*), Yamhill (*Yr2*, *Yr4a*, *YrYam*)
PST-20	Lemhi (*Yr21*), Druchamp (*Yr3a*, *YrD*, *YrDru*), Produra (*YrPr1*, *YrPr2*), Stephens (*Yr3a*, *YrS*, *YrSte*), Fielder (*Yr6*, *Yr20*)
PST-21	Chinese 166 (*Yr1*)
PST-23	Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*), Druchamp (*Yr3a*, *YrD*, *YrDru*), Yamhill (*Yr2*,*Yr4a*, *YrYam*), Stephens (*Yr3a*, *YrS*, *YrSte*)
PST-25	Heines VII (*Yr2*, *YrHVII*), Lemhi (*Yr21*), Druchamp (*Yr3a*, *YrD*, *YrDru*), Produra (*YrPr1*, *YrPr2*) Stephens (*Yr3a*, *YrS*, *YrSte*), Fielder (*Yr6*, *Yr20*) Yamhill (*Yr2*,*Yr4a*, *YrYam*)
PST-29	Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*), Moro (*Yr10*, *YrMor*), Paha (*YrPa1*, *YrPa2*, *YrPa3*)
PST-35	Lemhi (*Yr21*), Stephens (*Yr3a*, *YrS*, *YrSte*)
PST-37	Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*), Druchamp (*Yr3a*, *YrD*, *YrDru*), Produra (*YrPr1*, *YrPr2*), Yamhill (*Yr2*,*Yr4a*, *YrYam*), Stephens (*Yr3a*, *YrS*, *YrSte*), Lee (*Yr7*, *Yr22*, *Yr23*), Fielder (*Yr6*, *Yr20*)
PST-41	Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*), Moro (*Yr10*, *YrMor*), Tres (*YrTr1*, *YrTr2*)
PST-43	Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*), Moro (*Yr10*, *YrMor*), Paha (*YrPa1*, *YrPa2*, *YrPa3*), Fielder (*Yr6*, *Yr20*), Tres (*YrTr1*, *YrTr2*)
PST-45	Hyak (*Yr17*,*YrTye*) Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*), Fielder (*Yr6*, *Yr20*), Tyee (*YrTye*)
PST-74	Lemhi (*Yr21*), Produra (*YrPr1*, *YrPr2*), Stephens (*Yr3a*, *YrS*, *YrSte*), Fielder (*Yr6*, *Yr20*),*Yr8*, *Yr9*, Clement (*Yr9 YrCle*)
PST-77	Lemhi (*Yr21*), Lee (*Yr7*, *Yr22*, *Yr23*), Fielder (*Yr6*, *Yr20*), *Yr8*, *Yr9*, Clement (Yr9, *YrCle*), Compair (*Yr8*, *Yr19*)
PST-78	Lemhi (*Yr21*), Lee (*Yr7*, *Yr22*, *Yr23*), Fielder (*Yr6*, *Yr20*), *Yr8*, *Yr9*, Clement (Yr9, *YrCle*), Compair (*Yr8*, *Yr19*) Heines VII (*Yr2*, *YrHVII*)
PST-84	Lemhi (*Yr21*), Produra (*YrPr1*, *YrPr2*), Stephens (*Yr3a*, *YrS*, *YrSte*), Fielder (*Yr6*, *Yr20*), *Yr9*
PST-89	Lemhi (*Yr21*), Fielder (*Yr6*, *Yr20*), Express (unknown),*Yr8*, *Yr9*, Clement (*Yr9*, *YrCle*),Compair (*Yr8*, *Yr19*)
PST-95	Lemhi (*Yr21*), Moro (*Yr10*, *YrMor*), Produra (*YrPr1*, *YrPr2*), Stephens (*Yr3a*, *YrS*, *YrSte*), Fielder (*Yr6*, *Yr20*), Tres (*YrTr1*, *YrTr2*)
PST-96	Lemhi (*Yr21*), Moro (*Yr10*, *YrMor*), Produra (*YrPr1*, *YrPr2*), Stephens (*Yr3a*, *YrS*, *YrSte*), Fielder (*Yr6*, *Yr20*), Tres (*YrTr1*, *YrTr2*), Druchamp (*Yr3a*, *YrD*, *YrDru*)
PST-97	Lemhi (*Yr21*), Lee (*Yr7*, *Yr22*, *Yr23*), Fielder (*Yr6*, *Yr20*), *Yr8*, *Yr9*, Clement (*Yr9*, *YrCle*),Compair (*Yr8*, *Yr19*), Heines VII (*Yr2*, *YrHVII*) Stephens (*Yr3a*, *YrS*, *YrSte*)

Footnote: (1) Differential genotype name is followed by gene name in parenthesis.

Table3: List of progenies selected as stripe rust resistanct in the winter wheat populations WA7697 x A96330 and WA7697 x A9622 ($F_{3:6}$)

No.	**Pedigree**	**Plot Number.**	**Progeny number**
1	WA7697 x A96330	19008	92
2	WA7697 x A96330	19009	255
3	WA7697 x A96330	19015	312
4	WA7697 x A96330	19023	47
5	WA7697 x A96330	19027	172
6	WA7697 x A96330	19032	165
7	WA7697 x A96330	19033	314
8	WA7697 x A96330	19036	226
9	WA7697 x A96330	19046	137
10	WA7697 x A96330	19048	109
11	WA7697 x A96330	19051	296
12	WA7697 x A96330	19054	166
13	WA7697 x A96330	19056	178
14	WA7697 x A96330	19062	238
15	WA7697 x A96330	19067	138
16	WA7697 x A96330	19076	326
17	WA7697 x A96330	19085	81
18	WA7697 x A96330	19092	119
19	WA7697 x A96330	19094	301
20	WA7697 x A96330	19096	281
21	WA7697 x A96330	19100	309
22	WA7697 x A96330	19113	266
23	WA7697 x A96330	19121	337
24	WA7697 x A96330	19126	225
25	WA7697 x A96330	19131	5
26	WA7697 x A96330	19144	306
27	WA7697 x A96330	19149	269
28	WA7697 x A96330	19167	319
29	WA7697 x A96330	19171	232
30	WA7697 x A96330	19172	87
31	WA7697 x A96330	19175	61
32	WA7697 x A96330	19177	25
33	WA7697 x A96330	19178	260
34	WA7697 x A96330	19195	139
35	WA7697 x A96330	19202	136
36	WA7697 x A96330	19203	160
37	WA7697 x A96330	19210	350
38	WA7697 x A96330	19212	122
39	WA7697 x A96330	19219	222
40	WA7697 x A96330	19222	143
41	WA7697 x A96330	19226	210

Table3: List of progenies selected as stripe rust resistant in the winter wheat populations WA7697 x A96330 and WA7697 x A9622 ($F_{3:6}$)

No.	**Pedigree**	**Plot Number**	**Progeny number**
42	WA7697 x A96330	19233	203
43	WA7697 x A96330	19235	84
44	WA7697 x A96330	19250	221
45	WA7697 x A96330	19251	150
46	WA7697 x A9622	19258	78
47	WA7697 x A9622	19261	33
48	WA7697 x A9622	19264	86
49	WA7697 x A9622	19270	56
50	WA7697 x A9622	19276	178
51	WA7697 x A9622	19290	18
52	WA7697 x A9622	19293	31
53	WA7697 x A9622	19297	58
54	WA7697 x A9622	19301	265
55	WA7697 x A9622	19305	41
56	WA7697 x A9622	19306	65
57	WA7697 x A9622	19314	307
58	WA7697 x A9622	19325	147
59	WA7697 x A9622	19336	14
60	WA7697 x A9622	19337	260
61	WA7697 x A9622	19342	112
62	WA7697 x A9622	19348	311
63	WA7697 x A9622	19363	239
64	WA7697 x A9622	19365	66
65	WA7697 x A9622	19366	50
66	WA7697 x A9622	19371	39
67	WA7697 x A9622	19375	168
68	WA7697 x A9622	19378	45
69	WA7697 x A9622	19380	295
70	WA7697 x A9622	19383	149
71	WA7697 x A9622	19407	195
72	WA7697 x A9622	19412	111
73	WA7697 x A9622	19423	204
74	WA7697 x A9622	19428	197
75	WA7697 x A9622	19442	259
76	WA7697 x A9622	19448	132
77	WA7697 x A9622	19458	120
78	WA7697 x A9622	19466	157
79	WA7697 x A9622	19470	301
80	WA7697 x A9622	19472	110
81	WA7697 x A9622	19476	135
82	WA7697 x A9622	19490	304

Table3: List of progenies selected as stripe rust resistant in the winter wheat populations WA7697 x A96330 and WA7697 x A9622 ($F_{3:6}$)

No.	**Pedigree**	**Plot Number**	**Progeny number**
83	WA7697 x A9622	19492	48
84	WA7697 x A9622	19496	128
85	WA7697 x A9622	19497	221
86	WA7697 x A9622	19500	254
87	WA7697 x A9622	19504	17
88	WA7697 x A9622	19515	243
89	WA7697 x A9622	19516	208
90	WA7697 x A9622	19523	15
91	WA7697 x A9622	19527	146
92	WA7697 x A9622	19528	199
93	WA7697 x A9622	19530	148

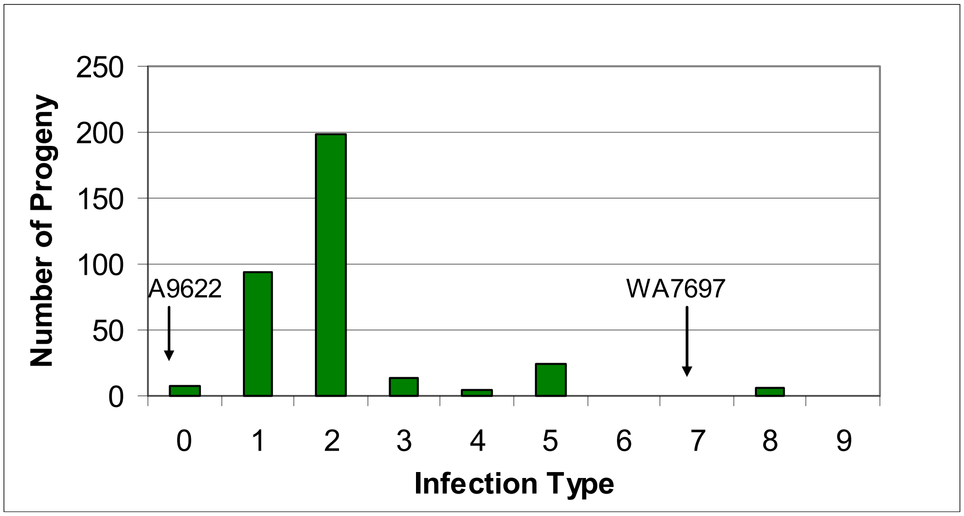


Figure 1 Frequencies of infection types on F_5 progenies of WA7697 x A9622 tested with race PST-23 of *Puccinia striiformis* f.sp. *tritici* in the seedling stage in the greenhouse.

Infection type rated on a 0-9 scale (Line and Qayoum 1992) where 0 = resistant and 9 = susceptible

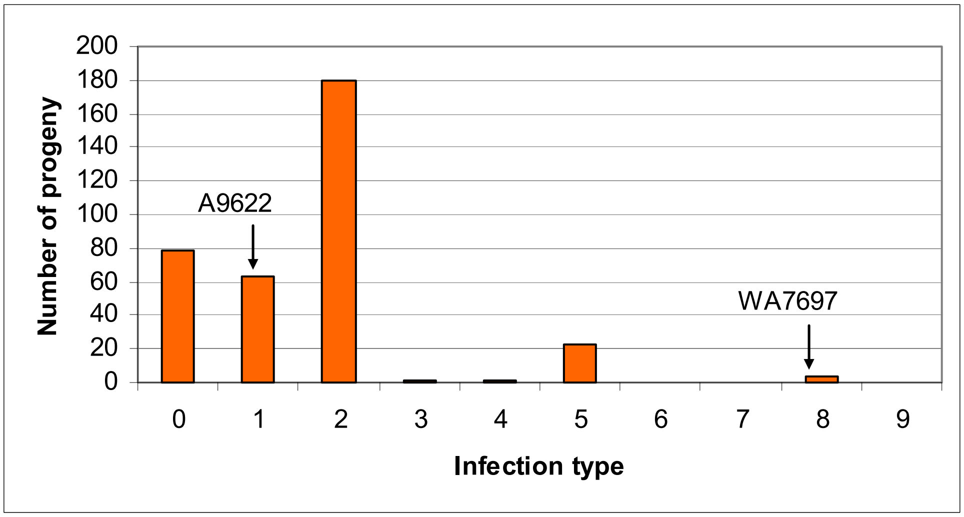


Figure 2 Frequencies of infection type on F_5 progenies of WA7697 x A9622 tested with race PST-37 of *Puccinia striiformis* f.sp. *tritici* in the seedling stage in the greenhouse

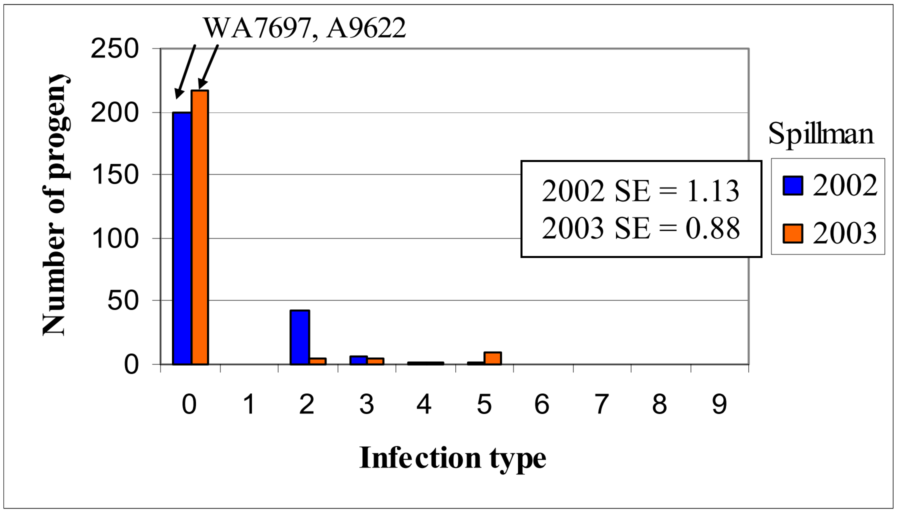


Figure 3 Frequencies of infection types of stripe rust at Spillman during 2002 and 2003 for F_3 and $F_{3:4}$ progenies of WA7697 x A9622

Infection type rated on a 0-9 scale (Line and Qayoum 1992) where 0 = resistant and 9 = susceptible. Data are the mean of three replicates over three readings per replicate taken at one week interval for three weeks beginning at stem elongation stage.

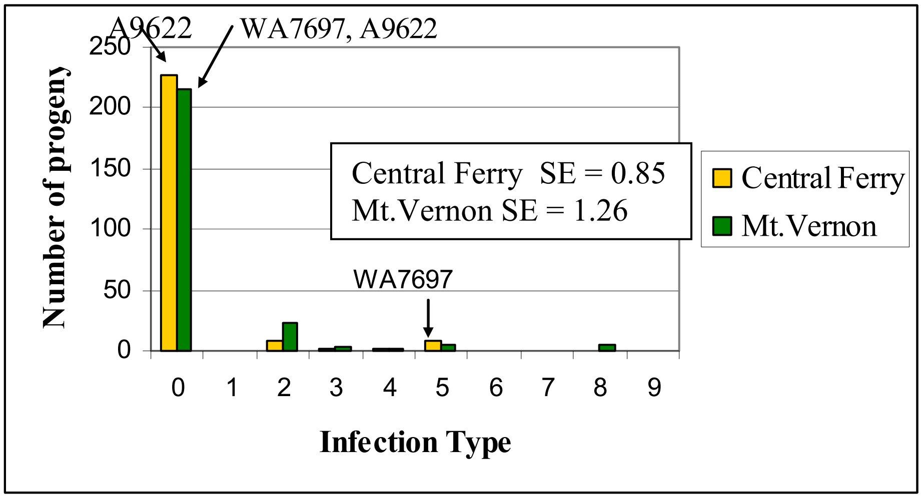


Figure 4 Frequencies of infection types of stripe rust at Central Ferry and Mt. Vernon during 2003 for $F_{3:4}$ progenies of WA7697 x A9622

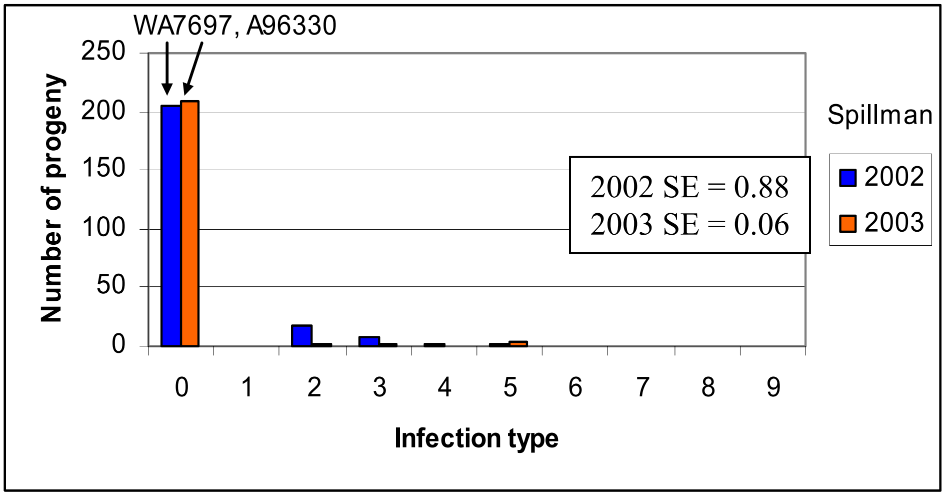


Figure 5 Frequencies of infection types of stripe rust at Spillman during 2002 and 2003 for F_3 and $F_{3:4}$ progenies of WA7697 x A96330

Infection type rated on a 0-9 scale (Line and Qayoum 1992) where 0 = resistant and 9 = susceptible. Data are the mean of three replicates over three readings per replicate taken at one week interval for three weeks beginning at stem elongation stage.

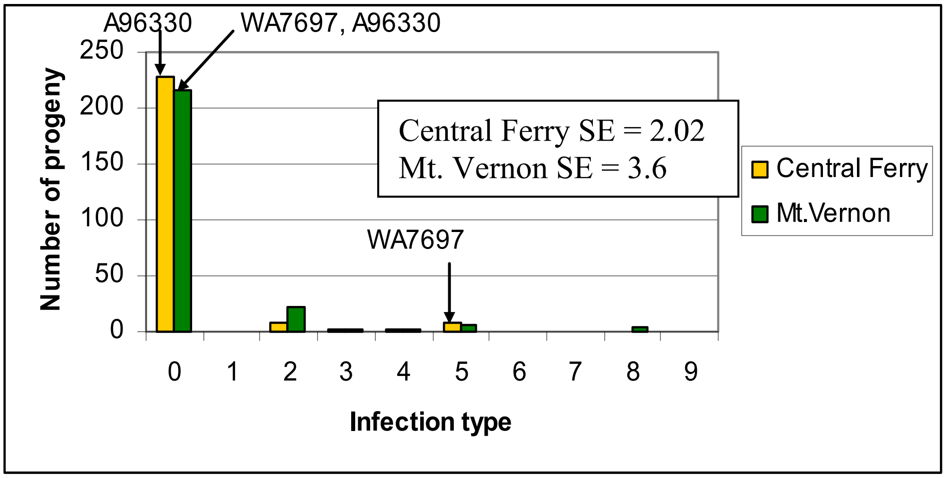


Figure 6 Frequencies of infection types of stripe rust at Central Ferry and Mt. Vernon during 2003 for $F_{3:4}$ progenies of WA7697 x A96330

INVESTIGATIONS IN WHEAT (*Triticum aestivum* L. em Thell) USING MOLECULAR AND CONVENTIONAL BREEDING TECHNIQUES FOR ABIOTIC AND BIOTIC STRESS

SUMMARY

Abiotic and biotic stresses including cold temperature and stripe rust disease cause production losses in wheat. Cold tolerance is a complex trait and has many physiological and biochemical consequences. Stripe rust is a constantly evolving pathogen that has recently become prevalent in wheat production regions throughout the US.

The goal of my research was to use molecular techniques to determine, (1) If there is any relationship between the molecular markers for *Vrn-1* genes and the cold tolerance of the Daws and Wanser Vrn-NILs, (2) To identify QTLs influencing cold tolerance and, (3) to identify genotypes with durable stripe rust resistance to the newer races of *P.striiformis*.

The molecular markers available to identify alleles at the *Vrn-A1*, *Vrn-B1* and *Vrn-D1* loci were used to evaluate the NILs that had been developed to vary at those loci. We observed that out of the five markers used for the *Vrn-A1*, *Vrn-B1* and *Vrn-D1* genes only the CAPS marker VA1-F/VA1-R was consistently diagnostic for the growth habit and cold tolerance of the Vrn-NILs varying for *Vrn-A1* allele. The markers for *Vrn-B1* and *Vrn-D1* were not reliable. Only *Vrn-A1* alleles consistently differed for cold tolerance and growth habit across genetic backgrounds. Information generated here will encourage scientists to be cautious when using these molecular markers in determining the growth habit and cold tolerance of different germplasm lines, since all the markers were not consistent with the genotypes used in this project. The cold tolerance in wheat is influenced by the *Vrn-B1* and *Vrn-D1* loci in addition to

the *Vrn-A1* locus, and these *VRN* genes probably interact with other genes in the plant providing different levels of cold tolerance in different cultivars.

In order to identify the loci involved in providing cold tolerance in wheat we have mapped SSR markers in two populations Centurk78/Norstar (winter/winter) and Z0031/2*Karl (winter/winter). Cold tolerance is influenced by vernalization and photoperiod in winter wheat. To study the effects of cold tolerance the best cross is a winter/winter wheat cross so that the major genes for vernalization and photoperiod are fixed in the two populations and we can identify the loci influencing cold tolerance. We have identified three putative QTLs in the Centurk78/Norstar population and two QTLs in the Z0031/2*Karl population which are good candidates for loci influencing cold tolerance. Since the QTLs identified on 5A in both the populations are probably in the same region as the published *Fr-A2* gene. Suggestions for future work to verify the QTLs is highlighted and will help in determining the control of cold tolerance in hexaploid wheat.

Stripe rust disease is influenced by the plant genotype, environment and the pathogen. The two breeding populations used were expected to have both high-temperature adult-plant resistance and all stage resistance. We used the progenies of the two populations WA7697 x A96330 and WA7697 x A9622 and screened them in the field and greenhouse with pathogen races and identified 93 progenies that have been resistant over several cycles of selection for stripe rust resistance. These progenies could possibly have three to four resistance genes segregating. Since the selected progenies have been resistant to the new races, further analysis of these progenies will provide information on the novelty of the resistant gene combination in these two populations. The progenies can then be used as a source of germplasm for breeding for stripe rust resistance or the progenies can be developed as cultivars.

Appendix 1 Details of the Daws and Wanser Vrn-NILs with their Entry Number, PI number and Pedigree

99 REA Entry No.	DNA label	PI numbers with Vrn gene	Entry Name	Source	Previous Pedigree
386	386	PI 639058 (*Vrn-A1a*)	92X915	97 Spr 7521-6	DAWS*2/TRIPLE DIRK D VRN1//5*DAWS
389	389	PI 639059 (*Vrn-A1a*)	92X915	97 Spr 7537-7	DAWS*2/TRIPLE DIRK D VRN1//5*DAWS
390	390	PI 639063 (*Vrn-A1b*)	92X915	98 REA 1186	DAWS*2/TRIPLE DIRK D VRN1//5*DAWS
394	394	PI 639064 (*Vrn-A1b*)	92X915	98 REA 1189	DAWS*2/TRIPLE DIRK D VRN1//5*DAWS
397	397	PI 639060 (*Vrn-A1a*)	92X916	97 Spr 7577-6	DAWS*2/TRIPLE DIRK D VRN1//5*DAWS
399	399	PI 639061 (*Vrn-A1a*)	92X916	97 Spr 7609-4	DAWS*2/TRIPLE DIRK D VRN1//5*DAWS
400	400	PI 639065 (*Vrn-A1b*)	92X916	98 REA 1191	DAWS*2/TRIPLE DIRK D VRN1//5*DAWS
403	403	PI 639066 (*Vrn-A1b*)	92X916	98 REA 1194	DAWS*2/TRIPLE DIRK D VRN1//5*DAWS
411	411	PI 639068 (*Vrn-B1a*)	92X918	97 Spr 7737-5	DAWS*2/TRIPLE DIRK B VRN2//5*DAWS
412	412	PI 639069 (*Vrn-B1a*)	92X918	97 Spr 7745-1	DAWS*2/TRIPLE DIRK B VRN2//5*DAWS
415	415	PI 639073 (*Vrn-B1b*)	92X918	98 REA 1214	DAWS*2/TRIPLE DIRK B VRN2//5*DAWS
417	417	PI 639074 (*Vrn-B1b*)	92X918	98 REA 1216	DAWS*2/TRIPLE DIRK B VRN2//5*DAWS
419	419	PI 639070 (*Vrn-B1a*)	92X919	97 Spr 7833-2	DAWS*2/TRIPLE DIRK B VRN2//5*DAWS
425	425	PI 639075 (*Vrn-B1b*)	92X919	98 REA 1222	DAWS*2/TRIPLE DIRK B VRN2//5*DAWS
427	427	PI 639071 (*Vrn-B1a*)	92X920	97 Spr 7889-7	DAWS*2/TRIPLE DIRK B VRN2//5*DAWS
431	431	PI 639076 (*Vrn-B1b*)	92X920	98 REA 1227	DAWS*2/TRIPLE DIRK B VRN2//5*DAWS
443	443	PI 639078 (*Vrn-D1a*)	92X923	97 Spr 8121-1	DAWS*2/TRIPLE DIRK E VRN3//5*DAWS
448	448	PI 639083 (*Vrn-D1b*)	92X923	98 REA 1245	DAWS*2/TRIPLE DIRK E VRN3//5*DAWS
449	449	PI 639079 (*Vrn-D1a*)	92X925	97 Spr 8297-7	DAWS*2/TRIPLE DIRK E VRN3//5*DAWS
455	455	PI 639084 (*Vrn-D1b*)	92X925	98 REA 1256	DAWS*2/TRIPLE DIRK E VRN3//5*DAWS
457	457	PI 639080 (*Vrn-D1a*)	92X926	97 Spr 8361-3	DAWS*2/TRIPLE DIRK E VRN3//5*DAWS
459	459	PI 639081 (*Vrn-D1a*)	92X926	97 Spr 8401-7	DAWS*2/TRIPLE DIRK E VRN3//5*DAWS
460	460	PI 639085 (*Vrn-D1b*)	92X926	98 REA 1260	DAWS*2/TRIPLE DIRK E VRN3//5*DAWS
462	462	PI 639086 (*Vrn-D1b*)	92X926	98 REA 1264	DAWS*2/TRIPLE DIRK E VRN3//5*DAWS
470	470	PI 639088 (*Vrn-B1a*)	92X930	97 Spr 8665-6	DAWS*2/TRIPLE DIRK F//5*DAWS
471	471	PI 639093 (*Vrn-B1b*)	92X930	98 REA 1280	DAWS*2/TRIPLE DIRK F//5*DAWS
472	472	PI 639089 (*Vrn-B1a*)	92X931	97 Spr 8721-6	DAWS*2/TRIPLE DIRK F//5*DAWS
473	473	PI 639090 (*Vrn-B1a*)	92X931	97 Spr 8737-3	DAWS*2/TRIPLE DIRK F//5*DAWS
475	475	PI 639094 (*Vrn-B1b*)	92X931	98 REA 1285	DAWS*2/TRIPLE DIRK F//5*DAWS
477	477	PI 639095 (*Vrn-B1b*)	92X931	98 REA 1288	DAWS*2/TRIPLE DIRK F//5*DAWS
484	484	PI 639091 (*Vrn-B1a*)	92X934	97 Spr 8921-5	DAWS*2/TRIPLE DIRK F//5*DAWS
488	488	PI 639096 (*Vrn-B1b*)	92X934	98 REA 1297	DAWS*2/TRIPLE DIRK F//5*DAWS
768	768	PI 638622 (*Vrn-A1a*)	92X991	97 Spr 13385-7	WNS*2/TRIPLE DIRK D VRN1//5*WNS

Appendix 1 Details of the Daws and Wanser Vrn-NILs with their Entry Number, PI number and Pedigree

99 REA	**DNA**	**PI numbers**	**Entry**		**Previous**
Entry No.	**label**	**with Vrn gene**	**Name**	**Source**	**Pedigree**
769	769	PI 638623 (*Vrn-A1a*)	92X991	97 Spr 13401-7	WNS*2/TRIPLE DIRK D VRN1//5*WNS
771	771	PI 638626 (*Vrn-A1b*)	92X991	98 REA 1620	WNS*2/TRIPLE DIRK D VRN1//5*WNS
772	772	PI 638627 (*Vrn-A1b*)	92X991	98 REA 1621	WNS*2/TRIPLE DIRK D VRN1//5*WNS
774	774	PI 638624 (*Vrn-A1a*)	92X992	97 Spr 13465-3	WNS*2/TRIPLE DIRK D VRN1//5*WNS
776	776	PI 638621 (*Vrn-A1a*)	92X992	97 Spr 13505-5	WNS*2/TRIPLE DIRK D VRN1//5*WNS
778	778	PI 638628 (*Vrn-A1b*)	92X992	98 REA 1626	WNS*2/TRIPLE DIRK D VRN1//5*WNS
779	779	PI 638629 (*Vrn-A1b*)	92X992	98 REA 1627	WNS*2/TRIPLE DIRK D VRN1//5*WNS
783	783	PI 638630 (*Vrn-B1a*)	92X995	97 Spr 13641-5	WNS*2/TRIPLE DIRK B VRN2//5*WNS
788	788	PI 638635 (*Vrn-B1b*)	92X995	98 REA 1634	WNS*2/TRIPLE DIRK B VRN2//5*WNS
790	790	PI 638631 (*Vrn-B1a*)	92X997	97 Spr 13801-1	WNS*2/TRIPLE DIRK B VRN2//5*WNS
794	794	PI 638636 (*Vrn-B1b*)	92X997	98 REA 1640	WNS*2/TRIPLE DIRK B VRN2//5*WNS
795	795	PI 638632 (*Vrn-B1a*)	92X999	97 Spr 13929-4	WNS*2/TRIPLE DIRK B VRN2//5*WNS
796	796	PI 638633 (*Vrn-B1a*)	92X999	97 Spr 13969-3	WNS*2/TRIPLE DIRK B VRN2//5*WNS
798	798	PI 638637 (*Vrn-B1b*)	92X999	98 REA 1643	WNS*2/TRIPLE DIRK B VRN2//5*WNS
800	800	PI 638638 (*Vrn-B1b*)	92X999	98 REA 1646	WNS*2/TRIPLE DIRK B VRN2//5*WNS
802	802	PI 638639 (*Vrn-D1a*)	92X1001	97 Spr 14153-3	WNS*2/TRIPLE DIRK E VRN3//5*WNS
806	806	PI 638643 (*Vrn-D1b*)	92X1001	98 REA 1652	WNS*2/TRIPLE DIRK E VRN3//5*WNS
807	807	PI 638640 (*Vrn-D1a*)	92X1002	97 Spr 14225-4	WNS*2/TRIPLE DIRK E VRN3//5*WNS
810	810	PI 638644 (*Vrn-D1b*)	92X1002	98 REA 1659	WNS*2/TRIPLE DIRK E VRN3//5*WNS
814	814	PI 638641 (*Vrn-D1a*)	92X1003	97 Spr 14281-8	WNS*2/TRIPLE DIRK E VRN3//5*WNS
816	816	PI 638642 (*Vrn-D1a*)	92X1003	97 Spr 14305-3	WNS*2/TRIPLE DIRK E VRN3//5*WNS
817	817	PI 638645 (*Vrn-D1b*)	92X1003	98 REA 1663	WNS*2/TRIPLE DIRK E VRN3//5*WNS
822	822	PI 638647 (*Vrn-D1b*)	92X1004	98 REA 1668	WNS*2/TRIPLE DIRK E VRN3//5*WNS
828	828	PI 638648 (*Vrn-B1a*)	92X1006	97 Spr 14545-4	WNS*2/TRIPLE DIRK F//5*WNS
830	830	PI 638653 (*Vrn-B1b*)	92X1006	98 REA 1680	WNS*2/TRIPLE DIRK F//5*WNS
834	834	PI 638649 (*Vrn-B1a*)	92X1007	97 Spr 14593-3	WNS*2/TRIPLE DIRK F//5*WNS
836	836	PI 638654 (*Vrn-B1b*)	92X1007	98 REA 1686	WNS*2/TRIPLE DIRK F//5*WNS
838	838	PI 638650 (*Vrn-B1a*)	92X1008	97 Spr 14665-2	WNS*2/TRIPLE DIRK F//5*WNS
844	844	PI 638655 (*Vrn-B1b*)	92X1008	98 REA 1691	WNS*2/TRIPLE DIRK F//5*WNS
848	848	PI 638651 (*Vrn-B1a*)	92X1009	97 Spr 14801-7	WNS*2/TRIPLE DIRK F//5*WNS
851	851	PI 638656 (*Vrn-B1b*)	92X1009	98 REA 1699	WNS*2/TRIPLE DIRK F//5*WNS

Appendix 2 Details of all the genotypes used for mapping cold tolerance

Plot No.	Entry No.	Entry Name	Source	Genotype ID	Cross & SSD Generation	DNA label	LT50	Mean %Survival
10001	**1**	**Centurk 78**	99 K. Simmons			centurk 78	-16.01	7.5
10002	**2**	**Norstar**	99 K. Simmons			norstar	-18.62	100
10003	**3**	**Nor/Cent78 F7**	99 K. Simmons	8363	Nor/Cent78 F7	3	-18.96	10
10004	**4**	**Nor/Cent78 F7**	99 K. Simmons	8364	Nor/Cent78 F7	4	-18.12	65
10005	**5**	**Nor/Cent78 F7**	99 K. Simmons	8365	Nor/Cent78 F7	5	-14.11	12
10006	**6**	**Nor/Cent78 F7**	99 K. Simmons	8366	Nor/Cent78 F7	6	-15.51	25
10007	**7**	**Nor/Cent78 F7**	99 K. Simmons	8367	Nor/Cent78 F7	7	-15.44	27.5
10008	**8**	**Nor/Cent78 F7**	99 K. Simmons	8368	Nor/Cent78 F7	8	-18.43	30
10009	**9**	**Nor/Cent78 F7**	99 K. Simmons	8369	Nor/Cent78 F7	9	-17.78	35
10010	**10**	**Nor/Cent78 F7**	99 K. Simmons	8370	Nor/Cent78 F7	10	-17.93	10
10011	**11**	**Nor/Cent78 F7**	99 K. Simmons	8371	Nor/Cent78 F7	11	-16.88	30
10012	**12**	**Nor/Cent78 F7**	99 K. Simmons	8372	Nor/Cent78 F7	12	-18.24	62.5
10013	**13**	**Nor/Cent78 F7**	99 K. Simmons	8373	Nor/Cent78 F7	13	-16.66	35
10014	**14**	**Nor/Cent78 F7**	99 K. Simmons	8374	Nor/Cent78 F7	14	-15.89	20
10015	**15**	**Nor/Cent78 F7**	99 K. Simmons	8375	Nor/Cent78 F7	15	-18.42	16
10016	**16**	**Nor/Cent78 F7**	99 K. Simmons	8376	Nor/Cent78 F7	16	-17.79	5
10017	**17**	**Nor/Cent78 F7**	99 K. Simmons	8377	Nor/Cent78 F7	17	-19.95	82.5
10018	**18**	**Nor/Cent78 F7**	99 K. Simmons	8378	Nor/Cent78 F7	18	-19.36	47.5
10019	**19**	**Nor/Cent78 F7**	99 K. Simmons	8379	Nor/Cent78 F7	19	-16.82	37.5
10020	**20**	**Nor/Cent78 F7**	99 K. Simmons	8380	Nor/Cent78 F7	20	-17.41	35
10021	**21**	**Nor/Cent78 F7**	99 K. Simmons	8381	Nor/Cent78 F7	21	-17.27	27.5
10022	**22**	**Nor/Cent78 F7**	99 K. Simmons	8382	Nor/Cent78 F7	22	-17.17	27.5
10023	**23**	**Nor/Cent78 F7**	99 K. Simmons	8383	Nor/Cent78 F7	23	-15.75	2.5
10024	**24**	**Nor/Cent78 F7**	99 K. Simmons	8384	Nor/Cent78 F7	24	-21.02	2.5
10025	**25**	**Nor/Cent78 F7**	99 K. Simmons	8385	Nor/Cent78 F7	25	-15.58	3.3
10026	**26**	**Nor/Cent78 F7**	99 K. Simmons	8386	Nor/Cent78 F7	26	-17.38	.
10027	**27**	**Nor/Cent78 F7**	99 K. Simmons	8387	Nor/Cent78 F7	27	-17.71	.
10028	**28**	**Nor/Cent78 F7**	99 K. Simmons	8388	Nor/Cent78 F7	28	-18.17	20
10029	**29**	**Nor/Cent78 F7**	99 K. Simmons	8389	Nor/Cent78 F7	29	-17.31	50
10030	**30**	**Nor/Cent78 F7**	99 K. Simmons	8390	Nor/Cent78 F7	30	-17.45	20

Appendix 2 Details of all the genotypes used for mapping cold tolerance

Plot No.	Entry No.	Entry Name	Source	Genotype ID	Cross & SSD Generation	DNA label	LT50	Mean %Survival
10031	**31**	**Nor/Cent78 F7**	99 K. Simmons	8393	Nor/Cent78 F7	31	-17.29	5
10032	**32**	**Nor/Cent78 F7**	99 K. Simmons	8394	Nor/Cent78 F7	32	-17.23	20
10033	**33**	**Nor/Cent78 F7**	99 K. Simmons	8395	Nor/Cent78 F7	33	-20.1	10
10034	**34**	**Nor/Cent78 F7**	99 K. Simmons	8396	Nor/Cent78 F7	34	-21.2	32.5
10035	**35**	**Nor/Cent78 F7**	99 K. Simmons	8397	Nor/Cent78 F7	35	-16.72	5
10036	**36**	**Nor/Cent78 F7**	99 K. Simmons	8398	Nor/Cent78 F7	36	-16.4	2.5
10037	**37**	**Nor/Cent78 F7**	99 K. Simmons	8399	Nor/Cent78 F7	37	-16.26	27.5
10038	**38**	**Nor/Cent78 F7**	99 K. Simmons	8400	Nor/Cent78 F7	38	-19.87	37.5
10039	**39**	**Nor/Cent78 F7**	99 K. Simmons	8401	Nor/Cent78 F7	39	-16.13	0
10040	**40**	**Nor/Cent78 F7**	99 K. Simmons	8402	Nor/Cent78 F7	40	-17.36	7.5
10041	**41**	**Nor/Cent78 F7**	99 K. Simmons	8403	Nor/Cent78 F7	41	-18.52	30
10042	**42**	**Nor/Cent78 F7**	99 K. Simmons	8404	Nor/Cent78 F7	42	-16.63	0
10043	**43**	**Nor/Cent78 F7**	99 K. Simmons	8405	Nor/Cent78 F7	43	-17.14	47.5
10044	**44**	**Nor/Cent78 F7**	99 K. Simmons	8406	Nor/Cent78 F7	44	-17.16	2.5
10045	**45**	**Nor/Cent78 F7**	99 K. Simmons	8407	Nor/Cent78 F7	45	-17.63	32.5
10046	**46**	**Nor/Cent78 F7**	99 K. Simmons	8408	Nor/Cent78 F7	46	-17.95	25
10047	**47**	**Nor/Cent78 F7**	99 K. Simmons	8409	Nor/Cent78 F7	47	-17.7	2.5
10048	**48**	**Nor/Cent78 F7**	99 K. Simmons	8410	Nor/Cent78 F7	48	-16.59	20
10049	**49**	**Nor/Cent78 F7**	99 K. Simmons	8411	Nor/Cent78 F7	49	-19.13	62.5
10050	**50**	**Nor/Cent78 F7**	99 K. Simmons	8412	Nor/Cent78 F7	50	-17.22	27.5
10051	**51**	**Nor/Cent78 F7**	99 K. Simmons	8414	Nor/Cent78 F7	51	-16.45	17.5
10052	**52**	**Nor/Cent78 F7**	99 K. Simmons	8415	Nor/Cent78 F7	52	-17.79	25
10053	**53**	**Nor/Cent78 F7**	99 K. Simmons	8416	Nor/Cent78 F7	53	-18.24	27.5
10054	**54**	**Nor/Cent78 F7**	99 K. Simmons	8417	Nor/Cent78 F7	54	-18.45	52.5
10055	**55**	**Nor/Cent78 F7**	99 K. Simmons	8418	Nor/Cent78 F7	55	-17.33	6
10056	**56**	**Nor/Cent78 F7**	99 K. Simmons	8419	Nor/Cent78 F7	56	-18.99	13.3
10057	**57**	**Nor/Cent78 F7**	99 K. Simmons	8420	Nor/Cent78 F7	57	-18.31	52.5
10058	**58**	**Nor/Cent78 F7**	99 K. Simmons	8422	Nor/Cent78 F7	58	-18.87	15
10059	**59**	**Nor/Cent78 F7**	99 K. Simmons	8424	Nor/Cent78 F7	59	-16.89	12.5
10060	**60**	**Nor/Cent78 F7**	99 K. Simmons	8425	Nor/Cent78 F7	60	-17.23	40
10061	**61**	**Nor/Cent78 F7**	99 K. Simmons	8426	Nor/Cent78 F7	61	-16.06	7.5

Appendix 2 Details of all the genotypes used for mapping cold tolerance

Plot No.	Entry No.	Entry Name	Source	Genotype ID	Cross & SSD Generation	DNA label	LT50	Mean %Survival
10062	**62**	**Nor/Cent78 F7**	99 K. Simmons	8428	Nor/Cent78 F7	62	-19.61	35
10063	**63**	**Nor/Cent78 F7**	99 K. Simmons	8429	Nor/Cent78 F7	63	-15.16	12.5
10064	**64**	**Nor/Cent78 F7**	99 K. Simmons	8430	Nor/Cent78 F7	64	-16.36	5
10065	**65**	**Nor/Cent78 F7**	99 K. Simmons	8431	Nor/Cent78 F7	65	-17.57	56.7
10066	**66**	**Nor/Cent78 F7**	99 K. Simmons	8432	Nor/Cent78 F7	66	-15.5	5
10067	**67**	**Nor/Cent78 F7**	99 K. Simmons	8433	Nor/Cent78 F7	67	-18.17	52.5
10068	**68**	**Nor/Cent78 F7**	99 K. Simmons	8434	Nor/Cent78 F7	68	-15.69	5
10069	**69**	**Nor/Cent78 F7**	99 K. Simmons	8435	Nor/Cent78 F7	69	-17.3	5
10070	**70**	**Nor/Cent78 F7**	99 K. Simmons	8436	Nor/Cent78 F7	70	-17.29	15
10071	**71**	**Nor/Cent78 F7**	99 K. Simmons	8437	Nor/Cent78 F7	71	-17.91	47.5
10072	**72**	**Nor/Cent78 F7**	99 K. Simmons	8439	Nor/Cent78 F7	72	-17.11	20
10073	**73**	**Nor/Cent78 F7**	99 K. Simmons	8440	Nor/Cent78 F7	73	-18.79	18
10074	**74**	**Nor/Cent78 F7**	99 K. Simmons	8441	Nor/Cent78 F7	74	-18.72	5
10075	**75**	**Nor/Cent78 F7**	99 K. Simmons	8444	Nor/Cent78 F7	75	-14.48	7.5
10076	**76**	**Nor/Cent78 F7**	99 K. Simmons	8446	Nor/Cent78 F7	76	-16.56	10
10077	**77**	**Nor/Cent78 F7**	99 K. Simmons	8447	Nor/Cent78 F7	77	-17.63	16.7
10078	**78**	**Nor/Cent78 F7**	99 K. Simmons	8448	Nor/Cent78 F7	78	-16.79	23.3
10079	**79**	**Nor/Cent78 F7**	99 K. Simmons	8449	Nor/Cent78 F7	79	-17.73	2.5
10080	**80**	**Nor/Cent78 F7**	99 K. Simmons	8450	Nor/Cent78 F7	80	-20.87	0
10081	**81**	**Nor/Cent78 F7**	99 K. Simmons	8451	Nor/Cent78 F7	81	-16.65	8.3
10082	**82**	**Nor/Cent78 F7**	99 K. Simmons	8452	Nor/Cent78 F7	82	-14.69	3.3
10083	**83**	**Nor/Cent78 F7**	99 K. Simmons	8453	Nor/Cent78 F7	83	-17.05	2.5
10084	**84**	**Nor/Cent78 F7**	99 K. Simmons	8455	Nor/Cent78 F7	84	-16.47	5
10085	**85**	**Nor/Cent78 F7**	99 K. Simmons	8456	Nor/Cent78 F7	85	-17.17	30
10086	**86**	**Nor/Cent78 F7**	99 K. Simmons	8458	Nor/Cent78 F7	86	-16.83	36.7
10087	**87**	**Nor/Cent78 F7**	99 K. Simmons	8459	Nor/Cent78 F7	87	-15.46	5
10088	**88**	**Nor/Cent78 F7**	99 K. Simmons	8460	Nor/Cent78 F7	88	-16.75	0
10089	**89**	**Nor/Cent78 F7**	99 K. Simmons	8461	Nor/Cent78 F7	89	-15.53	5
10090	**90**	**Nor/Cent78 F7**	99 K. Simmons	8463	Nor/Cent78 F7	90	-16.53	12
10091	**91**	**Nor/Cent78 F7**	99 K. Simmons	8464	Nor/Cent78 F7	91	-15.97	2.5
10092	**92**	**Nor/Cent78 F7**	99 K. Simmons	8465	Nor/Cent78 F7	92	-18.2	47.5

Appendix 2 Details of all the genotypes used for mapping cold tolerance

Plot	**Entry**	**Entry**		**Genotype**	**Cross & SSD**	**DNA**		**Mean**
No.	**No.**	**Name**	**Source**	**ID**	**Generation**	**label**	**LT50**	**%Survival**
10093	**93**	**Nor/Cent78 F7**	99 K. Simmons	8466	Nor/Cent78 F7	93	-16.3	2.5
10094	**94**	**Nor/Cent78 F7**	99 K. Simmons	8467	Nor/Cent78 F7	94	-15.32	.
10095	**95**	**Nor/Cent78 F7**	99 K. Simmons	8469	Nor/Cent78 F7	95	-16.68	25
10096	**96**	**Nor/Cent78 F7**	99 K. Simmons	8471	Nor/Cent78 F7	96	-16.99	20
10097	**97**	**Nor/Cent78 F7**	99 K. Simmons	8473	Nor/Cent78 F7	97	-16.08	2.5
10098	**98**	**Nor/Cent78 F7**	99 K. Simmons	8476	Nor/Cent78 F7	98	-15.94	5
10099	**99**	**Nor/Cent78 F7**	99 K. Simmons	8478	Nor/Cent78 F7	99	-16.73	.
10100	**100**	**Nor/Cent78 F7**	99 K. Simmons	8479	Nor/Cent78 F7	100	-16.69	30
10101	**101**	**Karl**	99 K. Simmons	Karl		Karl	-18.19	
		Z0031	99 K. Simmons	Z0031		Z0031	-12.43	
10102	**102**	**Z0025**	99 K. Simmons	Z0025		Z0025	.	
10103	**103**	**Z0026**	99 K. Simmons	Z0026		Z0026	.	
10104	**104**	**Z0029**	99 K. Simmons	Z0029		Z0029	.	
10105	**105**	**Z0031/2*Karl F6**	99 K. Simmons	Z1	Z0031/2*Karl F6	105	-16.19	
10106	**106**	**Z0031/2*Karl F6**	99 K. Simmons	Z3	Z0031/2*Karl F6	106	-15.16	
10107	**107**	**Z0031/2*Karl F6**	99 K. Simmons	Z4	Z0031/2*Karl F6	107	-16.89	
10108	**108**	**Z0031/2*Karl F6**	99 K. Simmons	Z6	Z0031/2*Karl F6	108	-16.02	
10109	**109**	**Z0031/2*Karl F6**	99 K. Simmons	Z7	Z0031/2*Karl F6	109	-17.91	
10110	**110**	**Z0031/2*Karl F6**	99 K. Simmons	Z8	Z0031/2*Karl F6	110	-16.49	
10111	**111**	**Z0031/2*Karl F6**	99 K. Simmons	Z9	Z0031/2*Karl F6	111	-14.25	
10112	**112**	**Z0031/2*Karl F6**	99 K. Simmons	Z10	Z0031/2*Karl F6	112	-16.92	
10113	**113**	**Z0031/2*Karl F6**	99 K. Simmons	Z11	Z0031/2*Karl F6	113	-18.39	
10114	**114**	**Z0031/2*Karl F6**	99 K. Simmons	Z12	Z0031/2*Karl F6	114	-18.12	
10115	**115**	**Z0031/2*Karl F6**	99 K. Simmons	Z13	Z0031/2*Karl F6	115	-17.15	
10116	**116**	**Z0031/2*Karl F6**	99 K. Simmons	Z14	Z0031/2*Karl F6	116	-16.33	
10117	**117**	**Z0031/2*Karl F6**	99 K. Simmons	Z16	Z0031/2*Karl F6	117	-15.05	
10118	**118**	**Z0031/2*Karl F6**	99 K. Simmons	Z17	Z0031/2*Karl F6	118	-16.34	
10119	**119**	**Z0031/2*Karl F6**	99 K. Simmons	Z18	Z0031/2*Karl F6	119	-16.47	
10120	**120**	**Z0031/2*Karl F6**	99 K. Simmons	Z20	Z0031/2*Karl F6	120	-15.99	
10121	**121**	**Z0031/2*Karl F6**	99 K. Simmons	Z21	Z0031/2*Karl F6	121	-16.51	
10122	**122**	**Z0031/2*Karl F6**	99 K. Simmons	Z22	Z0031/2*Karl F6	122	-15.1	

Appendix 2 Details of all the genotypes used for mapping cold tolerance

Plot No.	Entry No.	Entry Name	Source	Genotype ID	Cross & SSD Generation	DNA label	LT50	Mean %Survival
10123	**123**	**Z0031/2*Karl F6**	99 K. Simmons	Z23	Z0031/2*Karl F6	123	-16.94	
10124	**124**	**Z0031/2*Karl F6**	99 K. Simmons	Z24	Z0031/2*Karl F6	124	-17.69	
10125	**125**	**Z0031/2*Karl F6**	99 K. Simmons	Z26	Z0031/2*Karl F6	125	-16.08	
10126	**126**	**Z0031/2*Karl F6**	99 K. Simmons	Z27	Z0031/2*Karl F6	126	-17.23	
10127	**127**	**Z0031/2*Karl F6**	99 K. Simmons	Z28	Z0031/2*Karl F6	127	-16.53	
10128	**128**	**Z0031/2*Karl F6**	99 K. Simmons	Z29	Z0031/2*Karl F6	128	-13.32	
10129	**129**	**Z0031/2*Karl F6**	99 K. Simmons	Z30	Z0031/2*Karl F6	129	-14.5	
10130	**130**	**Z0031/2*Karl F6**	99 K. Simmons	Z31	Z0031/2*Karl F6	130	-14.02	
10131	**131**	**Z0031/2*Karl F6**	99 K. Simmons	Z32	Z0031/2*Karl F6	131	-17.47	
10132	**132**	**Z0031/2*Karl F6**	99 K. Simmons	Z34	Z0031/2*Karl F6	132	-16.01	
10133	**133**	**Z0031/2*Karl F6**	99 K. Simmons	Z35	Z0031/2*Karl F6	133	-17.18	
10134	**134**	**Z0031/2*Karl F6**	99 K. Simmons	Z36	Z0031/2*Karl F6	134	-15.28	
10135	**135**	**Z0031/2*Karl F6**	99 K. Simmons	Z37	Z0031/2*Karl F6	135	-15.03	
10136	**136**	**Z0031/2*Karl F6**	99 K. Simmons	Z38	Z0031/2*Karl F6	136	-17.18	
10137	**137**	**Z0031/2*Karl F6**	99 K. Simmons	Z40	Z0031/2*Karl F6	137	-13.97	
10138	**138**	**Z0031/2*Karl F6**	99 K. Simmons	Z41	Z0031/2*Karl F6	138	-18.49	
10139	**139**	**Z0031/2*Karl F6**	99 K. Simmons	Z42	Z0031/2*Karl F6	139	-14.42	
10140	**140**	**Z0031/2*Karl F6**	99 K. Simmons	Z43	Z0031/2*Karl F6	140	-15.27	
10141	**141**	**Z0031/2*Karl F6**	99 K. Simmons	Z44	Z0031/2*Karl F6	141	-17.62	
10142	**142**	**Z0031/2*Karl F6**	99 K. Simmons	Z45	Z0031/2*Karl F6	142	-15.71	
10143	**143**	**Z0031/2*Karl F6**	99 K. Simmons	Z46	Z0031/2*Karl F6	143	-19.23	
10144	**144**	**Z0031/2*Karl F6**	99 K. Simmons	Z47	Z0031/2*Karl F6	144	-15.05	
10145	**145**	**Z0031/2*Karl F6**	99 K. Simmons	Z48	Z0031/2*Karl F6	145	-11.76	
10146	**146**	**Z0031/2*Karl F6**	99 K. Simmons	Z49	Z0031/2*Karl F6	146	-16.62	
10147	**147**	**Z0031/2*Karl F6**	99 K. Simmons	Z50	Z0031/2*Karl F6	147	-17.39	
10148	**148**	**Z0031/2*Karl F6**	99 K. Simmons	Z51	Z0031/2*Karl F6	148	-16.98	
10149	**149**	**Z0031/2*Karl F6**	99 K. Simmons	Z53	Z0031/2*Karl F6	149	-13.4	
10150	**150**	**Z0031/2*Karl F6**	99 K. Simmons	Z54	Z0031/2*Karl F6	150	-16.01	
10151	**151**	**Z0031/2*Karl F6**	99 K. Simmons	Z55	Z0031/2*Karl F6	151	-14.26	
10152	**152**	**Z0031/2*Karl F6**	99 K. Simmons	Z56	Z0031/2*Karl F6	152	-15.3	
10153	**153**	**Z0031/2*Karl F6**	99 K. Simmons	Z58	Z0031/2*Karl F6	153	.	

Appendix 2 Details of all the genotypes used for mapping cold tolerance

Plot No.	Entry No.	Entry Name	Source	Genotype ID	Cross & SSD Generation	DNA label	LT50	Mean %Survival
10154	**154**	**Z0031/2*Karl F6**	99 K. Simmons	Z60	Z0031/2*Karl F6	154	-15.12	
10155	**155**	**Z0031/2*Karl F6**	99 K. Simmons	Z62	Z0031/2*Karl F6	155	-15.95	
10156	**156**	**Z0031/2*Karl F6**	99 K. Simmons	Z63	Z0031/2*Karl F6	156	-16.88	
10157	**157**	**Z0031/2*Karl F6**	99 K. Simmons	Z64	Z0031/2*Karl F6	157	-16.79	
10158	**158**	**Z0031/2*Karl F6**	99 K. Simmons	Z65	Z0031/2*Karl F6	158	-15.15	
10159	**159**	**Z0031/2*Karl F6**	99 K. Simmons	Z66	Z0031/2*Karl F6	159	-16.7	
10160	**160**	**Z0031/2*Karl F6**	99 K. Simmons	Z67	Z0031/2*Karl F6	160	-18.09	
10161	**161**	**Z0031/2*Karl F6**	99 K. Simmons	Z68	Z0031/2*Karl F6	161	-15.54	
10162	**162**	**Z0031/2*Karl F6**	99 K. Simmons	Z69	Z0031/2*Karl F6	162	-14.78	
10163	**163**	**Z0031/2*Karl F6**	99 K. Simmons	Z70	Z0031/2*Karl F6	163	-15.8	
10164	**164**	**Z0031/2*Karl F6**	99 K. Simmons	Z71	Z0031/2*Karl F6	164	-15.7	
10165	**165**	**Z0031/2*Karl F6**	99 K. Simmons	Z73	Z0031/2*Karl F6	165	.	
10166	**166**	**Z0031/2*Karl F6**	99 K. Simmons	Z74	Z0031/2*Karl F6	166	.	
10167	**167**	**Z0031/2*Karl F6**	99 K. Simmons	Z76	Z0031/2*Karl F6	167	-14.92	
10168	**168**	**Z0031/2*Karl F6**	99 K. Simmons	Z77	Z0031/2*Karl F6	168	-13.74	
10169	**169**	**Z0031/2*Karl F6**	99 K. Simmons	Z78	Z0031/2*Karl F6	169	-16.38	
10170	**170**	**Z0031/2*Karl F6**	99 K. Simmons	Z80	Z0031/2*Karl F6	170	-16.16	
10171	**171**	**Z0031/2*Karl F6**	99 K. Simmons	Z81	Z0031/2*Karl F6	171	-14.93	
10172	**172**	**Z0031/2*Karl F6**	99 K. Simmons	Z82	Z0031/2*Karl F6	172	-17.15	
10173	**173**	**Z0031/2*Karl F6**	99 K. Simmons	Z83	Z0031/2*Karl F6	173	.	

Appendix 3a Seedling stripe rust reaction for PST21 in Z0031/2*Karl population

Line #	**Infection type score Race tested: PST 21**				
	P1	**P2**	**P3**	**P4**	**P5**
105	0	0	0	0	0
106	0	0	0	0	0
107	.				
108	0	0	0	0	0
109	0	0	0	0	0
110	.				
111	0	0	0	0	0
112	0	0	0	0	0
113	0	0	0	0	0
114	0	0	0	0	0
115	0	0	0	0	0
116	0	0	0	0	0
117	2	0	0	0	0
118	0	0	0	0	0
119	0	0	0	0	0
120	0	0	0	0	0
121	5	0	0	0	0
122	2	2	0	0	0
123	0	0	0	0	0
124	0	0	0	0	0
125	0	0	0	0	0
126	0	0	0	0	0
127	2	0	0	0	0
128	1	0	0	0	0
129	1	0	0	0	0
130	.				
131	0	0	0	0	0
132	1	0	0	0	
133	0	0	0	0	0
134	.				
135	0	0	0	0	0
136	0	0	0	0	0
137	0	0	0	0	0
138	3	0	0	0	
139	1	1	1	1	1
140	5	2	0	0	

Appendix 3a Seedling stripe rust reaction for PST21 in Z0031/2*Karl population

Line #	**Infection type score Race tested: PST 21**				
	P1	**P2**	**P3**	**P4**	**P5**
141	1	1	1	1	1
142	1	1	1	1	1
143	.				
144	1	1	1	1	1
145	5	0	0	0	0
146	1	0	0		
147	1	1	1	1	1
148	0	0	0	0	0
149	0	0	0	0	0
150	.				
151	.				
152	.				
153	1	1	1	1	1
154	1	1	1	1	1
155	0	0	0	0	0
156	5	2	5	2	
157	1	0	0	0	
158	2	0	0	0	0
159	0	0	0	0	0
160	0	0	0	0	0
161	1	1	1	1	1
162	1	0	0		
163	0	0	0	0	0
164	0	0	0	0	0
165	0	0	0	0	0
166	0	0	0	0	0
167	0	0	0	0	0
168	0	0	0	0	0
169	1	0	0		
170	0	0	0	0	0
171	0	0	0	0	0
172	1	1	1	1	1
173	0	0	0	0	0
Karl	1	1	1	1	1
Z0031	0	0	0	0	0

Appendix 3b Seedling stripe rust reaction for PST100 in the Z0031/2*Karl population

Line #	**Infection type score Race tested: PST100**				
	P1	**P2**	**P3**	**P4**	**P5**
105	5	5	5	5	5
106	5	5	5	5	5
107	.				
108	5	5	5	5	5
109	5	5	5	5	5
110	.				
111	5	5	5	5	5
112	5	5	5	5	5
113	5	5	5	5	5
114	4	4	4	4	4
115	5	5	5	5	5
116	5	5	5	5	5
117	5	5	5	5	5
118	5	5	5	5	5
119	8	8	8	8	8
120	5	5	5	5	5
121	5	5	5	5	5
122	5	7	7	5	
123	8	8	8	8	8
124	5	5	5	5	5
125	8	8	8	8	8
126	8	8	8	8	8
127	5	5	5	5	5
128	4	4	4	4	4
129	7	7	7	7	7
130	.				
131	8	8	8	8	8
132	7	7	7	7	7
133	8	8	8	8	8
134	.				
135	5	5	5	5	5
136	5	5	5	5	5
137	5	5	5	5	5
138	8	8	8	8	8
139	8	8	8	8	8
140	5	5	5	5	5
141	5	5	5	5	5
142	5	5	5	5	5
143	.				
144	5	5	5	5	5
145	8	8	8	8	8
146	8	8	8	8	8
147	5	5	5	5	5
148	5	5	5	5	5

Appendix 3b Seedling stripe rust reaction for PST100 in the Z0031/2*Karl population

Line #	**Infection type score Race tested: PST100**				
	P1	**P2**	**P3**	**P4**	**P5**
149	8	8	8	8	8
150	.				
151	.				
152	7	7	7	7	7
153	8	8	8	8	8
154	8	8	8	8	8
155	5	5	5	5	5
156	8	8	8	8	8
157	7	7	7	7	7
158	8	8	8	8	8
159	8	8	8	8	8
160	8	8	8	8	8
161	7	7	7	7	7
162	8	8	8	8	8
163	8	8	8	8	8
164	5	5	5	5	5
165	8	8	8	8	8
166	5	5	5	5	5
167	5	5	5	5	5
168	5	5	5	5	5
169	5	5	5	5	5
170	5	5	5	5	5
171	8	8	8	8	8
172	5	5	5	5	5
173	5	5	5	5	5
Karl	.				
Z0031	5	5	5	5	5

Appendix 3c Seedling stripe rust reaction for PST21 in the Centurk78/Norstar population

Line #	**Infection type score, Race tested: PST 21**				
	P1	**P2**	**P3**	**P4**	**P5**
3	5	0	0	0	0
4	2	2	2	2	2
5	0	0	0	0	0
6	0	0	0	0	0
7	2	2	2	2	2
8	2	2	2	2	2
9	0	0	0	0	0
10	2	2	2	2	2
11	0	0	0	0	0
12	2	2	2	2	2
13	2	2	2	2	2
14	2	2	2	2	2
15	4	4	4	4	4
16	2	2	2	2	2
17	2	2	2	2	2
18	2	2	2	2	2
19	5	5	5	5	5
20	0	0	0	0	0
21	3	3	3	3	3
22	3	3	3	3	3
23	2	2	2	2	2
24	2	2	2	2	2
25	2	2	2	2	2
26	2	2	2	2	2
27	2	2	2	2	2
28	4	4	4	4	4
29	5	5	5	5	5
30	5	5	5	5	5
31	2	2	2	2	2
32	5	5	5	5	5
33	2	2	2	2	2
34	2	2	2	2	2
35	4	4	4	4	4
36	5	5	5	5	5
37	4	4	4	4	4
38	5	5	5	5	5
39	5	5	5	5	5
40	2	2	2	2	2
41	3	3	3	3	3
42	3	3	3	3	3
43	0	0	0	0	0
44	2	2	2	2	2
45	5	5	5	5	5
46	4	4	4	4	4

Appendix 3c Seedling stripe rust reaction for PST21 in the Centurk78/Norstar population

Line #	**Infection type score, Race tested: PST 21**				
	P1	**P2**	**P3**	**P4**	**P5**
47	2	2	2	2	2
48	5	5	5	5	5
49	2	2	2	2	2
50	4	4	4	4	4
51	5	5	5	5	5
52	0	0	0	0	0
53	2	2	2	2	2
54	2	2	2	2	2
55	2	2	2	2	2
56	4	4	4	4	4
57	5	5	5	5	5
58	0	0	0	0	0
59	0	0	0	0	0
60	2	2	2	2	2
61	3	3	3	3	3
62	2	2	2	2	2
63	2	2	2	2	2
64	3	3	3	3	3
65	2	2	2	2	2
66	0	0	0	0	0
67	0	0	0	0	0
68	3	3	3	3	3
69	2	2	2	2	2
70	0	0	0	0	0
71	5	5	5	5	5
72	0	0	0	0	0
73	2	2	2	2	2
74	5	5	5	5	5
75	3	3	3	3	3
76	0	0	0	0	0
77	2	2	2	2	2
78	4	4	4	4	4
79	5	5	5	5	5
80	5	5	5	5	5
81	0	0	0	0	0
82	2	2	2	2	2
83	0	0	0	0	0
84	0	0	0	0	0
85	0	0	0	0	0
86	0	0	0	0	0
87	5	5	5	5	5
88	3	3	3	3	3
89	2	2	2	2	2
90	5	5	5	5	5

Appendix 3c Seedling stripe rust reaction for PST21 in the Centurk78/Norstar population

Line #	**Infection type score, Race tested: PST 21**				
	P1	**P2**	**P3**	**P4**	**P5**
91	3	3	3	3	3
92	2	2	2	2	2
93	0	0	0	0	0
94	5	5	5	5	5
95	0	0	0	0	0
96	4	4	4	4	4
97	0	0	0	0	0
98	0	0	0	0	0
99	0	0	0	0	0
100	2	2	2	2	2
101	5	5	5	5	5
102	5	5	5	5	5
Norstar	2	2	2	2	2
Centruk78	5	5	5	5	5

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
1	**5**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
2	**10**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
3	**18**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
4	**25**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
5	**29**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
6	**30**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
7	**31**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
8	**32**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
9	**33**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
10	**40**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
11	**44**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
12	**47**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
13	**48**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
14	**51**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
15	**53**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
16	**54**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
17	**55**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
18	**56**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
19	**57**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
20	**60**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
21	**61**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
22	**63**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
23	**64**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
24	**65**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
25	**68**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
26	**69**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
27	**70**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
28	**71**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
29	**78**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
30	**79**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
31	**80**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
32	**81**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
33	**82**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
34	**83**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
35	**84**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
36	**86**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
37	**87**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
38	**89**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
39	**90**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
40	**91**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
41	**92**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
42	**94**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
43	**95**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
44	**96**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
45	**97**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
46	**98**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
47	**100**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
48	**101**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
49	**102**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
50	**104**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
51	**105**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
52	**108**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
53	**109**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
54	**111**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
55	**112**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
56	**114**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
57	**115**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
58	**116**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
59	**117**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
60	**118**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
61	**119**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
62	**121**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
63	**122**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
64	**123**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
65	**124**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
66	**127**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
67	**130**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
68	**133**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
69	**134**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
70	**135**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
71	**136**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
72	**137**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
73	**138**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
74	**139**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
75	**140**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
76	**141**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
77	**143**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
78	**144**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
79	**148**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
80	**149**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
81	**150**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
82	**151**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
83	**154**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
84	**157**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
85	**158**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
86	**159**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
87	**160**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
88	**164**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
89	**165**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
90	**166**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
91	**168**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
92	**170**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
93	**172**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
94	**175**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
95	**176**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
96	**177**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
97	**178**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
98	**179**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
99	**182**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
100	**183**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
101	**187**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
102	**188**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
103	**190**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
104	**192**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
105	**194**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
106	**195**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
107	**196**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
108	**201**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
109	**202**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
110	**203**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
111	**204**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
112	**205**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
113	**206**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
114	**209**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
115	**210**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
116	**221**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
117	**222**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
118	**225**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
119	**226**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
120	**227**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
121	**228**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
122	**229**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
123	**230**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
124	**231**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
125	**232**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
126	**233**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
127	**234**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
128	**235**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
129	**236**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
130	**238**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
131	**239**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
132	**240**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
133	**241**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
134	**242**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
135	**243**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
136	**244**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
137	**245**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
138	**246**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
139	**247**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
140	**248**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
141	**249**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
142	**251**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
143	**252**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
144	**253**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
145	**254**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
146	**255**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
147	**256**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
148	**257**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
149	**258**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
150	**260**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
151	**261**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
152	**262**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
153	**263**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
154	**264**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
155	**265**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
156	**266**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
157	**267**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
158	**268**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
159	**269**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
160	**270**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
161	**271**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
162	**272**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
163	**273**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
164	**274**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
165	**275**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
166	**276**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
167	**277**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
168	**278**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
169	**279**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
170	**281**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
171	**282**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
172	**283**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
173	**284**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
174	**285**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
175	**286**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
176	**287**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
177	**288**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
178	**289**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
179	**290**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
180	**291**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
181	**292**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
182	**293**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
183	**294**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
184	**295**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
185	**296**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
186	**297**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
187	**298**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
188	**299**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
189	**300**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
190	**301**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
191	**302**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
192	**305**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
193	**306**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
194	**308**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
195	**309**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
196	**310**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
197	**311**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
198	**312**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
199	**313**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
200	**314**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
201	**316**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
202	**317**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
203	**318**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
204	**319**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
205	**320**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
206	**322**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
207	**323**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
208	**324**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
209	**325**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
210	**326**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
211	**327**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
212	**329**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
213	**330**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
214	**331**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
215	**334**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
216	**335**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
217	**337**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
218	**338**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
219	**340**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
220	**341**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
221	**344**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
222	**346**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
223	**348**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
224	**349**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
225	**350**	**97X358**	WA7697/A96330	WA7697//MADSEN/WA6910
226	**1**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
227	**2**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
228	**3**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
229	**4**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
230	**5**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
231	**6**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
232	**8**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
233	**9**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
234	**10**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
235	**11**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
236	**12**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
237	**14**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
238	**15**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
239	**16**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
240	**17**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
241	**18**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
242	**19**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
243	**20**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
244	**21**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
245	**22**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
246	**23**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
247	**24**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
248	**25**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
249	**26**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
250	**27**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
251	**28**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
252	**29**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
253	**30**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
254	**31**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
255	**32**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
256	**33**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
257	**34**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
258	**35**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
259	**36**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
260	**37**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
261	**38**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
262	**39**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
263	**40**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
264	**41**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
265	**42**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
266	**43**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
267	**44**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
268	**45**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
269	**46**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
270	**48**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
271	**49**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
272	**50**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
273	**51**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
274	**52**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
275	**53**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
276	**54**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
277	**55**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
278	**56**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
279	**57**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
280	**58**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
281	**59**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
282	**60**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
283	**61**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
284	**63**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
285	**65**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
286	**66**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
287	**67**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
288	**68**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
289	**70**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
290	**71**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
291	**72**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
292	**75**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
293	**76**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
294	**77**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
295	**78**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
296	**79**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
297	**80**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
298	**82**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
299	**83**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
300	**84**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
301	**85**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
302	**86**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
303	**87**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
304	**88**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
305	**90**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
306	**91**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
307	**94**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
308	**95**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
309	**96**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
310	**97**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
311	**98**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
312	**99**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
313	**100**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
314	**106**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
315	**107**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
316	**108**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
317	**109**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
318	**110**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
319	**111**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
320	**112**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
321	**113**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
322	**114**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
323	**115**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
324	**117**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
325	**118**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
326	**120**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
327	**121**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
328	**122**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
329	**123**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
330	**124**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
331	**125**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
332	**126**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
333	**127**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
334	**128**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
335	**129**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
336	**130**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
337	**132**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
338	**133**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
339	**134**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
340	**135**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
341	**136**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
342	**137**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
343	**139**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
344	**140**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
345	**141**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
346	**142**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
347	**143**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
348	**144**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
349	**145**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
350	**146**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
351	**147**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
352	**148**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
353	149	97X230	WA7697/A9622	WA7697//WA7665/RULO
354	150	97X230	WA7697/A9622	WA7697//WA7665/RULO
355	151	97X230	WA7697/A9622	WA7697//WA7665/RULO
356	154	97X230	WA7697/A9622	WA7697//WA7665/RULO
357	155	97X230	WA7697/A9622	WA7697//WA7665/RULO
358	157	97X230	WA7697/A9622	WA7697//WA7665/RULO
359	158	97X230	WA7697/A9622	WA7697//WA7665/RULO
360	159	97X230	WA7697/A9622	WA7697//WA7665/RULO
361	162	97X230	WA7697/A9622	WA7697//WA7665/RULO
362	163	97X230	WA7697/A9622	WA7697//WA7665/RULO
363	166	97X230	WA7697/A9622	WA7697//WA7665/RULO
364	168	97X230	WA7697/A9622	WA7697//WA7665/RULO
365	169	97X230	WA7697/A9622	WA7697//WA7665/RULO
366	170	97X230	WA7697/A9622	WA7697//WA7665/RULO
367	172	97X230	WA7697/A9622	WA7697//WA7665/RULO
368	174	97X230	WA7697/A9622	WA7697//WA7665/RULO
369	175	97X230	WA7697/A9622	WA7697//WA7665/RULO
370	178	97X230	WA7697/A9622	WA7697//WA7665/RULO
371	179	97X230	WA7697/A9622	WA7697//WA7665/RULO
372	180	97X230	WA7697/A9622	WA7697//WA7665/RULO
373	181	97X230	WA7697/A9622	WA7697//WA7665/RULO
374	185	97X230	WA7697/A9622	WA7697//WA7665/RULO
375	186	97X230	WA7697/A9622	WA7697//WA7665/RULO
376	187	97X230	WA7697/A9622	WA7697//WA7665/RULO
377	188	97X230	WA7697/A9622	WA7697//WA7665/RULO
378	189	97X230	WA7697/A9622	WA7697//WA7665/RULO
379	190	97X230	WA7697/A9622	WA7697//WA7665/RULO
380	191	97X230	WA7697/A9622	WA7697//WA7665/RULO
381	193	97X230	WA7697/A9622	WA7697//WA7665/RULO
382	195	97X230	WA7697/A9622	WA7697//WA7665/RULO
383	196	97X230	WA7697/A9622	WA7697//WA7665/RULO
384	197	97X230	WA7697/A9622	WA7697//WA7665/RULO
385	198	97X230	WA7697/A9622	WA7697//WA7665/RULO
386	199	97X230	WA7697/A9622	WA7697//WA7665/RULO
387	200	97X230	WA7697/A9622	WA7697//WA7665/RULO
388	202	97X230	WA7697/A9622	WA7697//WA7665/RULO
389	203	97X230	WA7697/A9622	WA7697//WA7665/RULO
390	204	97X230	WA7697/A9622	WA7697//WA7665/RULO
391	206	97X230	WA7697/A9622	WA7697//WA7665/RULO
392	207	97X230	WA7697/A9622	WA7697//WA7665/RULO
393	208	97X230	WA7697/A9622	WA7697//WA7665/RULO
394	209	97X230	WA7697/A9622	WA7697//WA7665/RULO
395	211	97X230	WA7697/A9622	WA7697//WA7665/RULO
396	212	97X230	WA7697/A9622	WA7697//WA7665/RULO

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
397	**214**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
398	**215**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
399	**217**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
400	**218**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
401	**220**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
402	**221**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
403	**222**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
404	**223**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
405	**224**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
406	**225**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
407	**228**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
408	**229**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
409	**230**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
410	**232**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
411	**233**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
412	**234**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
413	**237**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
414	**239**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
415	**240**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
416	**241**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
417	**243**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
418	**244**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
419	**247**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
420	**248**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
421	**250**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
422	**251**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
423	**252**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
424	**254**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
425	**255**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
426	**256**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
427	**257**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
428	**259**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
429	**260**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
430	**261**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
431	**262**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
432	**263**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
433	**265**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
434	**267**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
435	**268**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
436	**269**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
437	**270**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
438	**272**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
439	**273**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
440	**274**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO

Appendix 4a Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2002.

PLOT02	ENTRY	NAME	PEDIGREE	FULL PEDIGREE
441	**276**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
442	**277**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
443	**278**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
444	**279**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
445	**280**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
446	**281**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
447	**283**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
448	**284**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
449	**285**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
450	**286**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
451	**287**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
452	**289**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
453	**292**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
454	**294**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
455	**295**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
456	**296**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
457	**298**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
458	**300**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
459	**301**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
460	**303**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
461	**304**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
462	**305**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
463	**307**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
464	**308**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
465	**311**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
466	**315**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
467	**316**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
468	**319**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
469	**320**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
470	**328**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
471	**329**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
472	**330**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
473	**332**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
474	**336**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
475	**338**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO
476	**344**	**97X230**	WA7697/A9622	WA7697//WA7665/RULO

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source No.	Pedigree	Full Pedigree	Rep
19001	**WA7697**			STEPHENS//SU92 /3*OMAR	STEPHENS//SU92/3*OMAR	1
19002	**A96330**			MDN/WA6910	84X111 VPM/M951/YMH/HYS// HILL81///WA6910	1
19003	**A9622**			WA7665/RULO	WA7665/RULO	1
19004	**Coda**	2000 WSCI		Coda	Coda	1
19005	**97X358**	2002 SR Entry#	313	WA7697/A96330	WA7697//MADSEN/WA6910	1
19006	**97X358**	2002 SR Entry#	159	WA7697/A96330	WA7697//MADSEN/WA6910	1
19007	**97X358**	2002 SR Entry#	144	WA7697/A96330	WA7697//MADSEN/WA6910	1
19008	**97X358**	2002 SR Entry#	92	WA7697/A96330	WA7697//MADSEN/WA6910	1
19009	**97X358**	2002 SR Entry#	255	WA7697/A96330	WA7697//MADSEN/WA6910	1
19010	**97X358**	2002 SR Entry#	327	WA7697/A96330	WA7697//MADSEN/WA6910	1
19011	**97X358**	2002 SR Entry#	130	WA7697/A96330	WA7697//MADSEN/WA6910	1
19012	**97X358**	2002 SR Entry#	56	WA7697/A96330	WA7697//MADSEN/WA6910	1
19013	**97X358**	2002 SR Entry#	227	WA7697/A96330	WA7697//MADSEN/WA6910	1
19014	**97X358**	2002 SR Entry#	53	WA7697/A96330	WA7697//MADSEN/WA6910	1
19015	**97X358**	2002 SR Entry#	312	WA7697/A96330	WA7697//MADSEN/WA6910	1
19016	**97X358**	2002 SR Entry#	286	WA7697/A96330	WA7697//MADSEN/WA6910	1
19017	**97X358**	2002 SR Entry#	140	WA7697/A96330	WA7697//MADSEN/WA6910	1
19018	**97X358**	2002 SR Entry#	95	WA7697/A96330	WA7697//MADSEN/WA6910	1
19019	**97X358**	2002 SR Entry#	240	WA7697/A96330	WA7697//MADSEN/WA6910	1
19020	**97X358**	2002 SR Entry#	18	WA7697/A96330	WA7697//MADSEN/WA6910	1
19021	**97X358**	2002 SR Entry#	70	WA7697/A96330	WA7697//MADSEN/WA6910	1
19022	**97X358**	2002 SR Entry#	57	WA7697/A96330	WA7697//MADSEN/WA6910	1
19023	**97X358**	2002 SR Entry#	47	WA7697/A96330	WA7697//MADSEN/WA6910	1
19024	**97X358**	2002 SR Entry#	329	WA7697/A96330	WA7697//MADSEN/WA6910	1
19025	**97X358**	2002 SR Entry#	196	WA7697/A96330	WA7697//MADSEN/WA6910	1
19026	**97X358**	2002 SR Entry#	114	WA7697/A96330	WA7697//MADSEN/WA6910	1
19027	**97X358**	2002 SR Entry#	172	WA7697/A96330	WA7697//MADSEN/WA6910	1
19028	**97X358**	2002 SR Entry#	202	WA7697/A96330	WA7697//MADSEN/WA6910	1
19029	**97X358**	2002 SR Entry#	290	WA7697/A96330	WA7697//MADSEN/WA6910	1
19030	**97X358**	2002 SR Entry#	86	WA7697/A96330	WA7697//MADSEN/WA6910	1
19031	**97X358**	2002 SR Entry#	348	WA7697/A96330	WA7697//MADSEN/WA6910	1
19032	**97X358**	2002 SR Entry#	165	WA7697/A96330	WA7697//MADSEN/WA6910	1
19033	**97X358**	2002 SR Entry#	314	WA7697/A96330	WA7697//MADSEN/WA6910	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19034	**97X358**	2002 SR Entry#	157	WA7697/A96330	WA7697//MADSEN/WA6910	1
19035	**97X358**	2002 SR Entry#	100	WA7697/A96330	WA7697//MADSEN/WA6910	1
19036	**97X358**	2002 SR Entry#	226	WA7697/A96330	WA7697//MADSEN/WA6910	1
19037	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19038	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19039	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19040	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19041	**97X358**	2002 SR Entry#	236	WA7697/A96330	WA7697//MADSEN/WA6910	1
19042	**97X358**	2002 SR Entry#	263	WA7697/A96330	WA7697//MADSEN/WA6910	1
19043	**97X358**	2002 SR Entry#	71	WA7697/A96330	WA7697//MADSEN/WA6910	1
19044	**97X358**	2002 SR Entry#	235	WA7697/A96330	WA7697//MADSEN/WA6910	1
19045	**97X358**	2002 SR Entry#	32	WA7697/A96330	WA7697//MADSEN/WA6910	1
19046	**97X358**	2002 SR Entry#	137	WA7697/A96330	WA7697//MADSEN/WA6910	1
19047	**97X358**	2002 SR Entry#	308	WA7697/A96330	WA7697//MADSEN/WA6910	1
19048	**97X358**	2002 SR Entry#	109	WA7697/A96330	WA7697//MADSEN/WA6910	1
19049	**97X358**	2002 SR Entry#	245	WA7697/A96330	WA7697//MADSEN/WA6910	1
19050	**97X358**	2002 SR Entry#	127	WA7697/A96330	WA7697//MADSEN/WA6910	1
19051	**97X358**	2002 SR Entry#	296	WA7697/A96330	WA7697//MADSEN/WA6910	1
19052	**97X358**	2002 SR Entry#	288	WA7697/A96330	WA7697//MADSEN/WA6910	1
19053	**97X358**	2002 SR Entry#	121	WA7697/A96330	WA7697//MADSEN/WA6910	1
19054	**97X358**	2002 SR Entry#	166	WA7697/A96330	WA7697//MADSEN/WA6910	1
19055	**97X358**	2002 SR Entry#	244	WA7697/A96330	WA7697//MADSEN/WA6910	1
19056	**97X358**	2002 SR Entry#	178	WA7697/A96330	WA7697//MADSEN/WA6910	1
19057	**97X358**	2002 SR Entry#	148	WA7697/A96330	WA7697//MADSEN/WA6910	1
19058	**97X358**	2002 SR Entry#	256	WA7697/A96330	WA7697//MADSEN/WA6910	1
19059	**97X358**	2002 SR Entry#	298	WA7697/A96330	WA7697//MADSEN/WA6910	1
19060	**97X358**	2002 SR Entry#	91	WA7697/A96330	WA7697//MADSEN/WA6910	1
19061	**97X358**	2002 SR Entry#	310	WA7697/A96330	WA7697//MADSEN/WA6910	1
19062	**97X358**	2002 SR Entry#	238	WA7697/A96330	WA7697//MADSEN/WA6910	1
19063	**97X358**	2002 SR Entry#	124	WA7697/A96330	WA7697//MADSEN/WA6910	1
19064	**97X358**	2002 SR Entry#	40	WA7697/A96330	WA7697//MADSEN/WA6910	1
19065	**97X358**	2002 SR Entry#	239	WA7697/A96330	WA7697//MADSEN/WA6910	1
19066	**97X358**	2002 SR Entry#	230	WA7697/A96330	WA7697//MADSEN/WA6910	1
19067	**97X358**	2002 SR Entry#	138	WA7697/A96330	WA7697//MADSEN/WA6910	1
19068	**97X358**	2002 SR Entry#	320	WA7697/A96330	WA7697//MADSEN/WA6910	1
19069	**97X358**	2002 SR Entry#	179	WA7697/A96330	WA7697//MADSEN/WA6910	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19070	**97X358**	2002 SR Entry#	248	WA7697/A96330	WA7697//MADSEN/WA6910	1
19071	**97X358**	2002 SR Entry#	273	WA7697/A96330	WA7697//MADSEN/WA6910	1
19072	**97X358**	2002 SR Entry#	117	WA7697/A96330	WA7697//MADSEN/WA6910	1
19073	**97X358**	2002 SR Entry#	277	WA7697/A96330	WA7697//MADSEN/WA6910	1
19074	**97X358**	2002 SR Entry#	297	WA7697/A96330	WA7697//MADSEN/WA6910	1
19075	**97X358**	2002 SR Entry#	176	WA7697/A96330	WA7697//MADSEN/WA6910	1
19076	**97X358**	2002 SR Entry#	326	WA7697/A96330	WA7697//MADSEN/WA6910	1
19077	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19078	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19079	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19080	**Barley**	2002 Winter		Barley	Barley	1
19081	**97X358**	2002 SR Entry#	275	WA7697/A96330	WA7697//MADSEN/WA6910	1
19082	**97X358**	2002 SR Entry#	341	WA7697/A96330	WA7697//MADSEN/WA6910	1
19083	**97X358**	2002 SR Entry#	257	WA7697/A96330	WA7697//MADSEN/WA6910	1
19084	**97X358**	2002 SR Entry#	346	WA7697/A96330	WA7697//MADSEN/WA6910	1
19085	**97X358**	2002 SR Entry#	81	WA7697/A96330	WA7697//MADSEN/WA6910	1
19086	**97X358**	2002 SR Entry#	254	WA7697/A96330	WA7697//MADSEN/WA6910	1
19087	**97X358**	2002 SR Entry#	164	WA7697/A96330	WA7697//MADSEN/WA6910	1
19088	**97X358**	2002 SR Entry#	108	WA7697/A96330	WA7697//MADSEN/WA6910	1
19089	**97X358**	2002 SR Entry#	60	WA7697/A96330	WA7697//MADSEN/WA6910	1
19090	**97X358**	2002 SR Entry#	251	WA7697/A96330	WA7697//MADSEN/WA6910	1
19091	**97X358**	2002 SR Entry#	31	WA7697/A96330	WA7697//MADSEN/WA6910	1
19092	**97X358**	2002 SR Entry#	119	WA7697/A96330	WA7697//MADSEN/WA6910	1
19093	**97X358**	2002 SR Entry#	154	WA7697/A96330	WA7697//MADSEN/WA6910	1
19094	**97X358**	2002 SR Entry#	301	WA7697/A96330	WA7697//MADSEN/WA6910	1
19095	**97X358**	2002 SR Entry#	272	WA7697/A96330	WA7697//MADSEN/WA6910	1
19096	**97X358**	2002 SR Entry#	281	WA7697/A96330	WA7697//MADSEN/WA6910	1
19097	**97X358**	2002 SR Entry#	335	WA7697/A96330	WA7697//MADSEN/WA6910	1
19098	**97X358**	2002 SR Entry#	284	WA7697/A96330	WA7697//MADSEN/WA6910	1
19099	**97X358**	2002 SR Entry#	283	WA7697/A96330	WA7697//MADSEN/WA6910	1
19100	**97X358**	2002 SR Entry#	309	WA7697/A96330	WA7697//MADSEN/WA6910	1
19101	**97X358**	2002 SR Entry#	111	WA7697/A96330	WA7697//MADSEN/WA6910	1
19102	**97X358**	2002 SR Entry#	292	WA7697/A96330	WA7697//MADSEN/WA6910	1
19103	**97X358**	2002 SR Entry#	311	WA7697/A96330	WA7697//MADSEN/WA6910	1
19104	**97X358**	2002 SR Entry#	89	WA7697/A96330	WA7697//MADSEN/WA6910	1
19105	**97X358**	2002 SR Entry#	101	WA7697/A96330	WA7697//MADSEN/WA6910	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19106	**97X358**	2002 SR Entry#	141	WA7697/A96330	WA7697//MADSEN/WA6910	1
19107	**97X358**	2002 SR Entry#	195	WA7697/A96330	WA7697//MADSEN/WA6910	1
19108	**97X358**	2002 SR Entry#	262	WA7697/A96330	WA7697//MADSEN/WA6910	1
19109	**97X358**	2002 SR Entry#	187	WA7697/A96330	WA7697//MADSEN/WA6910	1
19110	**97X358**	2002 SR Entry#	115	WA7697/A96330	WA7697//MADSEN/WA6910	1
19111	**97X358**	2002 SR Entry#	276	WA7697/A96330	WA7697//MADSEN/WA6910	1
19112	**97X358**	2002 SR Entry#	278	WA7697/A96330	WA7697//MADSEN/WA6910	1
19113	**97X358**	2002 SR Entry#	266	WA7697/A96330	WA7697//MADSEN/WA6910	1
19114	**97X358**	2002 SR Entry#	228	WA7697/A96330	WA7697//MADSEN/WA6910	1
19115	**97X358**	2002 SR Entry#	300	WA7697/A96330	WA7697//MADSEN/WA6910	1
19116	**97X358**	2002 SR Entry#	295	WA7697/A96330	WA7697//MADSEN/WA6910	1
19117	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19118	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19119	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19120	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19121	**97X358**	2002 SR Entry#	337	WA7697/A96330	WA7697//MADSEN/WA6910	1
19122	**97X358**	2002 SR Entry#	116	WA7697/A96330	WA7697//MADSEN/WA6910	1
19123	**97X358**	2002 SR Entry#	69	WA7697/A96330	WA7697//MADSEN/WA6910	1
19124	**97X358**	2002 SR Entry#	149	WA7697/A96330	WA7697//MADSEN/WA6910	1
19125	**97X358**	2002 SR Entry#	82	WA7697/A96330	WA7697//MADSEN/WA6910	1
19126	**97X358**	2002 SR Entry#	225	WA7697/A96330	WA7697//MADSEN/WA6910	1
19127	**97X358**	2002 SR Entry#	299	WA7697/A96330	WA7697//MADSEN/WA6910	1
19128	**97X358**	2002 SR Entry#	349	WA7697/A96330	WA7697//MADSEN/WA6910	1
19129	**97X358**	2002 SR Entry#	322	WA7697/A96330	WA7697//MADSEN/WA6910	1
19130	**97X358**	2002 SR Entry#	316	WA7697/A96330	WA7697//MADSEN/WA6910	1
19131	**97X358**	2002 SR Entry#	5	WA7697/A96330	WA7697//MADSEN/WA6910	1
19132	**97X358**	2002 SR Entry#	291	WA7697/A96330	WA7697//MADSEN/WA6910	1
19133	**97X358**	2002 SR Entry#	268	WA7697/A96330	WA7697//MADSEN/WA6910	1
19134	**97X358**	2002 SR Entry#	55	WA7697/A96330	WA7697//MADSEN/WA6910	1
19135	**97X358**	2002 SR Entry#	79	WA7697/A96330	WA7697//MADSEN/WA6910	1
19136	**97X358**	2002 SR Entry#	323	WA7697/A96330	WA7697//MADSEN/WA6910	1
19137	**97X358**	2002 SR Entry#	68	WA7697/A96330	WA7697//MADSEN/WA6910	1
19138	**97X358**	2002 SR Entry#	289	WA7697/A96330	WA7697//MADSEN/WA6910	1
19139	**97X358**	2002 SR Entry#	264	WA7697/A96330	WA7697//MADSEN/WA6910	1
19140	**97X358**	2002 SR Entry#	10	WA7697/A96330	WA7697//MADSEN/WA6910	1
19141	**97X358**	2002 SR Entry#	340	WA7697/A96330	WA7697//MADSEN/WA6910	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19142	**97X358**	2002 SR Entry#	188	WA7697/A96330	WA7697//MADSEN/WA6910	1
19143	**97X358**	2002 SR Entry#	204	WA7697/A96330	WA7697//MADSEN/WA6910	1
19144	**97X358**	2002 SR Entry#	306	WA7697/A96330	WA7697//MADSEN/WA6910	1
19145	**97X358**	2002 SR Entry#	158	WA7697/A96330	WA7697//MADSEN/WA6910	1
19146	**97X358**	2002 SR Entry#	175	WA7697/A96330	WA7697//MADSEN/WA6910	1
19147	**97X358**	2002 SR Entry#	331	WA7697/A96330	WA7697//MADSEN/WA6910	1
19148	**97X358**	2002 SR Entry#	330	WA7697/A96330	WA7697//MADSEN/WA6910	1
19149	**97X358**	2002 SR Entry#	269	WA7697/A96330	WA7697//MADSEN/WA6910	1
19150	**97X358**	2002 SR Entry#	168	WA7697/A96330	WA7697//MADSEN/WA6910	1
19151	**97X358**	2002 SR Entry#	249	WA7697/A96330	WA7697//MADSEN/WA6910	1
19152	**97X358**	2002 SR Entry#	274	WA7697/A96330	WA7697//MADSEN/WA6910	1
19153	**97X358**	2002 SR Entry#	267	WA7697/A96330	WA7697//MADSEN/WA6910	1
19154	**97X358**	2002 SR Entry#	96	WA7697/A96330	WA7697//MADSEN/WA6910	1
19155	**97X358**	2002 SR Entry#	177	WA7697/A96330	WA7697//MADSEN/WA6910	1
19156	**97X358**	2002 SR Entry#	118	WA7697/A96330	WA7697//MADSEN/WA6910	1
19157	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19158	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19159	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19160	**Barley**	2002 Winter		Barley	Barley	1
19161	**97X358**	2002 SR Entry#	134	WA7697/A96330	WA7697//MADSEN/WA6910	1
19162	**97X358**	2002 SR Entry#	282	WA7697/A96330	WA7697//MADSEN/WA6910	1
19163	**97X358**	2002 SR Entry#	201	WA7697/A96330	WA7697//MADSEN/WA6910	1
19164	**97X358**	2002 SR Entry#	48	WA7697/A96330	WA7697//MADSEN/WA6910	1
19165	**97X358**	2002 SR Entry#	209	WA7697/A96330	WA7697//MADSEN/WA6910	1
19166	**97X358**	2002 SR Entry#	63	WA7697/A96330	WA7697//MADSEN/WA6910	1
19167	**97X358**	2002 SR Entry#	319	WA7697/A96330	WA7697//MADSEN/WA6910	1
19168	**97X358**	2002 SR Entry#	170	WA7697/A96330	WA7697//MADSEN/WA6910	1
19169	**97X358**	2002 SR Entry#	317	WA7697/A96330	WA7697//MADSEN/WA6910	1
19170	**97X358**	2002 SR Entry#	105	WA7697/A96330	WA7697//MADSEN/WA6910	1
19171	**97X358**	2002 SR Entry#	232	WA7697/A96330	WA7697//MADSEN/WA6910	1
19172	**97X358**	2002 SR Entry#	87	WA7697/A96330	WA7697//MADSEN/WA6910	1
19173	**97X358**	2002 SR Entry#	325	WA7697/A96330	WA7697//MADSEN/WA6910	1
19174	**97X358**	2002 SR Entry#	83	WA7697/A96330	WA7697//MADSEN/WA6910	1
19175	**97X358**	2002 SR Entry#	61	WA7697/A96330	WA7697//MADSEN/WA6910	1
19176	**97X358**	2002 SR Entry#	344	WA7697/A96330	WA7697//MADSEN/WA6910	1
19177	**97X358**	2002 SR Entry#	25	WA7697/A96330	WA7697//MADSEN/WA6910	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19178	**97X358**	2002 SR Entry#	260	WA7697/A96330	WA7697//MADSEN/WA6910	1
19179	**97X358**	2002 SR Entry#	33	WA7697/A96330	WA7697//MADSEN/WA6910	1
19180	**97X358**	2002 SR Entry#	285	WA7697/A96330	WA7697//MADSEN/WA6910	1
19181	**97X358**	2002 SR Entry#	261	WA7697/A96330	WA7697//MADSEN/WA6910	1
19182	**97X358**	2002 SR Entry#	229	WA7697/A96330	WA7697//MADSEN/WA6910	1
19183	**97X358**	2002 SR Entry#	112	WA7697/A96330	WA7697//MADSEN/WA6910	1
19184	**97X358**	2002 SR Entry#	233	WA7697/A96330	WA7697//MADSEN/WA6910	1
19185	**97X358**	2002 SR Entry#	247	WA7697/A96330	WA7697//MADSEN/WA6910	1
19186	**97X358**	2002 SR Entry#	192	WA7697/A96330	WA7697//MADSEN/WA6910	1
19187	**97X358**	2002 SR Entry#	293	WA7697/A96330	WA7697//MADSEN/WA6910	1
19188	**97X358**	2002 SR Entry#	338	WA7697/A96330	WA7697//MADSEN/WA6910	1
19189	**97X358**	2002 SR Entry#	231	WA7697/A96330	WA7697//MADSEN/WA6910	1
19190	**97X358**	2002 SR Entry#	194	WA7697/A96330	WA7697//MADSEN/WA6910	1
19191	**97X358**	2002 SR Entry#	271	WA7697/A96330	WA7697//MADSEN/WA6910	1
19192	**97X358**	2002 SR Entry#	135	WA7697/A96330	WA7697//MADSEN/WA6910	1
19193	**97X358**	2002 SR Entry#	64	WA7697/A96330	WA7697//MADSEN/WA6910	1
19194	**97X358**	2002 SR Entry#	234	WA7697/A96330	WA7697//MADSEN/WA6910	1
19195	**97X358**	2002 SR Entry#	139	WA7697/A96330	WA7697//MADSEN/WA6910	1
19196	**97X358**	2002 SR Entry#	270	WA7697/A96330	WA7697//MADSEN/WA6910	1
19197	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19198	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19199	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19200	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19201	**97X358**	2002 SR Entry#	97	WA7697/A96330	WA7697//MADSEN/WA6910	1
19202	**97X358**	2002 SR Entry#	136	WA7697/A96330	WA7697//MADSEN/WA6910	1
19203	**97X358**	2002 SR Entry#	160	WA7697/A96330	WA7697//MADSEN/WA6910	1
19204	**97X358**	2002 SR Entry#	318	WA7697/A96330	WA7697//MADSEN/WA6910	1
19205	**97X358**	2002 SR Entry#	183	WA7697/A96330	WA7697//MADSEN/WA6910	1
19206	**97X358**	2002 SR Entry#	182	WA7697/A96330	WA7697//MADSEN/WA6910	1
19207	**97X358**	2002 SR Entry#	324	WA7697/A96330	WA7697//MADSEN/WA6910	1
19208	**97X358**	2002 SR Entry#	54	WA7697/A96330	WA7697//MADSEN/WA6910	1
19209	**97X358**	2002 SR Entry#	241	WA7697/A96330	WA7697//MADSEN/WA6910	1
19210	**97X358**	2002 SR Entry#	350	WA7697/A96330	WA7697//MADSEN/WA6910	1
19211	**97X358**	2002 SR Entry#	206	WA7697/A96330	WA7697//MADSEN/WA6910	1
19212	**97X358**	2002 SR Entry#	122	WA7697/A96330	WA7697//MADSEN/WA6910	1
19213	**97X358**	2002 SR Entry#	123	WA7697/A96330	WA7697//MADSEN/WA6910	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19214	**97X358**	2002 SR Entry#	90	WA7697/A96330	WA7697//MADSEN/WA6910	1
19215	**97X358**	2002 SR Entry#	65	WA7697/A96330	WA7697//MADSEN/WA6910	1
19216	**97X358**	2002 SR Entry#	80	WA7697/A96330	WA7697//MADSEN/WA6910	1
19217	**97X358**	2002 SR Entry#	98	WA7697/A96330	WA7697//MADSEN/WA6910	1
19218	**97X358**	2002 SR Entry#	94	WA7697/A96330	WA7697//MADSEN/WA6910	1
19219	**97X358**	2002 SR Entry#	222	WA7697/A96330	WA7697//MADSEN/WA6910	1
19220	**97X358**	2002 SR Entry#	258	WA7697/A96330	WA7697//MADSEN/WA6910	1
19221	**97X358**	2002 SR Entry#	30	WA7697/A96330	WA7697//MADSEN/WA6910	1
19222	**97X358**	2002 SR Entry#	143	WA7697/A96330	WA7697//MADSEN/WA6910	1
19223	**97X358**	2002 SR Entry#	294	WA7697/A96330	WA7697//MADSEN/WA6910	1
19224	**97X358**	2002 SR Entry#	302	WA7697/A96330	WA7697//MADSEN/WA6910	1
19225	**97X358**	2002 SR Entry#	78	WA7697/A96330	WA7697//MADSEN/WA6910	1
19226	**97X358**	2002 SR Entry#	210	WA7697/A96330	WA7697//MADSEN/WA6910	1
19227	**97X358**	2002 SR Entry#	243	WA7697/A96330	WA7697//MADSEN/WA6910	1
19228	**97X358**	2002 SR Entry#	29	WA7697/A96330	WA7697//MADSEN/WA6910	1
19229	**97X358**	2002 SR Entry#	151	WA7697/A96330	WA7697//MADSEN/WA6910	1
19230	**97X358**	2002 SR Entry#	305	WA7697/A96330	WA7697//MADSEN/WA6910	1
19231	**97X358**	2002 SR Entry#	104	WA7697/A96330	WA7697//MADSEN/WA6910	1
19232	**97X358**	2002 SR Entry#	252	WA7697/A96330	WA7697//MADSEN/WA6910	1
19233	**97X358**	2002 SR Entry#	203	WA7697/A96330	WA7697//MADSEN/WA6910	1
19234	**97X358**	2002 SR Entry#	102	WA7697/A96330	WA7697//MADSEN/WA6910	1
19235	**97X358**	2002 SR Entry#	84	WA7697/A96330	WA7697//MADSEN/WA6910	1
19236	**97X358**	2002 SR Entry#	190	WA7697/A96330	WA7697//MADSEN/WA6910	1
19237	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19238	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19239	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19240	**Barley**	2002 Winter		Barley	Barley	1
19241	**97X358**	2002 SR Entry#	44	WA7697/A96330	WA7697//MADSEN/WA6910	1
19242	**97X358**	2002 SR Entry#	334	WA7697/A96330	WA7697//MADSEN/WA6910	1
19243	**97X358**	2002 SR Entry#	133	WA7697/A96330	WA7697//MADSEN/WA6910	1
19244	**97X358**	2002 SR Entry#	279	WA7697/A96330	WA7697//MADSEN/WA6910	1
19245	**97X358**	2002 SR Entry#	242	WA7697/A96330	WA7697//MADSEN/WA6910	1
19246	**97X358**	2002 SR Entry#	287	WA7697/A96330	WA7697//MADSEN/WA6910	1
19246	**97X358**	2002 SR Entry#	287	WA7697/A96330	WA7697//MADSEN/WA6910	1
19247	**97X358**	2002 SR Entry#	253	WA7697/A96330	WA7697//MADSEN/WA6910	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19248	**97X358**	2002 SR Entry#	51	WA7697/A96330	WA7697//MADSEN/WA6910	1
19249	**97X358**	2002 SR Entry#	246	WA7697/A96330	WA7697//MADSEN/WA6910	1
19250	**97X358**	2002 SR Entry#	221	WA7697/A96330	WA7697//MADSEN/WA6910	1
19251	**97X358**	2002 SR Entry#	150	WA7697/A96330	WA7697//MADSEN/WA6910	1
19252	**97X358**	2002 SR Entry#	205	WA7697/A96330	WA7697//MADSEN/WA6910	1
19253	**97X358**	2002 SR Entry#	265	WA7697/A96330	WA7697//MADSEN/WA6910	1
19254	**WA7697**			STEPHENS//SU92/3*OMAR	STEPHENS//SU92/3*OMAR	1
19255	**A96330**			MDN/WA6910	84X111 VPM/M951/YMH/HYS//HILL81///WA6910	1
19256	**A9622**			WA7665/RULO	WA7665/RULO	1
19257	**97X230**	2002 SR Entry#	229	WA7697/A9622	WA7697//WA7665/RULO	1
19258	**97X230**	2002 SR Entry#	78	WA7697/A9622	WA7697//WA7665/RULO	1
19259	**97X230**	2002 SR Entry#	289	WA7697/A9622	WA7697//WA7665/RULO	1
19260	**97X230**	2002 SR Entry#	261	WA7697/A9622	WA7697//WA7665/RULO	1
19261	**97X230**	2002 SR Entry#	33	WA7697/A9622	WA7697//WA7665/RULO	1
19262	**97X230**	2002 SR Entry#	298	WA7697/A9622	WA7697//WA7665/RULO	1
19263	**97X230**	2002 SR Entry#	344	WA7697/A9622	WA7697//WA7665/RULO	1
19264	**97X230**	2002 SR Entry#	86	WA7697/A9622	WA7697//WA7665/RULO	1
19265	**97X230**	2002 SR Entry#	225	WA7697/A9622	WA7697//WA7665/RULO	1
19266	**97X230**	2002 SR Entry#	280	WA7697/A9622	WA7697//WA7665/RULO	1
19267	**97X230**	2002 SR Entry#	207	WA7697/A9622	WA7697//WA7665/RULO	1
19268	**97X230**	2002 SR Entry#	257	WA7697/A9622	WA7697//WA7665/RULO	1
19269	**97X230**	2002 SR Entry#	180	WA7697/A9622	WA7697//WA7665/RULO	1
19270	**97X230**	2002 SR Entry#	56	WA7697/A9622	WA7697//WA7665/RULO	1
19271	**97X230**	2002 SR Entry#	83	WA7697/A9622	WA7697//WA7665/RULO	1
19272	**97X230**	2002 SR Entry#	113	WA7697/A9622	WA7697//WA7665/RULO	1
19273	**97X230**	2002 SR Entry#	251	WA7697/A9622	WA7697//WA7665/RULO	1
19274	**97X230**	2002 SR Entry#	218	WA7697/A9622	WA7697//WA7665/RULO	1
19275	**97X230**	2002 SR Entry#	296	WA7697/A9622	WA7697//WA7665/RULO	1
19276	**97X230**	2002 SR Entry#	178	WA7697/A9622	WA7697//WA7665/RULO	1
19277	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19278	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19279	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19280	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19281	**97X230**	2002 SR Entry#	237	WA7697/A9622	WA7697//WA7665/RULO	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19282	**97X230**	2002 SR Entry#	292	WA7697/A9622	WA7697//WA7665/RULO	1
19283	**97X230**	2002 SR Entry#	255	WA7697/A9622	WA7697//WA7665/RULO	1
19284	**97X230**	2002 SR Entry#	97	WA7697/A9622	WA7697//WA7665/RULO	1
19285	**97X230**	2002 SR Entry#	186	WA7697/A9622	WA7697//WA7665/RULO	1
19286	**97X230**	2002 SR Entry#	46	WA7697/A9622	WA7697//WA7665/RULO	1
19287	**97X230**	2002 SR Entry#	332	WA7697/A9622	WA7697//WA7665/RULO	1
19288	**97X230**	2002 SR Entry#	124	WA7697/A9622	WA7697//WA7665/RULO	1
19289	**97X230**	2002 SR Entry#	60	WA7697/A9622	WA7697//WA7665/RULO	1
19290	**97X230**	2002 SR Entry#	18	WA7697/A9622	WA7697//WA7665/RULO	1
19291	**97X230**	2002 SR Entry#	10	WA7697/A9622	WA7697//WA7665/RULO	1
19292	**97X230**	2002 SR Entry#	4	WA7697/A9622	WA7697//WA7665/RULO	1
19293	**97X230**	2002 SR Entry#	31	WA7697/A9622	WA7697//WA7665/RULO	1
19294	**97X230**	2002 SR Entry#	34	WA7697/A9622	WA7697//WA7665/RULO	1
19295	**97X230**	2002 SR Entry#	137	WA7697/A9622	WA7697//WA7665/RULO	1
19296	**97X230**	2002 SR Entry#	90	WA7697/A9622	WA7697//WA7665/RULO	1
19297	**97X230**	2002 SR Entry#	58	WA7697/A9622	WA7697//WA7665/RULO	1
19298	**97X230**	2002 SR Entry#	209	WA7697/A9622	WA7697//WA7665/RULO	1
19299	**97X230**	2002 SR Entry#	123	WA7697/A9622	WA7697//WA7665/RULO	1
19300	**97X230**	2002 SR Entry#	163	WA7697/A9622	WA7697//WA7665/RULO	1
19301	**97X230**	2002 SR Entry#	265	WA7697/A9622	WA7697//WA7665/RULO	1
19302	**97X230**	2002 SR Entry#	79	WA7697/A9622	WA7697//WA7665/RULO	1
19303	**97X230**	2002 SR Entry#	9	WA7697/A9622	WA7697//WA7665/RULO	1
19304	**97X230**	2002 SR Entry#	129	WA7697/A9622	WA7697//WA7665/RULO	1
19305	**97X230**	2002 SR Entry#	41	WA7697/A9622	WA7697//WA7665/RULO	1
19306	**97X230**	2002 SR Entry#	65	WA7697/A9622	WA7697//WA7665/RULO	1
19307	**97X230**	2002 SR Entry#	286	WA7697/A9622	WA7697//WA7665/RULO	1
19308	**97X230**	2002 SR Entry#	202	WA7697/A9622	WA7697//WA7665/RULO	1
19309	**97X230**	2002 SR Entry#	279	WA7697/A9622	WA7697//WA7665/RULO	1
19310	**97X230**	2002 SR Entry#	55	WA7697/A9622	WA7697//WA7665/RULO	1
19311	**97X230**	2002 SR Entry#	305	WA7697/A9622	WA7697//WA7665/RULO	1
19312	**97X230**	2002 SR Entry#	240	WA7697/A9622	WA7697//WA7665/RULO	1
19313	**97X230**	2002 SR Entry#	336	WA7697/A9622	WA7697//WA7665/RULO	1
19314	**97X230**	2002 SR Entry#	307	WA7697/A9622	WA7697//WA7665/RULO	1
19315	**97X230**	2002 SR Entry#	212	WA7697/A9622	WA7697//WA7665/RULO	1
19316	**97X230**	2002 SR Entry#	191	WA7697/A9622	WA7697//WA7665/RULO	1
19317	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19318	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19319	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19320	**Barley**	2002 Winter		Barley	Barley	1
19321	**97X230**	2002 SR Entry#	193	WA7697/A9622	WA7697//WA7665/RULO	1
19322	**97X230**	2002 SR Entry#	122	WA7697/A9622	WA7697//WA7665/RULO	1
19323	**97X230**	2002 SR Entry#	185	WA7697/A9622	WA7697//WA7665/RULO	1
19324	**97X230**	2002 SR Entry#	118	WA7697/A9622	WA7697//WA7665/RULO	1
19325	**97X230**	2002 SR Entry#	147	WA7697/A9622	WA7697//WA7665/RULO	1
19326	**97X230**	2002 SR Entry#	70	WA7697/A9622	WA7697//WA7665/RULO	1
19327	**97X230**	2002 SR Entry#	211	WA7697/A9622	WA7697//WA7665/RULO	1
19328	**97X230**	2002 SR Entry#	206	WA7697/A9622	WA7697//WA7665/RULO	1
19329	**97X230**	2002 SR Entry#	150	WA7697/A9622	WA7697//WA7665/RULO	1
19330	**97X230**	2002 SR Entry#	134	WA7697/A9622	WA7697//WA7665/RULO	1
19331	**97X230**	2002 SR Entry#	115	WA7697/A9622	WA7697//WA7665/RULO	1
19332	**97X230**	2002 SR Entry#	196	WA7697/A9622	WA7697//WA7665/RULO	1
19333	**97X230**	2002 SR Entry#	330	WA7697/A9622	WA7697//WA7665/RULO	1
19334	**97X230**	2002 SR Entry#	80	WA7697/A9622	WA7697//WA7665/RULO	1
19335	**97X230**	2002 SR Entry#	228	WA7697/A9622	WA7697//WA7665/RULO	1
19336	**97X230**	2002 SR Entry#	14	WA7697/A9622	WA7697//WA7665/RULO	1
19337	**97X230**	2002 SR Entry#	260	WA7697/A9622	WA7697//WA7665/RULO	1
19338	**97X230**	2002 SR Entry#	200	WA7697/A9622	WA7697//WA7665/RULO	1
19339	**97X230**	2002 SR Entry#	267	WA7697/A9622	WA7697//WA7665/RULO	1
19340	**97X230**	2002 SR Entry#	159	WA7697/A9622	WA7697//WA7665/RULO	1
19341	**97X230**	2002 SR Entry#	294	WA7697/A9622	WA7697//WA7665/RULO	1
19342	**97X230**	2002 SR Entry#	112	WA7697/A9622	WA7697//WA7665/RULO	1
19343	**97X230**	2002 SR Entry#	133	WA7697/A9622	WA7697//WA7665/RULO	1
19344	**97X230**	2002 SR Entry#	151	WA7697/A9622	WA7697//WA7665/RULO	1
19345	**97X230**	2002 SR Entry#	77	WA7697/A9622	WA7697//WA7665/RULO	1
19346	**97X230**	2002 SR Entry#	51	WA7697/A9622	WA7697//WA7665/RULO	1
19347	**97X230**	2002 SR Entry#	76	WA7697/A9622	WA7697//WA7665/RULO	1
19348	**97X230**	2002 SR Entry#	311	WA7697/A9622	WA7697//WA7665/RULO	1
19349	**97X230**	2002 SR Entry#	68	WA7697/A9622	WA7697//WA7665/RULO	1
19350	**97X230**	2002 SR Entry#	166	WA7697/A9622	WA7697//WA7665/RULO	1
19351	**97X230**	2002 SR Entry#	172	WA7697/A9622	WA7697//WA7665/RULO	1
19352	**97X230**	2002 SR Entry#	273	WA7697/A9622	WA7697//WA7665/RULO	1
19353	**97X230**	2002 SR Entry#	59	WA7697/A9622	WA7697//WA7665/RULO	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19354	**97X230**	2002 SR Entry#	188	WA7697/A9622	WA7697//WA7665/RULO	1
19355	**97X230**	2002 SR Entry#	88	WA7697/A9622	WA7697//WA7665/RULO	1
19356	**97X230**	2002 SR Entry#	187	WA7697/A9622	WA7697//WA7665/RULO	1
19357	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19358	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19359	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19360	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19361	**97X230**	2002 SR Entry#	217	WA7697/A9622	WA7697//WA7665/RULO	1
19362	**97X230**	2002 SR Entry#	30	WA7697/A9622	WA7697//WA7665/RULO	1
19363	**97X230**	2002 SR Entry#	239	WA7697/A9622	WA7697//WA7665/RULO	1
19364	**97X230**	2002 SR Entry#	256	WA7697/A9622	WA7697//WA7665/RULO	1
19365	**97X230**	2002 SR Entry#	66	WA7697/A9622	WA7697//WA7665/RULO	1
19366	**97X230**	2002 SR Entry#	50	WA7697/A9622	WA7697//WA7665/RULO	1
19367	**97X230**	2002 SR Entry#	190	WA7697/A9622	WA7697//WA7665/RULO	1
19368	**97X230**	2002 SR Entry#	222	WA7697/A9622	WA7697//WA7665/RULO	1
19369	**97X230**	2002 SR Entry#	95	WA7697/A9622	WA7697//WA7665/RULO	1
19370	**97X230**	2002 SR Entry#	36	WA7697/A9622	WA7697//WA7665/RULO	1
19371	**97X230**	2002 SR Entry#	39	WA7697/A9622	WA7697//WA7665/RULO	1
19372	**97X230**	2002 SR Entry#	91	WA7697/A9622	WA7697//WA7665/RULO	1
19373	**97X230**	2002 SR Entry#	189	WA7697/A9622	WA7697//WA7665/RULO	1
19374	**97X230**	2002 SR Entry#	203	WA7697/A9622	WA7697//WA7665/RULO	1
19375	**97X230**	2002 SR Entry#	168	WA7697/A9622	WA7697//WA7665/RULO	1
19376	**97X230**	2002 SR Entry#	230	WA7697/A9622	WA7697//WA7665/RULO	1
19377	**97X230**	2002 SR Entry#	85	WA7697/A9622	WA7697//WA7665/RULO	1
19378	**97X230**	2002 SR Entry#	45	WA7697/A9622	WA7697//WA7665/RULO	1
19379	**97X230**	2002 SR Entry#	126	WA7697/A9622	WA7697//WA7665/RULO	1
19380	**97X230**	2002 SR Entry#	295	WA7697/A9622	WA7697//WA7665/RULO	1
19381	**97X230**	2002 SR Entry#	277	WA7697/A9622	WA7697//WA7665/RULO	1
19382	**97X230**	2002 SR Entry#	179	WA7697/A9622	WA7697//WA7665/RULO	1
19383	**97X230**	2002 SR Entry#	149	WA7697/A9622	WA7697//WA7665/RULO	1
19384	**97X230**	2002 SR Entry#	121	WA7697/A9622	WA7697//WA7665/RULO	1
19385	**97X230**	2002 SR Entry#	142	WA7697/A9622	WA7697//WA7665/RULO	1
19386	**97X230**	2002 SR Entry#	198	WA7697/A9622	WA7697//WA7665/RULO	1
19387	**97X230**	2002 SR Entry#	252	WA7697/A9622	WA7697//WA7665/RULO	1
19388	**97X230**	2002 SR Entry#	155	WA7697/A9622	WA7697//WA7665/RULO	1
19389	**97X230**	2002 SR Entry#	244	WA7697/A9622	WA7697//WA7665/RULO	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19390	**97X230**	2002 SR Entry#	170	WA7697/A9622	WA7697//WA7665/RULO	1
19391	**97X230**	2002 SR Entry#	117	WA7697/A9622	WA7697//WA7665/RULO	1
19392	**97X230**	2002 SR Entry#	26	WA7697/A9622	WA7697//WA7665/RULO	1
19393	**97X230**	2002 SR Entry#	141	WA7697/A9622	WA7697//WA7665/RULO	1
19394	**97X230**	2002 SR Entry#	281	WA7697/A9622	WA7697//WA7665/RULO	1
19395	**97X230**	2002 SR Entry#	143	WA7697/A9622	WA7697//WA7665/RULO	1
19396	**97X230**	2002 SR Entry#	57	WA7697/A9622	WA7697//WA7665/RULO	1
19397	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19398	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19399	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19400	**Barley**	2002 Winter		Barley	Barley	1
19401	**97X230**	2002 SR Entry#	98	WA7697/A9622	WA7697//WA7665/RULO	1
19402	**97X230**	2002 SR Entry#	63	WA7697/A9622	WA7697//WA7665/RULO	1
19403	**97X230**	2002 SR Entry#	338	WA7697/A9622	WA7697//WA7665/RULO	1
19404	**97X230**	2002 SR Entry#	234	WA7697/A9622	WA7697//WA7665/RULO	1
19405	**97X230**	2002 SR Entry#	71	WA7697/A9622	WA7697//WA7665/RULO	1
19406	**97X230**	2002 SR Entry#	127	WA7697/A9622	WA7697//WA7665/RULO	1
19407	**97X230**	2002 SR Entry#	195	WA7697/A9622	WA7697//WA7665/RULO	1
19408	**97X230**	2002 SR Entry#	174	WA7697/A9622	WA7697//WA7665/RULO	1
19409	**97X230**	2002 SR Entry#	263	WA7697/A9622	WA7697//WA7665/RULO	1
19410	**97X230**	2002 SR Entry#	23	WA7697/A9622	WA7697//WA7665/RULO	1
19411	**97X230**	2002 SR Entry#	87	WA7697/A9622	WA7697//WA7665/RULO	1
19412	**97X230**	2002 SR Entry#	111	WA7697/A9622	WA7697//WA7665/RULO	1
19413	**97X230**	2002 SR Entry#	67	WA7697/A9622	WA7697//WA7665/RULO	1
19414	**97X230**	2002 SR Entry#	1	WA7697/A9622	WA7697//WA7665/RULO	1
19415	**97X230**	2002 SR Entry#	11	WA7697/A9622	WA7697//WA7665/RULO	1
19416	**97X230**	2002 SR Entry#	181	WA7697/A9622	WA7697//WA7665/RULO	1
19417	**97X230**	2002 SR Entry#	320	WA7697/A9622	WA7697//WA7665/RULO	1
19418	**97X230**	2002 SR Entry#	175	WA7697/A9622	WA7697//WA7665/RULO	1
19419	**97X230**	2002 SR Entry#	276	WA7697/A9622	WA7697//WA7665/RULO	1
19420	**97X230**	2002 SR Entry#	274	WA7697/A9622	WA7697//WA7665/RULO	1
19421	**97X230**	2002 SR Entry#	12	WA7697/A9622	WA7697//WA7665/RULO	1
19422	**97X230**	2002 SR Entry#	99	WA7697/A9622	WA7697//WA7665/RULO	1
19423	**97X230**	2002 SR Entry#	204	WA7697/A9622	WA7697//WA7665/RULO	1
19424	**97X230**	2002 SR Entry#	24	WA7697/A9622	WA7697//WA7665/RULO	1
19425	**97X230**	2002 SR Entry#	262	WA7697/A9622	WA7697//WA7665/RULO	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19426	**97X230**	2002 SR Entry#	27	WA7697/A9622	WA7697//WA7665/RULO	1
19427	**97X230**	2002 SR Entry#	82	WA7697/A9622	WA7697//WA7665/RULO	1
19428	**97X230**	2002 SR Entry#	197	WA7697/A9622	WA7697//WA7665/RULO	1
19429	**97X230**	2002 SR Entry#	49	WA7697/A9622	WA7697//WA7665/RULO	1
19430	**97X230**	2002 SR Entry#	108	WA7697/A9622	WA7697//WA7665/RULO	1
19431	**97X230**	2002 SR Entry#	43	WA7697/A9622	WA7697//WA7665/RULO	1
19432	**97X230**	2002 SR Entry#	268	WA7697/A9622	WA7697//WA7665/RULO	1
19433	**97X230**	2002 SR Entry#	214	WA7697/A9622	WA7697//WA7665/RULO	1
19434	**97X230**	2002 SR Entry#	284	WA7697/A9622	WA7697//WA7665/RULO	1
19435	**97X230**	2002 SR Entry#	158	WA7697/A9622	WA7697//WA7665/RULO	1
19436	**97X230**	2002 SR Entry#	140	WA7697/A9622	WA7697//WA7665/RULO	1
19437	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19438	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19439	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19440	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19441	**97X230**	2002 SR Entry#	109	WA7697/A9622	WA7697//WA7665/RULO	1
19442	**97X230**	2002 SR Entry#	259	WA7697/A9622	WA7697//WA7665/RULO	1
19443	**97X230**	2002 SR Entry#	316	WA7697/A9622	WA7697//WA7665/RULO	1
19444	**97X230**	2002 SR Entry#	100	WA7697/A9622	WA7697//WA7665/RULO	1
19445	**97X230**	2002 SR Entry#	25	WA7697/A9622	WA7697//WA7665/RULO	1
19446	**97X230**	2002 SR Entry#	29	WA7697/A9622	WA7697//WA7665/RULO	1
19447	**97X230**	2002 SR Entry#	248	WA7697/A9622	WA7697//WA7665/RULO	1
19448	**97X230**	2002 SR Entry#	132	WA7697/A9622	WA7697//WA7665/RULO	1
19449	**97X230**	2002 SR Entry#	241	WA7697/A9622	WA7697//WA7665/RULO	1
19450	**97X230**	2002 SR Entry#	114	WA7697/A9622	WA7697//WA7665/RULO	1
19451	**97X230**	2002 SR Entry#	272	WA7697/A9622	WA7697//WA7665/RULO	1
19452	**97X230**	2002 SR Entry#	106	WA7697/A9622	WA7697//WA7665/RULO	1
19453	**97X230**	2002 SR Entry#	285	WA7697/A9622	WA7697//WA7665/RULO	1
19454	**97X230**	2002 SR Entry#	224	WA7697/A9622	WA7697//WA7665/RULO	1
19455	**97X230**	2002 SR Entry#	94	WA7697/A9622	WA7697//WA7665/RULO	1
19456	**97X230**	2002 SR Entry#	220	WA7697/A9622	WA7697//WA7665/RULO	1
19457	**97X230**	2002 SR Entry#	44	WA7697/A9622	WA7697//WA7665/RULO	1
19458	**97X230**	2002 SR Entry#	120	WA7697/A9622	WA7697//WA7665/RULO	1
19459	**97X230**	2002 SR Entry#	2	WA7697/A9622	WA7697//WA7665/RULO	1
19460	**97X230**	2002 SR Entry#	303	WA7697/A9622	WA7697//WA7665/RULO	1
19461	**97X230**	2002 SR Entry#	28	WA7697/A9622	WA7697//WA7665/RULO	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19462	**97X230**	2002 SR Entry#	144	WA7697/A9622	WA7697//WA7665/RULO	1
19463	**97X230**	2002 SR Entry#	3	WA7697/A9622	WA7697//WA7665/RULO	1
19464	**97X230**	2002 SR Entry#	35	WA7697/A9622	WA7697//WA7665/RULO	1
19465	**97X230**	2002 SR Entry#	233	WA7697/A9622	WA7697//WA7665/RULO	1
19466	**97X230**	2002 SR Entry#	157	WA7697/A9622	WA7697//WA7665/RULO	1
19467	**97X230**	2002 SR Entry#	52	WA7697/A9622	WA7697//WA7665/RULO	1
19468	**97X230**	2002 SR Entry#	84	WA7697/A9622	WA7697//WA7665/RULO	1
19469	**97X230**	2002 SR Entry#	5	WA7697/A9622	WA7697//WA7665/RULO	1
19470	**97X230**	2002 SR Entry#	301	WA7697/A9622	WA7697//WA7665/RULO	1
19471	**97X230**	2002 SR Entry#	269	WA7697/A9622	WA7697//WA7665/RULO	1
19472	**97X230**	2002 SR Entry#	110	WA7697/A9622	WA7697//WA7665/RULO	1
19473	**97X230**	2002 SR Entry#	162	WA7697/A9622	WA7697//WA7665/RULO	1
19474	**97X230**	2002 SR Entry#	22	WA7697/A9622	WA7697//WA7665/RULO	1
19475	**97X230**	2002 SR Entry#	16	WA7697/A9622	WA7697//WA7665/RULO	1
19476	**97X230**	2002 SR Entry#	135	WA7697/A9622	WA7697//WA7665/RULO	1
19477	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19478	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19479	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19480	**Barley**	2002 Winter		Barley	Barley	1
19481	**97X230**	2002 SR Entry#	75	WA7697/A9622	WA7697//WA7665/RULO	1
19482	**97X230**	2002 SR Entry#	300	WA7697/A9622	WA7697//WA7665/RULO	1
19483	**97X230**	2002 SR Entry#	223	WA7697/A9622	WA7697//WA7665/RULO	1
19484	**97X230**	2002 SR Entry#	329	WA7697/A9622	WA7697//WA7665/RULO	1
19485	**97X230**	2002 SR Entry#	278	WA7697/A9622	WA7697//WA7665/RULO	1
19486	**97X230**	2002 SR Entry#	283	WA7697/A9622	WA7697//WA7665/RULO	1
19487	**97X230**	2002 SR Entry#	37	WA7697/A9622	WA7697//WA7665/RULO	1
19488	**97X230**	2002 SR Entry#	54	WA7697/A9622	WA7697//WA7665/RULO	1
19489	**97X230**	2002 SR Entry#	319	WA7697/A9622	WA7697//WA7665/RULO	1
19490	**97X230**	2002 SR Entry#	304	WA7697/A9622	WA7697//WA7665/RULO	1
19491	**97X230**	2002 SR Entry#	247	WA7697/A9622	WA7697//WA7665/RULO	1
19492	**97X230**	2002 SR Entry#	48	WA7697/A9622	WA7697//WA7665/RULO	1
19493	**97X230**	2002 SR Entry#	145	WA7697/A9622	WA7697//WA7665/RULO	1
19494	**97X230**	2002 SR Entry#	308	WA7697/A9622	WA7697//WA7665/RULO	1
19495	**97X230**	2002 SR Entry#	8	WA7697/A9622	WA7697//WA7665/RULO	1
19496	**97X230**	2002 SR Entry#	128	WA7697/A9622	WA7697//WA7665/RULO	1
19497	**97X230**	2002 SR Entry#	221	WA7697/A9622	WA7697//WA7665/RULO	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19498	**97X230**	2002 SR Entry#	38	WA7697/A9622	WA7697//WA7665/RULO	1
19499	**97X230**	2002 SR Entry#	6	WA7697/A9622	WA7697//WA7665/RULO	1
19500	**97X230**	2002 SR Entry#	254	WA7697/A9622	WA7697//WA7665/RULO	1
19501	**97X230**	2002 SR Entry#	61	WA7697/A9622	WA7697//WA7665/RULO	1
19502	**97X230**	2002 SR Entry#	139	WA7697/A9622	WA7697//WA7665/RULO	1
19503	**97X230**	2002 SR Entry#	40	WA7697/A9622	WA7697//WA7665/RULO	1
19504	**97X230**	2002 SR Entry#	17	WA7697/A9622	WA7697//WA7665/RULO	1
19505	**97X230**	2002 SR Entry#	125	WA7697/A9622	WA7697//WA7665/RULO	1
19506	**97X230**	2002 SR Entry#	107	WA7697/A9622	WA7697//WA7665/RULO	1
19507	**97X230**	2002 SR Entry#	287	WA7697/A9622	WA7697//WA7665/RULO	1
19508	**97X230**	2002 SR Entry#	328	WA7697/A9622	WA7697//WA7665/RULO	1
19509	**97X230**	2002 SR Entry#	215	WA7697/A9622	WA7697//WA7665/RULO	1
19510	**97X230**	2002 SR Entry#	130	WA7697/A9622	WA7697//WA7665/RULO	1
19511	**97X230**	2002 SR Entry#	20	WA7697/A9622	WA7697//WA7665/RULO	1
19512	**97X230**	2002 SR Entry#	154	WA7697/A9622	WA7697//WA7665/RULO	1
19513	**97X230**	2002 SR Entry#	136	WA7697/A9622	WA7697//WA7665/RULO	1
19514	**97X230**	2002 SR Entry#	315	WA7697/A9622	WA7697//WA7665/RULO	1
19515	**97X230**	2002 SR Entry#	243	WA7697/A9622	WA7697//WA7665/RULO	1
19516	**97X230**	2002 SR Entry#	208	WA7697/A9622	WA7697//WA7665/RULO	1
19517	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19518	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19519	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19520	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19521	**97X230**	2002 SR Entry#	96	WA7697/A9622	WA7697//WA7665/RULO	1
19522	**97X230**	2002 SR Entry#	169	WA7697/A9622	WA7697//WA7665/RULO	1
19523	**97X230**	2002 SR Entry#	15	WA7697/A9622	WA7697//WA7665/RULO	1
19524	**97X230**	2002 SR Entry#	21	WA7697/A9622	WA7697//WA7665/RULO	1
19525	**97X230**	2002 SR Entry#	270	WA7697/A9622	WA7697//WA7665/RULO	1
19526	**97X230**	2002 SR Entry#	72	WA7697/A9622	WA7697//WA7665/RULO	1
19527	**97X230**	2002 SR Entry#	146	WA7697/A9622	WA7697//WA7665/RULO	1
19528	**97X230**	2002 SR Entry#	199	WA7697/A9622	WA7697//WA7665/RULO	1
19529	**97X230**	2002 SR Entry#	42	WA7697/A9622	WA7697//WA7665/RULO	1
19530	**97X230**	2002 SR Entry#	148	WA7697/A9622	WA7697//WA7665/RULO	1
19531	**97X230**	2002 SR Entry#	32	WA7697/A9622	WA7697//WA7665/RULO	1
19532	**97X230**	2002 SR Entry#	19	WA7697/A9622	WA7697//WA7665/RULO	1
19533	**97X230**	2002 SR Entry#	232	WA7697/A9622	WA7697//WA7665/RULO	1

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19534	**97X230**	2002 SR Entry#	53	WA7697/A9622	WA7697//WA7665/RULO	1
19535	**97X230**	2002 SR Entry#	250	WA7697/A9622	WA7697//WA7665/RULO	1
19536	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	1
19537	**WA7697**			STEPHENS//SU92/3*OMAR	STEPHENS//SU92/3*OMAR	2
19538	**A96330**			MDN/WA6910	84X111 VPM/M951/YMH/HYS//HILL81///WA6910	2
19539	**A9622**			WA7665/RULO	WA7665/RULO	2
19540	**SPN**	2000 WSCI		STEPHENS	STEPHENS	2
19541	**97X358**	2002 SR Entry#	313	WA7697/A96330	WA7697//MADSEN/WA6910	2
19542	**97X358**	2002 SR Entry#	159	WA7697/A96330	WA7697//MADSEN/WA6910	2
19543	**97X358**	2002 SR Entry#	144	WA7697/A96330	WA7697//MADSEN/WA6910	2
19544	**97X358**	2002 SR Entry#	92	WA7697/A96330	WA7697//MADSEN/WA6910	2
19545	**97X358**	2002 SR Entry#	255	WA7697/A96330	WA7697//MADSEN/WA6910	2
19546	**97X358**	2002 SR Entry#	327	WA7697/A96330	WA7697//MADSEN/WA6910	2
19547	**97X358**	2002 SR Entry#	130	WA7697/A96330	WA7697//MADSEN/WA6910	2
19548	**97X358**	2002 SR Entry#	56	WA7697/A96330	WA7697//MADSEN/WA6910	2
19549	**97X358**	2002 SR Entry#	227	WA7697/A96330	WA7697//MADSEN/WA6910	2
19550	**97X358**	2002 SR Entry#	53	WA7697/A96330	WA7697//MADSEN/WA6910	2
19551	**97X358**	2002 SR Entry#	312	WA7697/A96330	WA7697//MADSEN/WA6910	2
19552	**97X358**	2002 SR Entry#	286	WA7697/A96330	WA7697//MADSEN/WA6910	2
19553	**97X358**	2002 SR Entry#	140	WA7697/A96330	WA7697//MADSEN/WA6910	2
19554	**97X358**	2002 SR Entry#	95	WA7697/A96330	WA7697//MADSEN/WA6910	2
19555	**97X358**	2002 SR Entry#	240	WA7697/A96330	WA7697//MADSEN/WA6910	2
19556	**97X358**	2002 SR Entry#	18	WA7697/A96330	WA7697//MADSEN/WA6910	2
19557	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19558	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19559	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19560	**Barley**	2002 Winter		Barley	Barley	2
19561	**97X358**	2002 SR Entry#	70	WA7697/A96330	WA7697//MADSEN/WA6910	2
19562	**97X358**	2002 SR Entry#	57	WA7697/A96330	WA7697//MADSEN/WA6910	2
19563	**97X358**	2002 SR Entry#	47	WA7697/A96330	WA7697//MADSEN/WA6910	2
19564	**97X358**	2002 SR Entry#	329	WA7697/A96330	WA7697//MADSEN/WA6910	2
19565	**97X358**	2002 SR Entry#	196	WA7697/A96330	WA7697//MADSEN/WA6910	2
19566	**97X358**	2002 SR Entry#	114	WA7697/A96330	WA7697//MADSEN/WA6910	2
19567	**97X358**	2002 SR Entry#	172	WA7697/A96330	WA7697//MADSEN/WA6910	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19568	**97X358**	2002 SR Entry#	202	WA7697/A96330	WA7697//MADSEN/WA6910	2
19569	**97X358**	2002 SR Entry#	290	WA7697/A96330	WA7697//MADSEN/WA6910	2
19570	**97X358**	2002 SR Entry#	86	WA7697/A96330	WA7697//MADSEN/WA6910	2
19571	**97X358**	2002 SR Entry#	348	WA7697/A96330	WA7697//MADSEN/WA6910	2
19572	**97X358**	2002 SR Entry#	165	WA7697/A96330	WA7697//MADSEN/WA6910	2
19573	**97X358**	2002 SR Entry#	314	WA7697/A96330	WA7697//MADSEN/WA6910	2
19574	**97X358**	2002 SR Entry#	157	WA7697/A96330	WA7697//MADSEN/WA6910	2
19575	**97X358**	2002 SR Entry#	100	WA7697/A96330	WA7697//MADSEN/WA6910	2
19576	**97X358**	2002 SR Entry#	226	WA7697/A96330	WA7697//MADSEN/WA6910	2
19577	**97X358**	2002 SR Entry#	236	WA7697/A96330	WA7697//MADSEN/WA6910	2
19578	**97X358**	2002 SR Entry#	263	WA7697/A96330	WA7697//MADSEN/WA6910	2
19579	**97X358**	2002 SR Entry#	71	WA7697/A96330	WA7697//MADSEN/WA6910	2
19580	**97X358**	2002 SR Entry#	235	WA7697/A96330	WA7697//MADSEN/WA6910	2
19581	**97X358**	2002 SR Entry#	32	WA7697/A96330	WA7697//MADSEN/WA6910	2
19582	**97X358**	2002 SR Entry#	137	WA7697/A96330	WA7697//MADSEN/WA6910	2
19583	**97X358**	2002 SR Entry#	308	WA7697/A96330	WA7697//MADSEN/WA6910	2
19584	**97X358**	2002 SR Entry#	109	WA7697/A96330	WA7697//MADSEN/WA6910	2
19585	**97X358**	2002 SR Entry#	245	WA7697/A96330	WA7697//MADSEN/WA6910	2
19586	**97X358**	2002 SR Entry#	127	WA7697/A96330	WA7697//MADSEN/WA6910	2
19587	**97X358**	2002 SR Entry#	296	WA7697/A96330	WA7697//MADSEN/WA6910	2
19588	**97X358**	2002 SR Entry#	288	WA7697/A96330	WA7697//MADSEN/WA6910	2
19589	**97X358**	2002 SR Entry#	121	WA7697/A96330	WA7697//MADSEN/WA6910	2
19590	**97X358**	2002 SR Entry#	166	WA7697/A96330	WA7697//MADSEN/WA6910	2
19591	**97X358**	2002 SR Entry#	244	WA7697/A96330	WA7697//MADSEN/WA6910	2
19592	**97X358**	2002 SR Entry#	178	WA7697/A96330	WA7697//MADSEN/WA6910	2
19593	**97X358**	2002 SR Entry#	148	WA7697/A96330	WA7697//MADSEN/WA6910	2
19594	**97X358**	2002 SR Entry#	256	WA7697/A96330	WA7697//MADSEN/WA6910	2
19595	**97X358**	2002 SR Entry#	298	WA7697/A96330	WA7697//MADSEN/WA6910	2
19596	**97X358**	2002 SR Entry#	91	WA7697/A96330	WA7697//MADSEN/WA6910	2
19597	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19598	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19599	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19600	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19601	**97X358**	2002 SR Entry#	310	WA7697/A96330	WA7697//MADSEN/WA6910	2
19602	**97X358**	2002 SR Entry#	238	WA7697/A96330	WA7697//MADSEN/WA6910	2
19603	**97X358**	2002 SR Entry#	124	WA7697/A96330	WA7697//MADSEN/WA6910	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19604	**97X358**	2002 SR Entry#	40	WA7697/A96330	WA7697//MADSEN/WA6910	2
19605	**97X358**	2002 SR Entry#	239	WA7697/A96330	WA7697//MADSEN/WA6910	2
19606	**97X358**	2002 SR Entry#	230	WA7697/A96330	WA7697//MADSEN/WA6910	2
19607	**97X358**	2002 SR Entry#	138	WA7697/A96330	WA7697//MADSEN/WA6910	2
19608	**97X358**	2002 SR Entry#	320	WA7697/A96330	WA7697//MADSEN/WA6910	2
19609	**97X358**	2002 SR Entry#	179	WA7697/A96330	WA7697//MADSEN/WA6910	2
19610	**97X358**	2002 SR Entry#	248	WA7697/A96330	WA7697//MADSEN/WA6910	2
19611	**97X358**	2002 SR Entry#	273	WA7697/A96330	WA7697//MADSEN/WA6910	2
19612	**97X358**	2002 SR Entry#	117	WA7697/A96330	WA7697//MADSEN/WA6910	2
19613	**97X358**	2002 SR Entry#	277	WA7697/A96330	WA7697//MADSEN/WA6910	2
19614	**97X358**	2002 SR Entry#	297	WA7697/A96330	WA7697//MADSEN/WA6910	2
19615	**97X358**	2002 SR Entry#	176	WA7697/A96330	WA7697//MADSEN/WA6910	2
19616	**97X358**	2002 SR Entry#	326	WA7697/A96330	WA7697//MADSEN/WA6910	2
19617	**97X358**	2002 SR Entry#	275	WA7697/A96330	WA7697//MADSEN/WA6910	2
19618	**97X358**	2002 SR Entry#	341	WA7697/A96330	WA7697//MADSEN/WA6910	2
19619	**97X358**	2002 SR Entry#	257	WA7697/A96330	WA7697//MADSEN/WA6910	2
19620	**97X358**	2002 SR Entry#	346	WA7697/A96330	WA7697//MADSEN/WA6910	2
19621	**97X358**	2002 SR Entry#	81	WA7697/A96330	WA7697//MADSEN/WA6910	2
19622	**97X358**	2002 SR Entry#	254	WA7697/A96330	WA7697//MADSEN/WA6910	2
19623	**97X358**	2002 SR Entry#	164	WA7697/A96330	WA7697//MADSEN/WA6910	2
19624	**97X358**	2002 SR Entry#	108	WA7697/A96330	WA7697//MADSEN/WA6910	2
19625	**97X358**	2002 SR Entry#	60	WA7697/A96330	WA7697//MADSEN/WA6910	2
19626	**97X358**	2002 SR Entry#	251	WA7697/A96330	WA7697//MADSEN/WA6910	2
19627	**97X358**	2002 SR Entry#	31	WA7697/A96330	WA7697//MADSEN/WA6910	2
19628	**97X358**	2002 SR Entry#	119	WA7697/A96330	WA7697//MADSEN/WA6910	2
19629	**97X358**	2002 SR Entry#	154	WA7697/A96330	WA7697//MADSEN/WA6910	2
19630	**97X358**	2002 SR Entry#	301	WA7697/A96330	WA7697//MADSEN/WA6910	2
19631	**97X358**	2002 SR Entry#	272	WA7697/A96330	WA7697//MADSEN/WA6910	2
19632	**97X358**	2002 SR Entry#	281	WA7697/A96330	WA7697//MADSEN/WA6910	2
19633	**97X358**	2002 SR Entry#	335	WA7697/A96330	WA7697//MADSEN/WA6910	2
19634	**97X358**	2002 SR Entry#	284	WA7697/A96330	WA7697//MADSEN/WA6910	2
19635	**97X358**	2002 SR Entry#	283	WA7697/A96330	WA7697//MADSEN/WA6910	2
19636	**97X358**	2002 SR Entry#	309	WA7697/A96330	WA7697//MADSEN/WA6910	2
19637	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19638	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19639	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19640	**Barley**	2002 Winter		Barley	Barley	2
19641	**97X358**	2002 SR Entry#	111	WA7697/A96330	WA7697//MADSEN/WA6910	2
19642	**97X358**	2002 SR Entry#	292	WA7697/A96330	WA7697//MADSEN/WA6910	2
19643	**97X358**	2002 SR Entry#	311	WA7697/A96330	WA7697//MADSEN/WA6910	2
19644	**97X358**	2002 SR Entry#	89	WA7697/A96330	WA7697//MADSEN/WA6910	2
19645	**97X358**	2002 SR Entry#	101	WA7697/A96330	WA7697//MADSEN/WA6910	2
19646	**97X358**	2002 SR Entry#	141	WA7697/A96330	WA7697//MADSEN/WA6910	2
19647	**97X358**	2002 SR Entry#	195	WA7697/A96330	WA7697//MADSEN/WA6910	2
19648	**97X358**	2002 SR Entry#	262	WA7697/A96330	WA7697//MADSEN/WA6910	2
19649	**97X358**	2002 SR Entry#	187	WA7697/A96330	WA7697//MADSEN/WA6910	2
19650	**97X358**	2002 SR Entry#	115	WA7697/A96330	WA7697//MADSEN/WA6910	2
19651	**97X358**	2002 SR Entry#	276	WA7697/A96330	WA7697//MADSEN/WA6910	2
19652	**97X358**	2002 SR Entry#	278	WA7697/A96330	WA7697//MADSEN/WA6910	2
19653	**97X358**	2002 SR Entry#	266	WA7697/A96330	WA7697//MADSEN/WA6910	2
19654	**97X358**	2002 SR Entry#	228	WA7697/A96330	WA7697//MADSEN/WA6910	2
19655	**97X358**	2002 SR Entry#	300	WA7697/A96330	WA7697//MADSEN/WA6910	2
19656	**97X358**	2002 SR Entry#	295	WA7697/A96330	WA7697//MADSEN/WA6910	2
19657	**97X358**	2002 SR Entry#	337	WA7697/A96330	WA7697//MADSEN/WA6910	2
19658	**97X358**	2002 SR Entry#	116	WA7697/A96330	WA7697//MADSEN/WA6910	2
19659	**97X358**	2002 SR Entry#	69	WA7697/A96330	WA7697//MADSEN/WA6910	2
19660	**97X358**	2002 SR Entry#	149	WA7697/A96330	WA7697//MADSEN/WA6910	2
19661	**97X358**	2002 SR Entry#	82	WA7697/A96330	WA7697//MADSEN/WA6910	2
19662	**97X358**	2002 SR Entry#	225	WA7697/A96330	WA7697//MADSEN/WA6910	2
19663	**97X358**	2002 SR Entry#	299	WA7697/A96330	WA7697//MADSEN/WA6910	2
19664	**97X358**	2002 SR Entry#	349	WA7697/A96330	WA7697//MADSEN/WA6910	2
19665	**97X358**	2002 SR Entry#	322	WA7697/A96330	WA7697//MADSEN/WA6910	2
19666	**97X358**	2002 SR Entry#	316	WA7697/A96330	WA7697//MADSEN/WA6910	2
19667	**97X358**	2002 SR Entry#	5	WA7697/A96330	WA7697//MADSEN/WA6910	2
19668	**97X358**	2002 SR Entry#	291	WA7697/A96330	WA7697//MADSEN/WA6910	2
19669	**97X358**	2002 SR Entry#	268	WA7697/A96330	WA7697//MADSEN/WA6910	2
19670	**97X358**	2002 SR Entry#	55	WA7697/A96330	WA7697//MADSEN/WA6910	2
19671	**97X358**	2002 SR Entry#	79	WA7697/A96330	WA7697//MADSEN/WA6910	2
19672	**97X358**	2002 SR Entry#	323	WA7697/A96330	WA7697//MADSEN/WA6910	2
19673	**97X358**	2002 SR Entry#	68	WA7697/A96330	WA7697//MADSEN/WA6910	2
19674	**97X358**	2002 SR Entry#	289	WA7697/A96330	WA7697//MADSEN/WA6910	2
19675	**97X358**	2002 SR Entry#	264	WA7697/A96330	WA7697//MADSEN/WA6910	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19676	**97X358**	2002 SR Entry#	10	WA7697/A96330	WA7697//MADSEN/WA6910	2
19677	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19678	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19679	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19680	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19681	**97X358**	2002 SR Entry#	340	WA7697/A96330	WA7697//MADSEN/WA6910	2
19682	**97X358**	2002 SR Entry#	188	WA7697/A96330	WA7697//MADSEN/WA6910	2
19683	**97X358**	2002 SR Entry#	204	WA7697/A96330	WA7697//MADSEN/WA6910	2
19684	**97X358**	2002 SR Entry#	306	WA7697/A96330	WA7697//MADSEN/WA6910	2
19685	**97X358**	2002 SR Entry#	158	WA7697/A96330	WA7697//MADSEN/WA6910	2
19686	**97X358**	2002 SR Entry#	175	WA7697/A96330	WA7697//MADSEN/WA6910	2
19687	**97X358**	2002 SR Entry#	331	WA7697/A96330	WA7697//MADSEN/WA6910	2
19688	**97X358**	2002 SR Entry#	330	WA7697/A96330	WA7697//MADSEN/WA6910	2
19689	**97X358**	2002 SR Entry#	269	WA7697/A96330	WA7697//MADSEN/WA6910	2
19690	**97X358**	2002 SR Entry#	168	WA7697/A96330	WA7697//MADSEN/WA6910	2
19691	**97X358**	2002 SR Entry#	249	WA7697/A96330	WA7697//MADSEN/WA6910	2
19692	**97X358**	2002 SR Entry#	274	WA7697/A96330	WA7697//MADSEN/WA6910	2
19693	**97X358**	2002 SR Entry#	267	WA7697/A96330	WA7697//MADSEN/WA6910	2
19694	**97X358**	2002 SR Entry#	96	WA7697/A96330	WA7697//MADSEN/WA6910	2
19695	**97X358**	2002 SR Entry#	177	WA7697/A96330	WA7697//MADSEN/WA6910	2
19696	**97X358**	2002 SR Entry#	118	WA7697/A96330	WA7697//MADSEN/WA6910	2
19697	**97X358**	2002 SR Entry#	134	WA7697/A96330	WA7697//MADSEN/WA6910	2
19698	**97X358**	2002 SR Entry#	282	WA7697/A96330	WA7697//MADSEN/WA6910	2
19699	**97X358**	2002 SR Entry#	201	WA7697/A96330	WA7697//MADSEN/WA6910	2
19700	**97X358**	2002 SR Entry#	48	WA7697/A96330	WA7697//MADSEN/WA6910	2
19701	**97X358**	2002 SR Entry#	209	WA7697/A96330	WA7697//MADSEN/WA6910	2
19702	**97X358**	2002 SR Entry#	63	WA7697/A96330	WA7697//MADSEN/WA6910	2
19703	**97X358**	2002 SR Entry#	319	WA7697/A96330	WA7697//MADSEN/WA6910	2
19704	**97X358**	2002 SR Entry#	170	WA7697/A96330	WA7697//MADSEN/WA6910	2
19705	**97X358**	2002 SR Entry#	317	WA7697/A96330	WA7697//MADSEN/WA6910	2
19706	**97X358**	2002 SR Entry#	105	WA7697/A96330	WA7697//MADSEN/WA6910	2
19707	**97X358**	2002 SR Entry#	232	WA7697/A96330	WA7697//MADSEN/WA6910	2
19708	**97X358**	2002 SR Entry#	87	WA7697/A96330	WA7697//MADSEN/WA6910	2
19709	**97X358**	2002 SR Entry#	325	WA7697/A96330	WA7697//MADSEN/WA6910	2
19710	**97X358**	2002 SR Entry#	83	WA7697/A96330	WA7697//MADSEN/WA6910	2
19711	**97X358**	2002 SR Entry#	61	WA7697/A96330	WA7697//MADSEN/WA6910	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19712	**97X358**	2002 SR Entry#	344	WA7697/A96330	WA7697//MADSEN/WA6910	2
19713	**97X358**	2002 SR Entry#	25	WA7697/A96330	WA7697//MADSEN/WA6910	2
19714	**97X358**	2002 SR Entry#	260	WA7697/A96330	WA7697//MADSEN/WA6910	2
19715	**97X358**	2002 SR Entry#	33	WA7697/A96330	WA7697//MADSEN/WA6910	2
19716	**97X358**	2002 SR Entry#	285	WA7697/A96330	WA7697//MADSEN/WA6910	2
19717	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19718	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19719	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19720	**Barley**	2002 Winter		Barley	Barley	2
19721	**97X358**	2002 SR Entry#	261	WA7697/A96330	WA7697//MADSEN/WA6910	2
19722	**97X358**	2002 SR Entry#	229	WA7697/A96330	WA7697//MADSEN/WA6910	2
19723	**97X358**	2002 SR Entry#	112	WA7697/A96330	WA7697//MADSEN/WA6910	2
19724	**97X358**	2002 SR Entry#	233	WA7697/A96330	WA7697//MADSEN/WA6910	2
19725	**97X358**	2002 SR Entry#	247	WA7697/A96330	WA7697//MADSEN/WA6910	2
19726	**97X358**	2002 SR Entry#	192	WA7697/A96330	WA7697//MADSEN/WA6910	2
19727	**97X358**	2002 SR Entry#	293	WA7697/A96330	WA7697//MADSEN/WA6910	2
19728	**97X358**	2002 SR Entry#	338	WA7697/A96330	WA7697//MADSEN/WA6910	2
19729	**97X358**	2002 SR Entry#	231	WA7697/A96330	WA7697//MADSEN/WA6910	2
19730	**97X358**	2002 SR Entry#	194	WA7697/A96330	WA7697//MADSEN/WA6910	2
19731	**97X358**	2002 SR Entry#	271	WA7697/A96330	WA7697//MADSEN/WA6910	2
19732	**97X358**	2002 SR Entry#	135	WA7697/A96330	WA7697//MADSEN/WA6910	2
19733	**97X358**	2002 SR Entry#	64	WA7697/A96330	WA7697//MADSEN/WA6910	2
19734	**97X358**	2002 SR Entry#	234	WA7697/A96330	WA7697//MADSEN/WA6910	2
19735	**97X358**	2002 SR Entry#	139	WA7697/A96330	WA7697//MADSEN/WA6910	2
19736	**97X358**	2002 SR Entry#	270	WA7697/A96330	WA7697//MADSEN/WA6910	2
19737	**97X358**	2002 SR Entry#	97	WA7697/A96330	WA7697//MADSEN/WA6910	2
19738	**97X358**	2002 SR Entry#	136	WA7697/A96330	WA7697//MADSEN/WA6910	2
19739	**97X358**	2002 SR Entry#	160	WA7697/A96330	WA7697//MADSEN/WA6910	2
19740	**97X358**	2002 SR Entry#	318	WA7697/A96330	WA7697//MADSEN/WA6910	2
19741	**97X358**	2002 SR Entry#	183	WA7697/A96330	WA7697//MADSEN/WA6910	2
19742	**97X358**	2002 SR Entry#	182	WA7697/A96330	WA7697//MADSEN/WA6910	2
19743	**97X358**	2002 SR Entry#	324	WA7697/A96330	WA7697//MADSEN/WA6910	2
19744	**97X358**	2002 SR Entry#	54	WA7697/A96330	WA7697//MADSEN/WA6910	2
19745	**97X358**	2002 SR Entry#	241	WA7697/A96330	WA7697//MADSEN/WA6910	2
19746	**97X358**	2002 SR Entry#	350	WA7697/A96330	WA7697//MADSEN/WA6910	2
19747	**97X358**	2002 SR Entry#	206	WA7697/A96330	WA7697//MADSEN/WA6910	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19748	**97X358**	2002 SR Entry#	122	WA7697/A96330	WA7697//MADSEN/WA6910	2
19749	**97X358**	2002 SR Entry#	123	WA7697/A96330	WA7697//MADSEN/WA6910	2
19750	**97X358**	2002 SR Entry#	90	WA7697/A96330	WA7697//MADSEN/WA6910	2
19751	**97X358**	2002 SR Entry#	65	WA7697/A96330	WA7697//MADSEN/WA6910	2
19752	**97X358**	2002 SR Entry#	80	WA7697/A96330	WA7697//MADSEN/WA6910	2
19753	**97X358**	2002 SR Entry#	98	WA7697/A96330	WA7697//MADSEN/WA6910	2
19754	**97X358**	2002 SR Entry#	94	WA7697/A96330	WA7697//MADSEN/WA6910	2
19755	**97X358**	2002 SR Entry#	222	WA7697/A96330	WA7697//MADSEN/WA6910	2
19756	**97X358**	2002 SR Entry#	258	WA7697/A96330	WA7697//MADSEN/WA6910	2
19757	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19758	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19759	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19760	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19761	**97X358**	2002 SR Entry#	30	WA7697/A96330	WA7697//MADSEN/WA6910	2
19762	**97X358**	2002 SR Entry#	143	WA7697/A96330	WA7697//MADSEN/WA6910	2
19763	**97X358**	2002 SR Entry#	294	WA7697/A96330	WA7697//MADSEN/WA6910	2
19764	**97X358**	2002 SR Entry#	302	WA7697/A96330	WA7697//MADSEN/WA6910	2
19765	**97X358**	2002 SR Entry#	78	WA7697/A96330	WA7697//MADSEN/WA6910	2
19766	**97X358**	2002 SR Entry#	210	WA7697/A96330	WA7697//MADSEN/WA6910	2
19767	**97X358**	2002 SR Entry#	243	WA7697/A96330	WA7697//MADSEN/WA6910	2
19768	**97X358**	2002 SR Entry#	29	WA7697/A96330	WA7697//MADSEN/WA6910	2
19769	**97X358**	2002 SR Entry#	151	WA7697/A96330	WA7697//MADSEN/WA6910	2
19770	**97X358**	2002 SR Entry#	305	WA7697/A96330	WA7697//MADSEN/WA6910	2
19771	**97X358**	2002 SR Entry#	104	WA7697/A96330	WA7697//MADSEN/WA6910	2
19772	**97X358**	2002 SR Entry#	252	WA7697/A96330	WA7697//MADSEN/WA6910	2
19773	**97X358**	2002 SR Entry#	203	WA7697/A96330	WA7697//MADSEN/WA6910	2
19774	**97X358**	2002 SR Entry#	102	WA7697/A96330	WA7697//MADSEN/WA6910	2
19775	**97X358**	2002 SR Entry#	84	WA7697/A96330	WA7697//MADSEN/WA6910	2
19776	**97X358**	2002 SR Entry#	190	WA7697/A96330	WA7697//MADSEN/WA6910	2
19777	**97X358**	2002 SR Entry#	44	WA7697/A96330	WA7697//MADSEN/WA6910	2
19778	**97X358**	2002 SR Entry#	334	WA7697/A96330	WA7697//MADSEN/WA6910	2
19779	**97X358**	2002 SR Entry#	133	WA7697/A96330	WA7697//MADSEN/WA6910	2
19780	**97X358**	2002 SR Entry#	279	WA7697/A96330	WA7697//MADSEN/WA6910	2
19781	**97X358**	2002 SR Entry#	242	WA7697/A96330	WA7697//MADSEN/WA6910	2
19782	**97X358**	2002 SR Entry#	287	WA7697/A96330	WA7697//MADSEN/WA6910	2
19783	**97X358**	2002 SR Entry#	253	WA7697/A96330	WA7697//MADSEN/WA6910	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
19784	**97X358**	2002 SR Entry#	51	WA7697/A96330	WA7697//MADSEN/WA6910	2
19785	**97X358**	2002 SR Entry#	246	WA7697/A96330	WA7697//MADSEN/WA6910	2
19786	**97X358**	2002 SR Entry#	221	WA7697/A96330	WA7697//MADSEN/WA6910	2
19787	**97X358**	2002 SR Entry#	150	WA7697/A96330	WA7697//MADSEN/WA6910	2
19788	**97X358**	2002 SR Entry#	205	WA7697/A96330	WA7697//MADSEN/WA6910	2
19789	**97X358**	2002 SR Entry#	265	WA7697/A96330	WA7697//MADSEN/WA6910	2
19790	**WA7697**			STEPHENS//SU92/3*OMAR	STEPHENS//SU92/3*OMAR	2
19791	**A96330**			MDN/WA6910	84X111 VPM/M951/YMH/HYS//HILL81///WA6910	2
19792	**A9622**			WA7665/RULO	WA7665/RULO	2
19793	**97X230**	2002 SR Entry#	229	WA7697/A9622	WA7697//WA7665/RULO	2
19794	**97X230**	2002 SR Entry#	78	WA7697/A9622	WA7697//WA7665/RULO	2
19795	**97X230**	2002 SR Entry#	289	WA7697/A9622	WA7697//WA7665/RULO	2
19796	**97X230**	2002 SR Entry#	261	WA7697/A9622	WA7697//WA7665/RULO	2
19797	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19798	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19799	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19800	**Barley**	2002 Winter		Barley	Barley	2
19801	**97X230**	2002 SR Entry#	33	WA7697/A9622	WA7697//WA7665/RULO	2
19802	**97X230**	2002 SR Entry#	298	WA7697/A9622	WA7697//WA7665/RULO	2
19803	**97X230**	2002 SR Entry#	344	WA7697/A9622	WA7697//WA7665/RULO	2
19804	**97X230**	2002 SR Entry#	86	WA7697/A9622	WA7697//WA7665/RULO	2
19805	**97X230**	2002 SR Entry#	225	WA7697/A9622	WA7697//WA7665/RULO	2
19806	**97X230**	2002 SR Entry#	280	WA7697/A9622	WA7697//WA7665/RULO	2
19807	**97X230**	2002 SR Entry#	207	WA7697/A9622	WA7697//WA7665/RULO	2
19808	**97X230**	2002 SR Entry#	257	WA7697/A9622	WA7697//WA7665/RULO	2
19809	**97X230**	2002 SR Entry#	180	WA7697/A9622	WA7697//WA7665/RULO	2
19810	**97X230**	2002 SR Entry#	56	WA7697/A9622	WA7697//WA7665/RULO	2
19811	**97X230**	2002 SR Entry#	83	WA7697/A9622	WA7697//WA7665/RULO	2
19812	**97X230**	2002 SR Entry#	113	WA7697/A9622	WA7697//WA7665/RULO	2
19813	**97X230**	2002 SR Entry#	251	WA7697/A9622	WA7697//WA7665/RULO	2
19814	**97X230**	2002 SR Entry#	218	WA7697/A9622	WA7697//WA7665/RULO	2
19815	**97X230**	2002 SR Entry#	296	WA7697/A9622	WA7697//WA7665/RULO	2
19816	**97X230**	2002 SR Entry#	178	WA7697/A9622	WA7697//WA7665/RULO	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19817	**97X230**	2002 SR Entry#	237	WA7697/A9622	WA7697//WA7665/RULO	2
19818	**97X230**	2002 SR Entry#	292	WA7697/A9622	WA7697//WA7665/RULO	2
19819	**97X230**	2002 SR Entry#	255	WA7697/A9622	WA7697//WA7665/RULO	2
19820	**97X230**	2002 SR Entry#	97	WA7697/A9622	WA7697//WA7665/RULO	2
19821	**97X230**	2002 SR Entry#	186	WA7697/A9622	WA7697//WA7665/RULO	2
19822	**97X230**	2002 SR Entry#	46	WA7697/A9622	WA7697//WA7665/RULO	2
19823	**97X230**	2002 SR Entry#	332	WA7697/A9622	WA7697//WA7665/RULO	2
19824	**97X230**	2002 SR Entry#	124	WA7697/A9622	WA7697//WA7665/RULO	2
19825	**97X230**	2002 SR Entry#	60	WA7697/A9622	WA7697//WA7665/RULO	2
19826	**97X230**	2002 SR Entry#	18	WA7697/A9622	WA7697//WA7665/RULO	2
19827	**97X230**	2002 SR Entry#	10	WA7697/A9622	WA7697//WA7665/RULO	2
19828	**97X230**	2002 SR Entry#	4	WA7697/A9622	WA7697//WA7665/RULO	2
19829	**97X230**	2002 SR Entry#	31	WA7697/A9622	WA7697//WA7665/RULO	2
19830	**97X230**	2002 SR Entry#	34	WA7697/A9622	WA7697//WA7665/RULO	2
19831	**97X230**	2002 SR Entry#	137	WA7697/A9622	WA7697//WA7665/RULO	2
19832	**97X230**	2002 SR Entry#	90	WA7697/A9622	WA7697//WA7665/RULO	2
19833	**97X230**	2002 SR Entry#	58	WA7697/A9622	WA7697//WA7665/RULO	2
19834	**97X230**	2002 SR Entry#	209	WA7697/A9622	WA7697//WA7665/RULO	2
19835	**97X230**	2002 SR Entry#	123	WA7697/A9622	WA7697//WA7665/RULO	2
19836	**97X230**	2002 SR Entry#	163	WA7697/A9622	WA7697//WA7665/RULO	2
19837	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19838	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19839	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19840	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19841	**97X230**	2002 SR Entry#	265	WA7697/A9622	WA7697//WA7665/RULO	2
19842	**97X230**	2002 SR Entry#	79	WA7697/A9622	WA7697//WA7665/RULO	2
19843	**97X230**	2002 SR Entry#	9	WA7697/A9622	WA7697//WA7665/RULO	2
19844	**97X230**	2002 SR Entry#	129	WA7697/A9622	WA7697//WA7665/RULO	2
19845	**97X230**	2002 SR Entry#	41	WA7697/A9622	WA7697//WA7665/RULO	2
19846	**97X230**	2002 SR Entry#	65	WA7697/A9622	WA7697//WA7665/RULO	2
19847	**97X230**	2002 SR Entry#	286	WA7697/A9622	WA7697//WA7665/RULO	2
19848	**97X230**	2002 SR Entry#	202	WA7697/A9622	WA7697//WA7665/RULO	2
19849	**97X230**	2002 SR Entry#	279	WA7697/A9622	WA7697//WA7665/RULO	2
19850	**97X230**	2002 SR Entry#	55	WA7697/A9622	WA7697//WA7665/RULO	2
19851	**97X230**	2002 SR Entry#	305	WA7697/A9622	WA7697//WA7665/RULO	2
19852	**97X230**	2002 SR Entry#	240	WA7697/A9622	WA7697//WA7665/RULO	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19853	**97X230**	2002 SR Entry#	336	WA7697/A9622	WA7697//WA7665/RULO	2
19854	**97X230**	2002 SR Entry#	307	WA7697/A9622	WA7697//WA7665/RULO	2
19855	**97X230**	2002 SR Entry#	212	WA7697/A9622	WA7697//WA7665/RULO	2
19856	**97X230**	2002 SR Entry#	191	WA7697/A9622	WA7697//WA7665/RULO	2
19857	**97X230**	2002 SR Entry#	193	WA7697/A9622	WA7697//WA7665/RULO	2
19858	**97X230**	2002 SR Entry#	122	WA7697/A9622	WA7697//WA7665/RULO	2
19859	**97X230**	2002 SR Entry#	185	WA7697/A9622	WA7697//WA7665/RULO	2
19860	**97X230**	2002 SR Entry#	118	WA7697/A9622	WA7697//WA7665/RULO	2
19861	**97X230**	2002 SR Entry#	147	WA7697/A9622	WA7697//WA7665/RULO	2
19862	**97X230**	2002 SR Entry#	70	WA7697/A9622	WA7697//WA7665/RULO	2
19863	**97X230**	2002 SR Entry#	211	WA7697/A9622	WA7697//WA7665/RULO	2
19864	**97X230**	2002 SR Entry#	206	WA7697/A9622	WA7697//WA7665/RULO	2
19865	**97X230**	2002 SR Entry#	150	WA7697/A9622	WA7697//WA7665/RULO	2
19866	**97X230**	2002 SR Entry#	134	WA7697/A9622	WA7697//WA7665/RULO	2
19867	**97X230**	2002 SR Entry#	115	WA7697/A9622	WA7697//WA7665/RULO	2
19868	**97X230**	2002 SR Entry#	196	WA7697/A9622	WA7697//WA7665/RULO	2
19869	**97X230**	2002 SR Entry#	330	WA7697/A9622	WA7697//WA7665/RULO	2
19870	**97X230**	2002 SR Entry#	80	WA7697/A9622	WA7697//WA7665/RULO	2
19871	**97X230**	2002 SR Entry#	228	WA7697/A9622	WA7697//WA7665/RULO	2
19872	**97X230**	2002 SR Entry#	14	WA7697/A9622	WA7697//WA7665/RULO	2
19873	**97X230**	2002 SR Entry#	260	WA7697/A9622	WA7697//WA7665/RULO	2
19874	**97X230**	2002 SR Entry#	200	WA7697/A9622	WA7697//WA7665/RULO	2
19875	**97X230**	2002 SR Entry#	267	WA7697/A9622	WA7697//WA7665/RULO	2
19876	**97X230**	2002 SR Entry#	159	WA7697/A9622	WA7697//WA7665/RULO	2
19877	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19878	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19879	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19880	**Barley**	2002 Winter		Barley	Barley	2
19881	**97X230**	2002 SR Entry#	294	WA7697/A9622	WA7697//WA7665/RULO	2
19882	**97X230**	2002 SR Entry#	112	WA7697/A9622	WA7697//WA7665/RULO	2
19883	**97X230**	2002 SR Entry#	133	WA7697/A9622	WA7697//WA7665/RULO	2
19884	**97X230**	2002 SR Entry#	151	WA7697/A9622	WA7697//WA7665/RULO	2
19885	**97X230**	2002 SR Entry#	77	WA7697/A9622	WA7697//WA7665/RULO	2
19886	**97X230**	2002 SR Entry#	51	WA7697/A9622	WA7697//WA7665/RULO	2
19887	**97X230**	2002 SR Entry#	76	WA7697/A9622	WA7697//WA7665/RULO	2
19888	**97X230**	2002 SR Entry#	311	WA7697/A9622	WA7697//WA7665/RULO	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19889	**97X230**	2002 SR Entry#	68	WA7697/A9622	WA7697//WA7665/RULO	2
19890	**97X230**	2002 SR Entry#	166	WA7697/A9622	WA7697//WA7665/RULO	2
19891	**97X230**	2002 SR Entry#	172	WA7697/A9622	WA7697//WA7665/RULO	2
19892	**97X230**	2002 SR Entry#	273	WA7697/A9622	WA7697//WA7665/RULO	2
19893	**97X230**	2002 SR Entry#	59	WA7697/A9622	WA7697//WA7665/RULO	2
19894	**97X230**	2002 SR Entry#	188	WA7697/A9622	WA7697//WA7665/RULO	2
19895	**97X230**	2002 SR Entry#	88	WA7697/A9622	WA7697//WA7665/RULO	2
19896	**97X230**	2002 SR Entry#	187	WA7697/A9622	WA7697//WA7665/RULO	2
19897	**97X230**	2002 SR Entry#	217	WA7697/A9622	WA7697//WA7665/RULO	2
19898	**97X230**	2002 SR Entry#	30	WA7697/A9622	WA7697//WA7665/RULO	2
19899	**97X230**	2002 SR Entry#	239	WA7697/A9622	WA7697//WA7665/RULO	2
19900	**97X230**	2002 SR Entry#	256	WA7697/A9622	WA7697//WA7665/RULO	2
19901	**97X230**	2002 SR Entry#	66	WA7697/A9622	WA7697//WA7665/RULO	2
19902	**97X230**	2002 SR Entry#	50	WA7697/A9622	WA7697//WA7665/RULO	2
19903	**97X230**	2002 SR Entry#	190	WA7697/A9622	WA7697//WA7665/RULO	2
19904	**97X230**	2002 SR Entry#	222	WA7697/A9622	WA7697//WA7665/RULO	2
19905	**97X230**	2002 SR Entry#	95	WA7697/A9622	WA7697//WA7665/RULO	2
19906	**97X230**	2002 SR Entry#	36	WA7697/A9622	WA7697//WA7665/RULO	2
19907	**97X230**	2002 SR Entry#	39	WA7697/A9622	WA7697//WA7665/RULO	2
19908	**97X230**	2002 SR Entry#	91	WA7697/A9622	WA7697//WA7665/RULO	2
19909	**97X230**	2002 SR Entry#	189	WA7697/A9622	WA7697//WA7665/RULO	2
19910	**97X230**	2002 SR Entry#	203	WA7697/A9622	WA7697//WA7665/RULO	2
19911	**97X230**	2002 SR Entry#	168	WA7697/A9622	WA7697//WA7665/RULO	2
19912	**97X230**	2002 SR Entry#	230	WA7697/A9622	WA7697//WA7665/RULO	2
19913	**97X230**	2002 SR Entry#	85	WA7697/A9622	WA7697//WA7665/RULO	2
19914	**97X230**	2002 SR Entry#	45	WA7697/A9622	WA7697//WA7665/RULO	2
19915	**97X230**	2002 SR Entry#	126	WA7697/A9622	WA7697//WA7665/RULO	2
19916	**97X230**	2002 SR Entry#	295	WA7697/A9622	WA7697//WA7665/RULO	2
19917	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19918	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19919	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19920	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19921	**97X230**	2002 SR Entry#	277	WA7697/A9622	WA7697//WA7665/RULO	2
19922	**97X230**	2002 SR Entry#	179	WA7697/A9622	WA7697//WA7665/RULO	2
19923	**97X230**	2002 SR Entry#	149	WA7697/A9622	WA7697//WA7665/RULO	2
19924	**97X230**	2002 SR Entry#	121	WA7697/A9622	WA7697//WA7665/RULO	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19925	**97X230**	2002 SR Entry#	142	WA7697/A9622	WA7697//WA7665/RULO	2
19926	**97X230**	2002 SR Entry#	198	WA7697/A9622	WA7697//WA7665/RULO	2
19927	**97X230**	2002 SR Entry#	252	WA7697/A9622	WA7697//WA7665/RULO	2
19928	**97X230**	2002 SR Entry#	155	WA7697/A9622	WA7697//WA7665/RULO	2
19929	**97X230**	2002 SR Entry#	244	WA7697/A9622	WA7697//WA7665/RULO	2
19930	**97X230**	2002 SR Entry#	170	WA7697/A9622	WA7697//WA7665/RULO	2
19931	**97X230**	2002 SR Entry#	117	WA7697/A9622	WA7697//WA7665/RULO	2
19932	**97X230**	2002 SR Entry#	26	WA7697/A9622	WA7697//WA7665/RULO	2
19933	**97X230**	2002 SR Entry#	141	WA7697/A9622	WA7697//WA7665/RULO	2
19934	**97X230**	2002 SR Entry#	281	WA7697/A9622	WA7697//WA7665/RULO	2
19935	**97X230**	2002 SR Entry#	143	WA7697/A9622	WA7697//WA7665/RULO	2
19936	**97X230**	2002 SR Entry#	57	WA7697/A9622	WA7697//WA7665/RULO	2
19937	**97X230**	2002 SR Entry#	98	WA7697/A9622	WA7697//WA7665/RULO	2
19938	**97X230**	2002 SR Entry#	63	WA7697/A9622	WA7697//WA7665/RULO	2
19939	**97X230**	2002 SR Entry#	338	WA7697/A9622	WA7697//WA7665/RULO	2
19940	**97X230**	2002 SR Entry#	234	WA7697/A9622	WA7697//WA7665/RULO	2
19941	**97X230**	2002 SR Entry#	71	WA7697/A9622	WA7697//WA7665/RULO	2
19942	**97X230**	2002 SR Entry#	127	WA7697/A9622	WA7697//WA7665/RULO	2
19943	**97X230**	2002 SR Entry#	195	WA7697/A9622	WA7697//WA7665/RULO	2
19944	**97X230**	2002 SR Entry#	174	WA7697/A9622	WA7697//WA7665/RULO	2
19945	**97X230**	2002 SR Entry#	263	WA7697/A9622	WA7697//WA7665/RULO	2
19946	**97X230**	2002 SR Entry#	23	WA7697/A9622	WA7697//WA7665/RULO	2
19947	**97X230**	2002 SR Entry#	87	WA7697/A9622	WA7697//WA7665/RULO	2
19948	**97X230**	2002 SR Entry#	111	WA7697/A9622	WA7697//WA7665/RULO	2
19949	**97X230**	2002 SR Entry#	67	WA7697/A9622	WA7697//WA7665/RULO	2
19950	**97X230**	2002 SR Entry#	1	WA7697/A9622	WA7697//WA7665/RULO	2
19951	**97X230**	2002 SR Entry#	11	WA7697/A9622	WA7697//WA7665/RULO	2
19952	**97X230**	2002 SR Entry#	181	WA7697/A9622	WA7697//WA7665/RULO	2
19953	**97X230**	2002 SR Entry#	320	WA7697/A9622	WA7697//WA7665/RULO	2
19954	**97X230**	2002 SR Entry#	175	WA7697/A9622	WA7697//WA7665/RULO	2
19955	**97X230**	2002 SR Entry#	276	WA7697/A9622	WA7697//WA7665/RULO	2
19956	**97X230**	2002 SR Entry#	274	WA7697/A9622	WA7697//WA7665/RULO	2
19957	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19958	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19959	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19960	**Barley**	2002 Winter		Barley	Barley	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19961	**97X230**	2002 SR Entry#	12	WA7697/A9622	WA7697//WA7665/RULO	2
19962	**97X230**	2002 SR Entry#	99	WA7697/A9622	WA7697//WA7665/RULO	2
19963	**97X230**	2002 SR Entry#	204	WA7697/A9622	WA7697//WA7665/RULO	2
19964	**97X230**	2002 SR Entry#	24	WA7697/A9622	WA7697//WA7665/RULO	2
19965	**97X230**	2002 SR Entry#	262	WA7697/A9622	WA7697//WA7665/RULO	2
19966	**97X230**	2002 SR Entry#	27	WA7697/A9622	WA7697//WA7665/RULO	2
19967	**97X230**	2002 SR Entry#	82	WA7697/A9622	WA7697//WA7665/RULO	2
19968	**97X230**	2002 SR Entry#	197	WA7697/A9622	WA7697//WA7665/RULO	2
19969	**97X230**	2002 SR Entry#	49	WA7697/A9622	WA7697//WA7665/RULO	2
19970	**97X230**	2002 SR Entry#	108	WA7697/A9622	WA7697//WA7665/RULO	2
19971	**97X230**	2002 SR Entry#	43	WA7697/A9622	WA7697//WA7665/RULO	2
19972	**97X230**	2002 SR Entry#	268	WA7697/A9622	WA7697//WA7665/RULO	2
19973	**97X230**	2002 SR Entry#	214	WA7697/A9622	WA7697//WA7665/RULO	2
19974	**97X230**	2002 SR Entry#	284	WA7697/A9622	WA7697//WA7665/RULO	2
19975	**97X230**	2002 SR Entry#	158	WA7697/A9622	WA7697//WA7665/RULO	2
19976	**97X230**	2002 SR Entry#	140	WA7697/A9622	WA7697//WA7665/RULO	2
19977	**97X230**	2002 SR Entry#	109	WA7697/A9622	WA7697//WA7665/RULO	2
19978	**97X230**	2002 SR Entry#	259	WA7697/A9622	WA7697//WA7665/RULO	2
19979	**97X230**	2002 SR Entry#	316	WA7697/A9622	WA7697//WA7665/RULO	2
19980	**97X230**	2002 SR Entry#	100	WA7697/A9622	WA7697//WA7665/RULO	2
19981	**97X230**	2002 SR Entry#	25	WA7697/A9622	WA7697//WA7665/RULO	2
19982	**97X230**	2002 SR Entry#	29	WA7697/A9622	WA7697//WA7665/RULO	2
19983	**97X230**	2002 SR Entry#	248	WA7697/A9622	WA7697//WA7665/RULO	2
19984	**97X230**	2002 SR Entry#	132	WA7697/A9622	WA7697//WA7665/RULO	2
19985	**97X230**	2002 SR Entry#	241	WA7697/A9622	WA7697//WA7665/RULO	2
19986	**97X230**	2002 SR Entry#	114	WA7697/A9622	WA7697//WA7665/RULO	2
19987	**97X230**	2002 SR Entry#	272	WA7697/A9622	WA7697//WA7665/RULO	2
19988	**97X230**	2002 SR Entry#	106	WA7697/A9622	WA7697//WA7665/RULO	2
19989	**97X230**	2002 SR Entry#	285	WA7697/A9622	WA7697//WA7665/RULO	2
19990	**97X230**	2002 SR Entry#	224	WA7697/A9622	WA7697//WA7665/RULO	2
19991	**97X230**	2002 SR Entry#	94	WA7697/A9622	WA7697//WA7665/RULO	2
19992	**97X230**	2002 SR Entry#	220	WA7697/A9622	WA7697//WA7665/RULO	2
19993	**97X230**	2002 SR Entry#	44	WA7697/A9622	WA7697//WA7665/RULO	2
19994	**97X230**	2002 SR Entry#	120	WA7697/A9622	WA7697//WA7665/RULO	2
19995	**97X230**	2002 SR Entry#	2	WA7697/A9622	WA7697//WA7665/RULO	2
19996	**97X230**	2002 SR Entry#	303	WA7697/A9622	WA7697//WA7665/RULO	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
19997	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19998	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
19999	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
20000	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
20001	**97X230**	2002 SR Entry#	28	WA7697/A9622	WA7697//WA7665/RULO	2
20002	**97X230**	2002 SR Entry#	144	WA7697/A9622	WA7697//WA7665/RULO	2
20003	**97X230**	2002 SR Entry#	3	WA7697/A9622	WA7697//WA7665/RULO	2
20004	**97X230**	2002 SR Entry#	35	WA7697/A9622	WA7697//WA7665/RULO	2
20005	**97X230**	2002 SR Entry#	233	WA7697/A9622	WA7697//WA7665/RULO	2
20006	**97X230**	2002 SR Entry#	157	WA7697/A9622	WA7697//WA7665/RULO	2
20007	**97X230**	2002 SR Entry#	52	WA7697/A9622	WA7697//WA7665/RULO	2
20008	**97X230**	2002 SR Entry#	84	WA7697/A9622	WA7697//WA7665/RULO	2
20009	**97X230**	2002 SR Entry#	5	WA7697/A9622	WA7697//WA7665/RULO	2
20010	**97X230**	2002 SR Entry#	301	WA7697/A9622	WA7697//WA7665/RULO	2
20011	**97X230**	2002 SR Entry#	269	WA7697/A9622	WA7697//WA7665/RULO	2
20012	**97X230**	2002 SR Entry#	110	WA7697/A9622	WA7697//WA7665/RULO	2
20013	**97X230**	2002 SR Entry#	162	WA7697/A9622	WA7697//WA7665/RULO	2
20014	**97X230**	2002 SR Entry#	22	WA7697/A9622	WA7697//WA7665/RULO	2
20015	**97X230**	2002 SR Entry#	16	WA7697/A9622	WA7697//WA7665/RULO	2
20016	**97X230**	2002 SR Entry#	135	WA7697/A9622	WA7697//WA7665/RULO	2
20017	**97X230**	2002 SR Entry#	75	WA7697/A9622	WA7697//WA7665/RULO	2
20018	**97X230**	2002 SR Entry#	300	WA7697/A9622	WA7697//WA7665/RULO	2
20019	**97X230**	2002 SR Entry#	223	WA7697/A9622	WA7697//WA7665/RULO	2
20020	**97X230**	2002 SR Entry#	329	WA7697/A9622	WA7697//WA7665/RULO	2
20021	**97X230**	2002 SR Entry#	278	WA7697/A9622	WA7697//WA7665/RULO	2
20022	**97X230**	2002 SR Entry#	283	WA7697/A9622	WA7697//WA7665/RULO	2
20023	**97X230**	2002 SR Entry#	37	WA7697/A9622	WA7697//WA7665/RULO	2
20024	**97X230**	2002 SR Entry#	54	WA7697/A9622	WA7697//WA7665/RULO	2
20025	**97X230**	2002 SR Entry#	319	WA7697/A9622	WA7697//WA7665/RULO	2
20026	**97X230**	2002 SR Entry#	304	WA7697/A9622	WA7697//WA7665/RULO	2
20027	**97X230**	2002 SR Entry#	247	WA7697/A9622	WA7697//WA7665/RULO	2
20028	**97X230**	2002 SR Entry#	48	WA7697/A9622	WA7697//WA7665/RULO	2
20029	**97X230**	2002 SR Entry#	145	WA7697/A9622	WA7697//WA7665/RULO	2
20030	**97X230**	2002 SR Entry#	308	WA7697/A9622	WA7697//WA7665/RULO	2
20031	**97X230**	2002 SR Entry#	8	WA7697/A9622	WA7697//WA7665/RULO	2
20032	**97X230**	2002 SR Entry#	128	WA7697/A9622	WA7697//WA7665/RULO	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20033	**97X230**	2002 SR Entry#	221	WA7697/A9622	WA7697//WA7665/RULO	2
20034	**97X230**	2002 SR Entry#	38	WA7697/A9622	WA7697//WA7665/RULO	2
20035	**97X230**	2002 SR Entry#	6	WA7697/A9622	WA7697//WA7665/RULO	2
20036	**97X230**	2002 SR Entry#	254	WA7697/A9622	WA7697//WA7665/RULO	2
20037	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
20038	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
20039	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
20040	**Barley**	2002 Winter		Barley	Barley	2
20041	**97X230**	2002 SR Entry#	61	WA7697/A9622	WA7697//WA7665/RULO	2
20042	**97X230**	2002 SR Entry#	139	WA7697/A9622	WA7697//WA7665/RULO	2
20043	**97X230**	2002 SR Entry#	40	WA7697/A9622	WA7697//WA7665/RULO	2
20044	**97X230**	2002 SR Entry#	17	WA7697/A9622	WA7697//WA7665/RULO	2
20045	**97X230**	2002 SR Entry#	125	WA7697/A9622	WA7697//WA7665/RULO	2
20046	**97X230**	2002 SR Entry#	107	WA7697/A9622	WA7697//WA7665/RULO	2
20047	**97X230**	2002 SR Entry#	287	WA7697/A9622	WA7697//WA7665/RULO	2
20048	**97X230**	2002 SR Entry#	328	WA7697/A9622	WA7697//WA7665/RULO	2
20049	**97X230**	2002 SR Entry#	215	WA7697/A9622	WA7697//WA7665/RULO	2
20050	**97X230**	2002 SR Entry#	130	WA7697/A9622	WA7697//WA7665/RULO	2
20051	**97X230**	2002 SR Entry#	20	WA7697/A9622	WA7697//WA7665/RULO	2
20052	**97X230**	2002 SR Entry#	154	WA7697/A9622	WA7697//WA7665/RULO	2
20053	**97X230**	2002 SR Entry#	136	WA7697/A9622	WA7697//WA7665/RULO	2
20054	**97X230**	2002 SR Entry#	315	WA7697/A9622	WA7697//WA7665/RULO	2
20055	**97X230**	2002 SR Entry#	243	WA7697/A9622	WA7697//WA7665/RULO	2
20056	**97X230**	2002 SR Entry#	208	WA7697/A9622	WA7697//WA7665/RULO	2
20057	**97X230**	2002 SR Entry#	96	WA7697/A9622	WA7697//WA7665/RULO	2
20058	**97X230**	2002 SR Entry#	169	WA7697/A9622	WA7697//WA7665/RULO	2
20059	**97X230**	2002 SR Entry#	15	WA7697/A9622	WA7697//WA7665/RULO	2
20060	**97X230**	2002 SR Entry#	21	WA7697/A9622	WA7697//WA7665/RULO	2
20061	**97X230**	2002 SR Entry#	270	WA7697/A9622	WA7697//WA7665/RULO	2
20062	**97X230**	2002 SR Entry#	72	WA7697/A9622	WA7697//WA7665/RULO	2
20063	**97X230**	2002 SR Entry#	146	WA7697/A9622	WA7697//WA7665/RULO	2
20064	**97X230**	2002 SR Entry#	199	WA7697/A9622	WA7697//WA7665/RULO	2
20065	**97X230**	2002 SR Entry#	42	WA7697/A9622	WA7697//WA7665/RULO	2
20066	**97X230**	2002 SR Entry#	148	WA7697/A9622	WA7697//WA7665/RULO	2
20067	**97X230**	2002 SR Entry#	32	WA7697/A9622	WA7697//WA7665/RULO	2
20068	**97X230**	2002 SR Entry#	19	WA7697/A9622	WA7697//WA7665/RULO	2

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
20069	**97X230**	2002 SR Entry#	232	WA7697/A9622	WA7697//WA7665/RULO	2
20070	**97X230**	2002 SR Entry#	53	WA7697/A9622	WA7697//WA7665/RULO	2
20071	**97X230**	2002 SR Entry#	250	WA7697/A9622	WA7697//WA7665/RULO	2
20072	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	2
20073	**WA7697**			STEPHENS//SU92/3*OMAR	STEPHENS//SU92/3*OMAR	3
20074	**A96330**			MDN/WA6910	84X111 VPM/M951/YMH/HYS//HILL81///WA6910	3
20075	**A9622**			WA7665/RULO	WA7665/RULO	3
20076	**SPN**	2000 WSCI		STEPHENS	STEPHENS	3
20077	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20078	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20079	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20080	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20081	**97X358**	2002 SR Entry#	313	WA7697/A96330	WA7697//MADSEN/WA6910	3
20082	**97X358**	2002 SR Entry#	159	WA7697/A96330	WA7697//MADSEN/WA6910	3
20083	**97X358**	2002 SR Entry#	144	WA7697/A96330	WA7697//MADSEN/WA6910	3
20084	**97X358**	2002 SR Entry#	92	WA7697/A96330	WA7697//MADSEN/WA6910	3
20085	**97X358**	2002 SR Entry#	255	WA7697/A96330	WA7697//MADSEN/WA6910	3
20086	**97X358**	2002 SR Entry#	327	WA7697/A96330	WA7697//MADSEN/WA6910	3
20087	**97X358**	2002 SR Entry#	130	WA7697/A96330	WA7697//MADSEN/WA6910	3
20088	**97X358**	2002 SR Entry#	56	WA7697/A96330	WA7697//MADSEN/WA6910	3
20089	**97X358**	2002 SR Entry#	227	WA7697/A96330	WA7697//MADSEN/WA6910	3
20090	**97X358**	2002 SR Entry#	53	WA7697/A96330	WA7697//MADSEN/WA6910	3
20091	**97X358**	2002 SR Entry#	312	WA7697/A96330	WA7697//MADSEN/WA6910	3
20092	**97X358**	2002 SR Entry#	286	WA7697/A96330	WA7697//MADSEN/WA6910	3
20093	**97X358**	2002 SR Entry#	140	WA7697/A96330	WA7697//MADSEN/WA6910	3
20094	**97X358**	2002 SR Entry#	95	WA7697/A96330	WA7697//MADSEN/WA6910	3
20095	**97X358**	2002 SR Entry#	240	WA7697/A96330	WA7697//MADSEN/WA6910	3
20096	**97X358**	2002 SR Entry#	18	WA7697/A96330	WA7697//MADSEN/WA6910	3
20097	**97X358**	2002 SR Entry#	70	WA7697/A96330	WA7697//MADSEN/WA6910	3
20098	**97X358**	2002 SR Entry#	57	WA7697/A96330	WA7697//MADSEN/WA6910	3
20099	**97X358**	2002 SR Entry#	47	WA7697/A96330	WA7697//MADSEN/WA6910	3
20100	**97X358**	2002 SR Entry#	329	WA7697/A96330	WA7697//MADSEN/WA6910	3
20101	**97X358**	2002 SR Entry#	196	WA7697/A96330	WA7697//MADSEN/WA6910	3
20102	**97X358**	2002 SR Entry#	114	WA7697/A96330	WA7697//MADSEN/WA6910	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20103	**97X358**	2002 SR Entry#	172	WA7697/A96330	WA7697//MADSEN/WA6910	3
20104	**97X358**	2002 SR Entry#	202	WA7697/A96330	WA7697//MADSEN/WA6910	3
20105	**97X358**	2002 SR Entry#	290	WA7697/A96330	WA7697//MADSEN/WA6910	3
20106	**97X358**	2002 SR Entry#	86	WA7697/A96330	WA7697//MADSEN/WA6910	3
20107	**97X358**	2002 SR Entry#	348	WA7697/A96330	WA7697//MADSEN/WA6910	3
20108	**97X358**	2002 SR Entry#	165	WA7697/A96330	WA7697//MADSEN/WA6910	3
20109	**97X358**	2002 SR Entry#	314	WA7697/A96330	WA7697//MADSEN/WA6910	3
20110	**97X358**	2002 SR Entry#	157	WA7697/A96330	WA7697//MADSEN/WA6910	3
20111	**97X358**	2002 SR Entry#	100	WA7697/A96330	WA7697//MADSEN/WA6910	3
20112	**97X358**	2002 SR Entry#	226	WA7697/A96330	WA7697//MADSEN/WA6910	3
20113	**97X358**	2002 SR Entry#	236	WA7697/A96330	WA7697//MADSEN/WA6910	3
20114	**97X358**	2002 SR Entry#	263	WA7697/A96330	WA7697//MADSEN/WA6910	3
20115	**97X358**	2002 SR Entry#	71	WA7697/A96330	WA7697//MADSEN/WA6910	3
20116	**97X358**	2002 SR Entry#	235	WA7697/A96330	WA7697//MADSEN/WA6910	3
20117	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20118	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20119	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20120	**Barley**	2002 Winter		Barley	Barley	3
20121	**97X358**	2002 SR Entry#	32	WA7697/A96330	WA7697//MADSEN/WA6910	3
20122	**97X358**	2002 SR Entry#	137	WA7697/A96330	WA7697//MADSEN/WA6910	3
20123	**97X358**	2002 SR Entry#	308	WA7697/A96330	WA7697//MADSEN/WA6910	3
20124	**97X358**	2002 SR Entry#	109	WA7697/A96330	WA7697//MADSEN/WA6910	3
20125	**97X358**	2002 SR Entry#	245	WA7697/A96330	WA7697//MADSEN/WA6910	3
20126	**97X358**	2002 SR Entry#	127	WA7697/A96330	WA7697//MADSEN/WA6910	3
20127	**97X358**	2002 SR Entry#	296	WA7697/A96330	WA7697//MADSEN/WA6910	3
20128	**97X358**	2002 SR Entry#	288	WA7697/A96330	WA7697//MADSEN/WA6910	3
20129	**97X358**	2002 SR Entry#	121	WA7697/A96330	WA7697//MADSEN/WA6910	3
20130	**97X358**	2002 SR Entry#	166	WA7697/A96330	WA7697//MADSEN/WA6910	3
20131	**97X358**	2002 SR Entry#	244	WA7697/A96330	WA7697//MADSEN/WA6910	3
20132	**97X358**	2002 SR Entry#	178	WA7697/A96330	WA7697//MADSEN/WA6910	3
20133	**97X358**	2002 SR Entry#	148	WA7697/A96330	WA7697//MADSEN/WA6910	3
20134	**97X358**	2002 SR Entry#	256	WA7697/A96330	WA7697//MADSEN/WA6910	3
20135	**97X358**	2002 SR Entry#	298	WA7697/A96330	WA7697//MADSEN/WA6910	3
20136	**97X358**	2002 SR Entry#	91	WA7697/A96330	WA7697//MADSEN/WA6910	3
20137	**97X358**	2002 SR Entry#	310	WA7697/A96330	WA7697//MADSEN/WA6910	3
20138	**97X358**	2002 SR Entry#	238	WA7697/A96330	WA7697//MADSEN/WA6910	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20139	**97X358**	2002 SR Entry#	124	WA7697/A96330	WA7697//MADSEN/WA6910	3
20140	**97X358**	2002 SR Entry#	40	WA7697/A96330	WA7697//MADSEN/WA6910	3
20141	**97X358**	2002 SR Entry#	239	WA7697/A96330	WA7697//MADSEN/WA6910	3
20142	**97X358**	2002 SR Entry#	230	WA7697/A96330	WA7697//MADSEN/WA6910	3
20143	**97X358**	2002 SR Entry#	138	WA7697/A96330	WA7697//MADSEN/WA6910	3
20144	**97X358**	2002 SR Entry#	320	WA7697/A96330	WA7697//MADSEN/WA6910	3
20145	**97X358**	2002 SR Entry#	179	WA7697/A96330	WA7697//MADSEN/WA6910	3
20146	**97X358**	2002 SR Entry#	248	WA7697/A96330	WA7697//MADSEN/WA6910	3
20147	**97X358**	2002 SR Entry#	273	WA7697/A96330	WA7697//MADSEN/WA6910	3
20148	**97X358**	2002 SR Entry#	117	WA7697/A96330	WA7697//MADSEN/WA6910	3
20149	**97X358**	2002 SR Entry#	277	WA7697/A96330	WA7697//MADSEN/WA6910	3
20150	**97X358**	2002 SR Entry#	297	WA7697/A96330	WA7697//MADSEN/WA6910	3
20151	**97X358**	2002 SR Entry#	176	WA7697/A96330	WA7697//MADSEN/WA6910	3
20152	**97X358**	2002 SR Entry#	326	WA7697/A96330	WA7697//MADSEN/WA6910	3
20153	**97X358**	2002 SR Entry#	275	WA7697/A96330	WA7697//MADSEN/WA6910	3
20154	**97X358**	2002 SR Entry#	341	WA7697/A96330	WA7697//MADSEN/WA6910	3
20155	**97X358**	2002 SR Entry#	257	WA7697/A96330	WA7697//MADSEN/WA6910	3
20156	**97X358**	2002 SR Entry#	346	WA7697/A96330	WA7697//MADSEN/WA6910	3
20157	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20158	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20159	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20160	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20161	**97X358**	2002 SR Entry#	81	WA7697/A96330	WA7697//MADSEN/WA6910	3
20162	**97X358**	2002 SR Entry#	254	WA7697/A96330	WA7697//MADSEN/WA6910	3
20163	**97X358**	2002 SR Entry#	164	WA7697/A96330	WA7697//MADSEN/WA6910	3
20164	**97X358**	2002 SR Entry#	108	WA7697/A96330	WA7697//MADSEN/WA6910	3
20165	**97X358**	2002 SR Entry#	60	WA7697/A96330	WA7697//MADSEN/WA6910	3
20166	**97X358**	2002 SR Entry#	251	WA7697/A96330	WA7697//MADSEN/WA6910	3
20167	**97X358**	2002 SR Entry#	31	WA7697/A96330	WA7697//MADSEN/WA6910	3
20168	**97X358**	2002 SR Entry#	119	WA7697/A96330	WA7697//MADSEN/WA6910	3
20169	**97X358**	2002 SR Entry#	154	WA7697/A96330	WA7697//MADSEN/WA6910	3
20170	**97X358**	2002 SR Entry#	301	WA7697/A96330	WA7697//MADSEN/WA6910	3
20171	**97X358**	2002 SR Entry#	272	WA7697/A96330	WA7697//MADSEN/WA6910	3
20172	**97X358**	2002 SR Entry#	281	WA7697/A96330	WA7697//MADSEN/WA6910	3
20173	**97X358**	2002 SR Entry#	335	WA7697/A96330	WA7697//MADSEN/WA6910	3
20174	**97X358**	2002 SR Entry#	284	WA7697/A96330	WA7697//MADSEN/WA6910	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
20175	**97X358**	2002 SR Entry#	283	WA7697/A96330	WA7697//MADSEN/WA6910	3
20176	**97X358**	2002 SR Entry#	309	WA7697/A96330	WA7697//MADSEN/WA6910	3
20177	**97X358**	2002 SR Entry#	111	WA7697/A96330	WA7697//MADSEN/WA6910	3
20178	**97X358**	2002 SR Entry#	292	WA7697/A96330	WA7697//MADSEN/WA6910	3
20179	**97X358**	2002 SR Entry#	311	WA7697/A96330	WA7697//MADSEN/WA6910	3
20180	**97X358**	2002 SR Entry#	89	WA7697/A96330	WA7697//MADSEN/WA6910	3
20181	**97X358**	2002 SR Entry#	101	WA7697/A96330	WA7697//MADSEN/WA6910	3
20182	**97X358**	2002 SR Entry#	141	WA7697/A96330	WA7697//MADSEN/WA6910	3
20183	**97X358**	2002 SR Entry#	195	WA7697/A96330	WA7697//MADSEN/WA6910	3
20184	**97X358**	2002 SR Entry#	262	WA7697/A96330	WA7697//MADSEN/WA6910	3
20185	**97X358**	2002 SR Entry#	187	WA7697/A96330	WA7697//MADSEN/WA6910	3
20186	**97X358**	2002 SR Entry#	115	WA7697/A96330	WA7697//MADSEN/WA6910	3
20187	**97X358**	2002 SR Entry#	276	WA7697/A96330	WA7697//MADSEN/WA6910	3
20188	**97X358**	2002 SR Entry#	278	WA7697/A96330	WA7697//MADSEN/WA6910	3
20189	**97X358**	2002 SR Entry#	266	WA7697/A96330	WA7697//MADSEN/WA6910	3
20190	**97X358**	2002 SR Entry#	228	WA7697/A96330	WA7697//MADSEN/WA6910	3
20191	**97X358**	2002 SR Entry#	300	WA7697/A96330	WA7697//MADSEN/WA6910	3
20192	**97X358**	2002 SR Entry#	295	WA7697/A96330	WA7697//MADSEN/WA6910	3
20193	**97X358**	2002 SR Entry#	337	WA7697/A96330	WA7697//MADSEN/WA6910	3
20194	**97X358**	2002 SR Entry#	116	WA7697/A96330	WA7697//MADSEN/WA6910	3
20195	**97X358**	2002 SR Entry#	69	WA7697/A96330	WA7697//MADSEN/WA6910	3
20196	**97X358**	2002 SR Entry#	149	WA7697/A96330	WA7697//MADSEN/WA6910	3
20197	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20198	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20199	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20200	**Barley**	2002 Winter		Barley	Barley	3
20201	**97X358**	2002 SR Entry#	82	WA7697/A96330	WA7697//MADSEN/WA6910	3
20202	**97X358**	2002 SR Entry#	225	WA7697/A96330	WA7697//MADSEN/WA6910	3
20203	**97X358**	2002 SR Entry#	299	WA7697/A96330	WA7697//MADSEN/WA6910	3
20204	**97X358**	2002 SR Entry#	349	WA7697/A96330	WA7697//MADSEN/WA6910	3
20205	**97X358**	2002 SR Entry#	322	WA7697/A96330	WA7697//MADSEN/WA6910	3
20206	**97X358**	2002 SR Entry#	316	WA7697/A96330	WA7697//MADSEN/WA6910	3
20207	**97X358**	2002 SR Entry#	5	WA7697/A96330	WA7697//MADSEN/WA6910	3
20208	**97X358**	2002 SR Entry#	291	WA7697/A96330	WA7697//MADSEN/WA6910	3
20209	**97X358**	2002 SR Entry#	268	WA7697/A96330	WA7697//MADSEN/WA6910	3
20210	**97X358**	2002 SR Entry#	55	WA7697/A96330	WA7697//MADSEN/WA6910	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
20211	**97X358**	2002 SR Entry#	79	WA7697/A96330	WA7697//MADSEN/WA6910	3
20212	**97X358**	2002 SR Entry#	323	WA7697/A96330	WA7697//MADSEN/WA6910	3
20213	**97X358**	2002 SR Entry#	68	WA7697/A96330	WA7697//MADSEN/WA6910	3
20214	**97X358**	2002 SR Entry#	289	WA7697/A96330	WA7697//MADSEN/WA6910	3
20215	**97X358**	2002 SR Entry#	264	WA7697/A96330	WA7697//MADSEN/WA6910	3
20216	**97X358**	2002 SR Entry#	10	WA7697/A96330	WA7697//MADSEN/WA6910	3
20217	**97X358**	2002 SR Entry#	340	WA7697/A96330	WA7697//MADSEN/WA6910	3
20218	**97X358**	2002 SR Entry#	188	WA7697/A96330	WA7697//MADSEN/WA6910	3
20219	**97X358**	2002 SR Entry#	204	WA7697/A96330	WA7697//MADSEN/WA6910	3
20220	**97X358**	2002 SR Entry#	306	WA7697/A96330	WA7697//MADSEN/WA6910	3
20221	**97X358**	2002 SR Entry#	158	WA7697/A96330	WA7697//MADSEN/WA6910	3
20222	**97X358**	2002 SR Entry#	175	WA7697/A96330	WA7697//MADSEN/WA6910	3
20223	**97X358**	2002 SR Entry#	331	WA7697/A96330	WA7697//MADSEN/WA6910	3
20224	**97X358**	2002 SR Entry#	330	WA7697/A96330	WA7697//MADSEN/WA6910	3
20225	**97X358**	2002 SR Entry#	269	WA7697/A96330	WA7697//MADSEN/WA6910	3
20226	**97X358**	2002 SR Entry#	168	WA7697/A96330	WA7697//MADSEN/WA6910	3
20227	**97X358**	2002 SR Entry#	249	WA7697/A96330	WA7697//MADSEN/WA6910	3
20228	**97X358**	2002 SR Entry#	274	WA7697/A96330	WA7697//MADSEN/WA6910	3
20229	**97X358**	2002 SR Entry#	267	WA7697/A96330	WA7697//MADSEN/WA6910	3
20230	**97X358**	2002 SR Entry#	96	WA7697/A96330	WA7697//MADSEN/WA6910	3
20231	**97X358**	2002 SR Entry#	177	WA7697/A96330	WA7697//MADSEN/WA6910	3
20232	**97X358**	2002 SR Entry#	118	WA7697/A96330	WA7697//MADSEN/WA6910	3
20233	**97X358**	2002 SR Entry#	134	WA7697/A96330	WA7697//MADSEN/WA6910	3
20234	**97X358**	2002 SR Entry#	282	WA7697/A96330	WA7697//MADSEN/WA6910	3
20235	**97X358**	2002 SR Entry#	201	WA7697/A96330	WA7697//MADSEN/WA6910	3
20236	**97X358**	2002 SR Entry#	48	WA7697/A96330	WA7697//MADSEN/WA6910	3
20237	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20238	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20239	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20240	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20241	**97X358**	2002 SR Entry#	209	WA7697/A96330	WA7697//MADSEN/WA6910	3
20242	**97X358**	2002 SR Entry#	63	WA7697/A96330	WA7697//MADSEN/WA6910	3
20243	**97X358**	2002 SR Entry#	319	WA7697/A96330	WA7697//MADSEN/WA6910	3
20244	**97X358**	2002 SR Entry#	170	WA7697/A96330	WA7697//MADSEN/WA6910	3
20245	**97X358**	2002 SR Entry#	317	WA7697/A96330	WA7697//MADSEN/WA6910	3
20246	**97X358**	2002 SR Entry#	105	WA7697/A96330	WA7697//MADSEN/WA6910	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20247	**97X358**	2002 SR Entry#	232	WA7697/A96330	WA7697//MADSEN/WA6910	3
20248	**97X358**	2002 SR Entry#	87	WA7697/A96330	WA7697//MADSEN/WA6910	3
20249	**97X358**	2002 SR Entry#	325	WA7697/A96330	WA7697//MADSEN/WA6910	3
20250	**97X358**	2002 SR Entry#	83	WA7697/A96330	WA7697//MADSEN/WA6910	3
20251	**97X358**	2002 SR Entry#	61	WA7697/A96330	WA7697//MADSEN/WA6910	3
20252	**97X358**	2002 SR Entry#	344	WA7697/A96330	WA7697//MADSEN/WA6910	3
20253	**97X358**	2002 SR Entry#	25	WA7697/A96330	WA7697//MADSEN/WA6910	3
20254	**97X358**	2002 SR Entry#	260	WA7697/A96330	WA7697//MADSEN/WA6910	3
20255	**97X358**	2002 SR Entry#	33	WA7697/A96330	WA7697//MADSEN/WA6910	3
20256	**97X358**	2002 SR Entry#	285	WA7697/A96330	WA7697//MADSEN/WA6910	3
20257	**97X358**	2002 SR Entry#	261	WA7697/A96330	WA7697//MADSEN/WA6910	3
20258	**97X358**	2002 SR Entry#	229	WA7697/A96330	WA7697//MADSEN/WA6910	3
20259	**97X358**	2002 SR Entry#	112	WA7697/A96330	WA7697//MADSEN/WA6910	3
20260	**97X358**	2002 SR Entry#	233	WA7697/A96330	WA7697//MADSEN/WA6910	3
20261	**97X358**	2002 SR Entry#	247	WA7697/A96330	WA7697//MADSEN/WA6910	3
20262	**97X358**	2002 SR Entry#	192	WA7697/A96330	WA7697//MADSEN/WA6910	3
20263	**97X358**	2002 SR Entry#	293	WA7697/A96330	WA7697//MADSEN/WA6910	3
20264	**97X358**	2002 SR Entry#	338	WA7697/A96330	WA7697//MADSEN/WA6910	3
20265	**97X358**	2002 SR Entry#	231	WA7697/A96330	WA7697//MADSEN/WA6910	3
20266	**97X358**	2002 SR Entry#	194	WA7697/A96330	WA7697//MADSEN/WA6910	3
20267	**97X358**	2002 SR Entry#	271	WA7697/A96330	WA7697//MADSEN/WA6910	3
20268	**97X358**	2002 SR Entry#	135	WA7697/A96330	WA7697//MADSEN/WA6910	3
20269	**97X358**	2002 SR Entry#	64	WA7697/A96330	WA7697//MADSEN/WA6910	3
20270	**97X358**	2002 SR Entry#	234	WA7697/A96330	WA7697//MADSEN/WA6910	3
20271	**97X358**	2002 SR Entry#	139	WA7697/A96330	WA7697//MADSEN/WA6910	3
20272	**97X358**	2002 SR Entry#	270	WA7697/A96330	WA7697//MADSEN/WA6910	3
20273	**97X358**	2002 SR Entry#	97	WA7697/A96330	WA7697//MADSEN/WA6910	3
20274	**97X358**	2002 SR Entry#	136	WA7697/A96330	WA7697//MADSEN/WA6910	3
20275	**97X358**	2002 SR Entry#	160	WA7697/A96330	WA7697//MADSEN/WA6910	3
20276	**97X358**	2002 SR Entry#	318	WA7697/A96330	WA7697//MADSEN/WA6910	3
20277	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20278	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20279	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20280	**Barley**	2002 Winter		Barley	Barley	3
20281	**97X358**	2002 SR Entry#	183	WA7697/A96330	WA7697//MADSEN/WA6910	3
20282	**97X358**	2002 SR Entry#	182	WA7697/A96330	WA7697//MADSEN/WA6910	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20283	**97X358**	2002 SR Entry#	324	WA7697/A96330	WA7697//MADSEN/WA6910	3
20284	**97X358**	2002 SR Entry#	54	WA7697/A96330	WA7697//MADSEN/WA6910	3
20285	**97X358**	2002 SR Entry#	241	WA7697/A96330	WA7697//MADSEN/WA6910	3
20286	**97X358**	2002 SR Entry#	350	WA7697/A96330	WA7697//MADSEN/WA6910	3
20287	**97X358**	2002 SR Entry#	206	WA7697/A96330	WA7697//MADSEN/WA6910	3
20288	**97X358**	2002 SR Entry#	122	WA7697/A96330	WA7697//MADSEN/WA6910	3
20289	**97X358**	2002 SR Entry#	123	WA7697/A96330	WA7697//MADSEN/WA6910	3
20290	**97X358**	2002 SR Entry#	90	WA7697/A96330	WA7697//MADSEN/WA6910	3
20291	**97X358**	2002 SR Entry#	65	WA7697/A96330	WA7697//MADSEN/WA6910	3
20292	**97X358**	2002 SR Entry#	80	WA7697/A96330	WA7697//MADSEN/WA6910	3
20293	**97X358**	2002 SR Entry#	98	WA7697/A96330	WA7697//MADSEN/WA6910	3
20294	**97X358**	2002 SR Entry#	94	WA7697/A96330	WA7697//MADSEN/WA6910	3
20295	**97X358**	2002 SR Entry#	222	WA7697/A96330	WA7697//MADSEN/WA6910	3
20296	**97X358**	2002 SR Entry#	258	WA7697/A96330	WA7697//MADSEN/WA6910	3
20297	**97X358**	2002 SR Entry#	30	WA7697/A96330	WA7697//MADSEN/WA6910	3
20298	**97X358**	2002 SR Entry#	143	WA7697/A96330	WA7697//MADSEN/WA6910	3
20299	**97X358**	2002 SR Entry#	294	WA7697/A96330	WA7697//MADSEN/WA6910	3
20300	**97X358**	2002 SR Entry#	302	WA7697/A96330	WA7697//MADSEN/WA6910	3
20301	**97X358**	2002 SR Entry#	78	WA7697/A96330	WA7697//MADSEN/WA6910	3
20302	**97X358**	2002 SR Entry#	210	WA7697/A96330	WA7697//MADSEN/WA6910	3
20303	**97X358**	2002 SR Entry#	243	WA7697/A96330	WA7697//MADSEN/WA6910	3
20304	**97X358**	2002 SR Entry#	29	WA7697/A96330	WA7697//MADSEN/WA6910	3
20305	**97X358**	2002 SR Entry#	151	WA7697/A96330	WA7697//MADSEN/WA6910	3
20306	**97X358**	2002 SR Entry#	305	WA7697/A96330	WA7697//MADSEN/WA6910	3
20307	**97X358**	2002 SR Entry#	104	WA7697/A96330	WA7697//MADSEN/WA6910	3
20308	**97X358**	2002 SR Entry#	252	WA7697/A96330	WA7697//MADSEN/WA6910	3
20309	**97X358**	2002 SR Entry#	203	WA7697/A96330	WA7697//MADSEN/WA6910	3
20310	**97X358**	2002 SR Entry#	102	WA7697/A96330	WA7697//MADSEN/WA6910	3
20311	**97X358**	2002 SR Entry#	84	WA7697/A96330	WA7697//MADSEN/WA6910	3
20312	**97X358**	2002 SR Entry#	190	WA7697/A96330	WA7697//MADSEN/WA6910	3
20313	**97X358**	2002 SR Entry#	44	WA7697/A96330	WA7697//MADSEN/WA6910	3
20314	**97X358**	2002 SR Entry#	334	WA7697/A96330	WA7697//MADSEN/WA6910	3
20315	**97X358**	2002 SR Entry#	133	WA7697/A96330	WA7697//MADSEN/WA6910	3
20316	**97X358**	2002 SR Entry#	279	WA7697/A96330	WA7697//MADSEN/WA6910	3
20317	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20318	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20319	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20320	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20321	**97X358**	2002 SR Entry#	242	WA7697/A96330	WA7697//MADSEN/WA6910	3
20322	**97X358**	2002 SR Entry#	287	WA7697/A96330	WA7697//MADSEN/WA6910	3
20323	**97X358**	2002 SR Entry#	253	WA7697/A96330	WA7697//MADSEN/WA6910	3
20324	**97X358**	2002 SR Entry#	51	WA7697/A96330	WA7697//MADSEN/WA6910	3
20325	**97X358**	2002 SR Entry#	246	WA7697/A96330	WA7697//MADSEN/WA6910	3
20326	**97X358**	2002 SR Entry#	221	WA7697/A96330	WA7697//MADSEN/WA6910	3
20327	**97X358**	2002 SR Entry#	150	WA7697/A96330	WA7697//MADSEN/WA6910	3
20328	**97X358**	2002 SR Entry#	205	WA7697/A96330	WA7697//MADSEN/WA6910	3
20329	**97X358**	2002 SR Entry#	265	WA7697/A96330	WA7697//MADSEN/WA6910	3
20330	**WA7697**			STEPHENS//SU92/3*OMAR	STEPHENS//SU92/3*OMAR	3
20331	**A96330**			MDN/WA6910	84X111 VPM/M951/YMH/HYS//HILL81///WA6910	3
20332	**A9622**			WA7665/RULO	WA7665/RULO	3
20333	**97X230**	2002 SR Entry#	229	WA7697/A9622	WA7697//WA7665/RULO	3
20334	**97X230**	2002 SR Entry#	78	WA7697/A9622	WA7697//WA7665/RULO	3
20335	**97X230**	2002 SR Entry#	289	WA7697/A9622	WA7697//WA7665/RULO	3
20336	**97X230**	2002 SR Entry#	261	WA7697/A9622	WA7697//WA7665/RULO	3
20337	**97X230**	2002 SR Entry#	33	WA7697/A9622	WA7697//WA7665/RULO	3
20338	**97X230**	2002 SR Entry#	298	WA7697/A9622	WA7697//WA7665/RULO	3
20339	**97X230**	2002 SR Entry#	344	WA7697/A9622	WA7697//WA7665/RULO	3
20340	**97X230**	2002 SR Entry#	86	WA7697/A9622	WA7697//WA7665/RULO	3
20341	**97X230**	2002 SR Entry#	225	WA7697/A9622	WA7697//WA7665/RULO	3
20342	**97X230**	2002 SR Entry#	280	WA7697/A9622	WA7697//WA7665/RULO	3
20343	**97X230**	2002 SR Entry#	207	WA7697/A9622	WA7697//WA7665/RULO	3
20344	**97X230**	2002 SR Entry#	257	WA7697/A9622	WA7697//WA7665/RULO	3
20345	**97X230**	2002 SR Entry#	180	WA7697/A9622	WA7697//WA7665/RULO	3
20346	**97X230**	2002 SR Entry#	56	WA7697/A9622	WA7697//WA7665/RULO	3
20347	**97X230**	2002 SR Entry#	83	WA7697/A9622	WA7697//WA7665/RULO	3
20348	**97X230**	2002 SR Entry#	113	WA7697/A9622	WA7697//WA7665/RULO	3
20349	**97X230**	2002 SR Entry#	251	WA7697/A9622	WA7697//WA7665/RULO	3
20350	**97X230**	2002 SR Entry#	218	WA7697/A9622	WA7697//WA7665/RULO	3
20351	**97X230**	2002 SR Entry#	296	WA7697/A9622	WA7697//WA7665/RULO	3
20352	**97X230**	2002 SR Entry#	178	WA7697/A9622	WA7697//WA7665/RULO	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20353	**97X230**	2002 SR Entry#	237	WA7697/A9622	WA7697//WA7665/RULO	3
20354	**97X230**	2002 SR Entry#	292	WA7697/A9622	WA7697//WA7665/RULO	3
20355	**97X230**	2002 SR Entry#	255	WA7697/A9622	WA7697//WA7665/RULO	3
20356	**97X230**	2002 SR Entry#	97	WA7697/A9622	WA7697//WA7665/RULO	3
20357	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20358	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20359	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20360	**Barley**	2002 Winter		Barley	Barley	3
20361	**97X230**	2002 SR Entry#	186	WA7697/A9622	WA7697//WA7665/RULO	3
20362	**97X230**	2002 SR Entry#	46	WA7697/A9622	WA7697//WA7665/RULO	3
20363	**97X230**	2002 SR Entry#	332	WA7697/A9622	WA7697//WA7665/RULO	3
20364	**97X230**	2002 SR Entry#	124	WA7697/A9622	WA7697//WA7665/RULO	3
20365	**97X230**	2002 SR Entry#	60	WA7697/A9622	WA7697//WA7665/RULO	3
20366	**97X230**	2002 SR Entry#	18	WA7697/A9622	WA7697//WA7665/RULO	3
20367	**97X230**	2002 SR Entry#	10	WA7697/A9622	WA7697//WA7665/RULO	3
20368	**97X230**	2002 SR Entry#	4	WA7697/A9622	WA7697//WA7665/RULO	3
20369	**97X230**	2002 SR Entry#	31	WA7697/A9622	WA7697//WA7665/RULO	3
20370	**97X230**	2002 SR Entry#	34	WA7697/A9622	WA7697//WA7665/RULO	3
20371	**97X230**	2002 SR Entry#	137	WA7697/A9622	WA7697//WA7665/RULO	3
20372	**97X230**	2002 SR Entry#	90	WA7697/A9622	WA7697//WA7665/RULO	3
20373	**97X230**	2002 SR Entry#	58	WA7697/A9622	WA7697//WA7665/RULO	3
20374	**97X230**	2002 SR Entry#	209	WA7697/A9622	WA7697//WA7665/RULO	3
20375	**97X230**	2002 SR Entry#	123	WA7697/A9622	WA7697//WA7665/RULO	3
20376	**97X230**	2002 SR Entry#	163	WA7697/A9622	WA7697//WA7665/RULO	3
20377	**97X230**	2002 SR Entry#	265	WA7697/A9622	WA7697//WA7665/RULO	3
20378	**97X230**	2002 SR Entry#	79	WA7697/A9622	WA7697//WA7665/RULO	3
20379	**97X230**	2002 SR Entry#	9	WA7697/A9622	WA7697//WA7665/RULO	3
20380	**97X230**	2002 SR Entry#	129	WA7697/A9622	WA7697//WA7665/RULO	3
20381	**97X230**	2002 SR Entry#	41	WA7697/A9622	WA7697//WA7665/RULO	3
20382	**97X230**	2002 SR Entry#	65	WA7697/A9622	WA7697//WA7665/RULO	3
20383	**97X230**	2002 SR Entry#	286	WA7697/A9622	WA7697//WA7665/RULO	3
20384	**97X230**	2002 SR Entry#	202	WA7697/A9622	WA7697//WA7665/RULO	3
20385	**97X230**	2002 SR Entry#	279	WA7697/A9622	WA7697//WA7665/RULO	3
20386	**97X230**	2002 SR Entry#	55	WA7697/A9622	WA7697//WA7665/RULO	3
20387	**97X230**	2002 SR Entry#	305	WA7697/A9622	WA7697//WA7665/RULO	3
20388	**97X230**	2002 SR Entry#	240	WA7697/A9622	WA7697//WA7665/RULO	3
20389	**97X230**	2002 SR Entry#	336	WA7697/A9622	WA7697//WA7665/RULO	3
20390	**97X230**	2002 SR Entry#	307	WA7697/A9622	WA7697//WA7665/RULO	3
20391	**97X230**	2002 SR Entry#	212	WA7697/A9622	WA7697//WA7665/RULO	3
20392	**97X230**	2002 SR Entry#	191	WA7697/A9622	WA7697//WA7665/RULO	3
20393	**97X230**	2002 SR Entry#	193	WA7697/A9622	WA7697//WA7665/RULO	3
20394	**97X230**	2002 SR Entry#	122	WA7697/A9622	WA7697//WA7665/RULO	3
20395	**97X230**	2002 SR Entry#	185	WA7697/A9622	WA7697//WA7665/RULO	3
20396	**97X230**	2002 SR Entry#	118	WA7697/A9622	WA7697//WA7665/RULO	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20397	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20398	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20399	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20400	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20401	**97X230**	2002 SR Entry#	147	WA7697/A9622	WA7697//WA7665/RULO	3
20402	**97X230**	2002 SR Entry#	70	WA7697/A9622	WA7697//WA7665/RULO	3
20403	**97X230**	2002 SR Entry#	211	WA7697/A9622	WA7697//WA7665/RULO	3
20404	**97X230**	2002 SR Entry#	206	WA7697/A9622	WA7697//WA7665/RULO	3
20405	**97X230**	2002 SR Entry#	150	WA7697/A9622	WA7697//WA7665/RULO	3
20406	**97X230**	2002 SR Entry#	134	WA7697/A9622	WA7697//WA7665/RULO	3
20407	**97X230**	2002 SR Entry#	115	WA7697/A9622	WA7697//WA7665/RULO	3
20408	**97X230**	2002 SR Entry#	196	WA7697/A9622	WA7697//WA7665/RULO	3
20409	**97X230**	2002 SR Entry#	330	WA7697/A9622	WA7697//WA7665/RULO	3
20410	**97X230**	2002 SR Entry#	80	WA7697/A9622	WA7697//WA7665/RULO	3
20411	**97X230**	2002 SR Entry#	228	WA7697/A9622	WA7697//WA7665/RULO	3
20412	**97X230**	2002 SR Entry#	14	WA7697/A9622	WA7697//WA7665/RULO	3
20413	**97X230**	2002 SR Entry#	260	WA7697/A9622	WA7697//WA7665/RULO	3
20414	**97X230**	2002 SR Entry#	200	WA7697/A9622	WA7697//WA7665/RULO	3
20415	**97X230**	2002 SR Entry#	267	WA7697/A9622	WA7697//WA7665/RULO	3
20416	**97X230**	2002 SR Entry#	159	WA7697/A9622	WA7697//WA7665/RULO	3
20417	**97X230**	2002 SR Entry#	294	WA7697/A9622	WA7697//WA7665/RULO	3
20418	**97X230**	2002 SR Entry#	112	WA7697/A9622	WA7697//WA7665/RULO	3
20419	**97X230**	2002 SR Entry#	133	WA7697/A9622	WA7697//WA7665/RULO	3
20420	**97X230**	2002 SR Entry#	151	WA7697/A9622	WA7697//WA7665/RULO	3
20421	**97X230**	2002 SR Entry#	77	WA7697/A9622	WA7697//WA7665/RULO	3
20422	**97X230**	2002 SR Entry#	51	WA7697/A9622	WA7697//WA7665/RULO	3
20423	**97X230**	2002 SR Entry#	76	WA7697/A9622	WA7697//WA7665/RULO	3
20424	**97X230**	2002 SR Entry#	311	WA7697/A9622	WA7697//WA7665/RULO	3
20425	**97X230**	2002 SR Entry#	68	WA7697/A9622	WA7697//WA7665/RULO	3
20426	**97X230**	2002 SR Entry#	166	WA7697/A9622	WA7697//WA7665/RULO	3
20427	**97X230**	2002 SR Entry#	172	WA7697/A9622	WA7697//WA7665/RULO	3
20428	**97X230**	2002 SR Entry#	273	WA7697/A9622	WA7697//WA7665/RULO	3
20429	**97X230**	2002 SR Entry#	59	WA7697/A9622	WA7697//WA7665/RULO	3
20430	**97X230**	2002 SR Entry#	188	WA7697/A9622	WA7697//WA7665/RULO	3
20431	**97X230**	2002 SR Entry#	88	WA7697/A9622	WA7697//WA7665/RULO	3
20432	**97X230**	2002 SR Entry#	187	WA7697/A9622	WA7697//WA7665/RULO	3
20433	**97X230**	2002 SR Entry#	217	WA7697/A9622	WA7697//WA7665/RULO	3
20434	**97X230**	2002 SR Entry#	30	WA7697/A9622	WA7697//WA7665/RULO	3
20435	**97X230**	2002 SR Entry#	239	WA7697/A9622	WA7697//WA7665/RULO	3
20436	**97X230**	2002 SR Entry#	256	WA7697/A9622	WA7697//WA7665/RULO	3
20437	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20438	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20439	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20440	**Barley**	2002 Winter		Barley	Barley	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20441	**97X230**	2002 SR Entry#	66	WA7697/A9622	WA7697//WA7665/RULO	3
20442	**97X230**	2002 SR Entry#	50	WA7697/A9622	WA7697//WA7665/RULO	3
20443	**97X230**	2002 SR Entry#	190	WA7697/A9622	WA7697//WA7665/RULO	3
20444	**97X230**	2002 SR Entry#	222	WA7697/A9622	WA7697//WA7665/RULO	3
20445	**97X230**	2002 SR Entry#	95	WA7697/A9622	WA7697//WA7665/RULO	3
20446	**97X230**	2002 SR Entry#	36	WA7697/A9622	WA7697//WA7665/RULO	3
20447	**97X230**	2002 SR Entry#	39	WA7697/A9622	WA7697//WA7665/RULO	3
20448	**97X230**	2002 SR Entry#	91	WA7697/A9622	WA7697//WA7665/RULO	3
20449	**97X230**	2002 SR Entry#	189	WA7697/A9622	WA7697//WA7665/RULO	3
20450	**97X230**	2002 SR Entry#	203	WA7697/A9622	WA7697//WA7665/RULO	3
20451	**97X230**	2002 SR Entry#	168	WA7697/A9622	WA7697//WA7665/RULO	3
20452	**97X230**	2002 SR Entry#	230	WA7697/A9622	WA7697//WA7665/RULO	3
20453	**97X230**	2002 SR Entry#	85	WA7697/A9622	WA7697//WA7665/RULO	3
20454	**97X230**	2002 SR Entry#	45	WA7697/A9622	WA7697//WA7665/RULO	3
20455	**97X230**	2002 SR Entry#	126	WA7697/A9622	WA7697//WA7665/RULO	3
20456	**97X230**	2002 SR Entry#	295	WA7697/A9622	WA7697//WA7665/RULO	3
20457	**97X230**	2002 SR Entry#	277	WA7697/A9622	WA7697//WA7665/RULO	3
20458	**97X230**	2002 SR Entry#	179	WA7697/A9622	WA7697//WA7665/RULO	3
20459	**97X230**	2002 SR Entry#	149	WA7697/A9622	WA7697//WA7665/RULO	3
20460	**97X230**	2002 SR Entry#	121	WA7697/A9622	WA7697//WA7665/RULO	3
20461	**97X230**	2002 SR Entry#	142	WA7697/A9622	WA7697//WA7665/RULO	3
20462	**97X230**	2002 SR Entry#	198	WA7697/A9622	WA7697//WA7665/RULO	3
20463	**97X230**	2002 SR Entry#	252	WA7697/A9622	WA7697//WA7665/RULO	3
20464	**97X230**	2002 SR Entry#	155	WA7697/A9622	WA7697//WA7665/RULO	3
20465	**97X230**	2002 SR Entry#	244	WA7697/A9622	WA7697//WA7665/RULO	3
20466	**97X230**	2002 SR Entry#	170	WA7697/A9622	WA7697//WA7665/RULO	3
20467	**97X230**	2002 SR Entry#	117	WA7697/A9622	WA7697//WA7665/RULO	3
20468	**97X230**	2002 SR Entry#	26	WA7697/A9622	WA7697//WA7665/RULO	3
20469	**97X230**	2002 SR Entry#	141	WA7697/A9622	WA7697//WA7665/RULO	3
20470	**97X230**	2002 SR Entry#	281	WA7697/A9622	WA7697//WA7665/RULO	3
20471	**97X230**	2002 SR Entry#	143	WA7697/A9622	WA7697//WA7665/RULO	3
20472	**97X230**	2002 SR Entry#	57	WA7697/A9622	WA7697//WA7665/RULO	3
20473	**97X230**	2002 SR Entry#	98	WA7697/A9622	WA7697//WA7665/RULO	3
20474	**97X230**	2002 SR Entry#	63	WA7697/A9622	WA7697//WA7665/RULO	3
20475	**97X230**	2002 SR Entry#	338	WA7697/A9622	WA7697//WA7665/RULO	3
20476	**97X230**	2002 SR Entry#	234	WA7697/A9622	WA7697//WA7665/RULO	3
20477	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20478	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20479	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20480	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20481	**97X230**	2002 SR Entry#	71	WA7697/A9622	WA7697//WA7665/RULO	3
20482	**97X230**	2002 SR Entry#	127	WA7697/A9622	WA7697//WA7665/RULO	3
20483	**97X230**	2002 SR Entry#	195	WA7697/A9622	WA7697//WA7665/RULO	3
20484	**97X230**	2002 SR Entry#	174	WA7697/A9622	WA7697//WA7665/RULO	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20485	**97X230**	2002 SR Entry#	263	WA7697/A9622	WA7697//WA7665/RULO	3
20486	**97X230**	2002 SR Entry#	23	WA7697/A9622	WA7697//WA7665/RULO	3
20487	**97X230**	2002 SR Entry#	87	WA7697/A9622	WA7697//WA7665/RULO	3
20488	**97X230**	2002 SR Entry#	111	WA7697/A9622	WA7697//WA7665/RULO	3
20489	**97X230**	2002 SR Entry#	67	WA7697/A9622	WA7697//WA7665/RULO	3
20490	**97X230**	2002 SR Entry#	1	WA7697/A9622	WA7697//WA7665/RULO	3
20491	**97X230**	2002 SR Entry#	11	WA7697/A9622	WA7697//WA7665/RULO	3
20492	**97X230**	2002 SR Entry#	181	WA7697/A9622	WA7697//WA7665/RULO	3
20493	**97X230**	2002 SR Entry#	320	WA7697/A9622	WA7697//WA7665/RULO	3
20494	**97X230**	2002 SR Entry#	175	WA7697/A9622	WA7697//WA7665/RULO	3
20495	**97X230**	2002 SR Entry#	276	WA7697/A9622	WA7697//WA7665/RULO	3
20496	**97X230**	2002 SR Entry#	274	WA7697/A9622	WA7697//WA7665/RULO	3
20497	**97X230**	2002 SR Entry#	12	WA7697/A9622	WA7697//WA7665/RULO	3
20498	**97X230**	2002 SR Entry#	99	WA7697/A9622	WA7697//WA7665/RULO	3
20499	**97X230**	2002 SR Entry#	204	WA7697/A9622	WA7697//WA7665/RULO	3
20500	**97X230**	2002 SR Entry#	24	WA7697/A9622	WA7697//WA7665/RULO	3
20501	**97X230**	2002 SR Entry#	262	WA7697/A9622	WA7697//WA7665/RULO	3
20502	**97X230**	2002 SR Entry#	27	WA7697/A9622	WA7697//WA7665/RULO	3
20503	**97X230**	2002 SR Entry#	82	WA7697/A9622	WA7697//WA7665/RULO	3
20504	**97X230**	2002 SR Entry#	197	WA7697/A9622	WA7697//WA7665/RULO	3
20505	**97X230**	2002 SR Entry#	49	WA7697/A9622	WA7697//WA7665/RULO	3
20506	**97X230**	2002 SR Entry#	108	WA7697/A9622	WA7697//WA7665/RULO	3
20507	**97X230**	2002 SR Entry#	43	WA7697/A9622	WA7697//WA7665/RULO	3
20508	**97X230**	2002 SR Entry#	268	WA7697/A9622	WA7697//WA7665/RULO	3
20509	**97X230**	2002 SR Entry#	214	WA7697/A9622	WA7697//WA7665/RULO	3
20510	**97X230**	2002 SR Entry#	284	WA7697/A9622	WA7697//WA7665/RULO	3
20511	**97X230**	2002 SR Entry#	158	WA7697/A9622	WA7697//WA7665/RULO	3
20512	**97X230**	2002 SR Entry#	140	WA7697/A9622	WA7697//WA7665/RULO	3
20513	**97X230**	2002 SR Entry#	109	WA7697/A9622	WA7697//WA7665/RULO	3
20514	**97X230**	2002 SR Entry#	259	WA7697/A9622	WA7697//WA7665/RULO	3
20515	**97X230**	2002 SR Entry#	316	WA7697/A9622	WA7697//WA7665/RULO	3
20516	**97X230**	2002 SR Entry#	100	WA7697/A9622	WA7697//WA7665/RULO	3
20517	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20518	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20519	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20520	**Barley**	2002 Winter		Barley	Barley	3
20521	**97X230**	2002 SR Entry#	25	WA7697/A9622	WA7697//WA7665/RULO	3
20522	**97X230**	2002 SR Entry#	29	WA7697/A9622	WA7697//WA7665/RULO	3
20523	**97X230**	2002 SR Entry#	248	WA7697/A9622	WA7697//WA7665/RULO	3
20524	**97X230**	2002 SR Entry#	132	WA7697/A9622	WA7697//WA7665/RULO	3
20525	**97X230**	2002 SR Entry#	241	WA7697/A9622	WA7697//WA7665/RULO	3
20526	**97X230**	2002 SR Entry#	114	WA7697/A9622	WA7697//WA7665/RULO	3
20527	**97X230**	2002 SR Entry#	272	WA7697/A9622	WA7697//WA7665/RULO	3
20528	**97X230**	2002 SR Entry#	106	WA7697/A9622	WA7697//WA7665/RULO	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	Name	Source Year	Source	Pedigree	Full Pedigree	Rep
20529	**97X230**	2002 SR Entry#	285	WA7697/A9622	WA7697//WA7665/RULO	3
20530	**97X230**	2002 SR Entry#	224	WA7697/A9622	WA7697//WA7665/RULO	3
20531	**97X230**	2002 SR Entry#	94	WA7697/A9622	WA7697//WA7665/RULO	3
20532	**97X230**	2002 SR Entry#	220	WA7697/A9622	WA7697//WA7665/RULO	3
20533	**97X230**	2002 SR Entry#	44	WA7697/A9622	WA7697//WA7665/RULO	3
20534	**97X230**	2002 SR Entry#	120	WA7697/A9622	WA7697//WA7665/RULO	3
20535	**97X230**	2002 SR Entry#	2	WA7697/A9622	WA7697//WA7665/RULO	3
20536	**97X230**	2002 SR Entry#	303	WA7697/A9622	WA7697//WA7665/RULO	3
20537	**97X230**	2002 SR Entry#	28	WA7697/A9622	WA7697//WA7665/RULO	3
20538	**97X230**	2002 SR Entry#	144	WA7697/A9622	WA7697//WA7665/RULO	3
20539	**97X230**	2002 SR Entry#	3	WA7697/A9622	WA7697//WA7665/RULO	3
20540	**97X230**	2002 SR Entry#	35	WA7697/A9622	WA7697//WA7665/RULO	3
20541	**97X230**	2002 SR Entry#	233	WA7697/A9622	WA7697//WA7665/RULO	3
20542	**97X230**	2002 SR Entry#	157	WA7697/A9622	WA7697//WA7665/RULO	3
20543	**97X230**	2002 SR Entry#	52	WA7697/A9622	WA7697//WA7665/RULO	3
20544	**97X230**	2002 SR Entry#	84	WA7697/A9622	WA7697//WA7665/RULO	3
20545	**97X230**	2002 SR Entry#	5	WA7697/A9622	WA7697//WA7665/RULO	3
20546	**97X230**	2002 SR Entry#	301	WA7697/A9622	WA7697//WA7665/RULO	3
20547	**97X230**	2002 SR Entry#	269	WA7697/A9622	WA7697//WA7665/RULO	3
20548	**97X230**	2002 SR Entry#	110	WA7697/A9622	WA7697//WA7665/RULO	3
20549	**97X230**	2002 SR Entry#	162	WA7697/A9622	WA7697//WA7665/RULO	3
20550	**97X230**	2002 SR Entry#	22	WA7697/A9622	WA7697//WA7665/RULO	3
20551	**97X230**	2002 SR Entry#	16	WA7697/A9622	WA7697//WA7665/RULO	3
20552	**97X230**	2002 SR Entry#	135	WA7697/A9622	WA7697//WA7665/RULO	3
20553	**97X230**	2002 SR Entry#	75	WA7697/A9622	WA7697//WA7665/RULO	3
20554	**97X230**	2002 SR Entry#	300	WA7697/A9622	WA7697//WA7665/RULO	3
20555	**97X230**	2002 SR Entry#	223	WA7697/A9622	WA7697//WA7665/RULO	3
20556	**97X230**	2002 SR Entry#	329	WA7697/A9622	WA7697//WA7665/RULO	3
20557	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20558	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20559	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20560	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20561	**97X230**	2002 SR Entry#	278	WA7697/A9622	WA7697//WA7665/RULO	3
20562	**97X230**	2002 SR Entry#	283	WA7697/A9622	WA7697//WA7665/RULO	3
20563	**97X230**	2002 SR Entry#	37	WA7697/A9622	WA7697//WA7665/RULO	3
20564	**97X230**	2002 SR Entry#	54	WA7697/A9622	WA7697//WA7665/RULO	3
20565	**97X230**	2002 SR Entry#	319	WA7697/A9622	WA7697//WA7665/RULO	3
20566	**97X230**	2002 SR Entry#	304	WA7697/A9622	WA7697//WA7665/RULO	3
20567	**97X230**	2002 SR Entry#	247	WA7697/A9622	WA7697//WA7665/RULO	3
20568	**97X230**	2002 SR Entry#	48	WA7697/A9622	WA7697//WA7665/RULO	3
20569	**97X230**	2002 SR Entry#	145	WA7697/A9622	WA7697//WA7665/RULO	3
20570	**97X230**	2002 SR Entry#	308	WA7697/A9622	WA7697//WA7665/RULO	3
20571	**97X230**	2002 SR Entry#	8	WA7697/A9622	WA7697//WA7665/RULO	3
20572	**97X230**	2002 SR Entry#	128	WA7697/A9622	WA7697//WA7665/RULO	3

Appendix 4b Details of the WA7697 x A96330 and WA7697 x A9622 genotypes with their plot number, entry number and pedigree details for 2003 ($F_{3:4}$)

Plot03	**Name**	**Source Year**	**Source**	**Pedigree**	**Full Pedigree**	**Rep**
20573	**97X230**	2002 SR Entry#	221	WA7697/A9622	WA7697//WA7665/RULO	3
20574	**97X230**	2002 SR Entry#	38	WA7697/A9622	WA7697//WA7665/RULO	3
20575	**97X230**	2002 SR Entry#	6	WA7697/A9622	WA7697//WA7665/RULO	3
20576	**97X230**	2002 SR Entry#	254	WA7697/A9622	WA7697//WA7665/RULO	3
20577	**97X230**	2002 SR Entry#	61	WA7697/A9622	WA7697//WA7665/RULO	3
20578	**97X230**	2002 SR Entry#	139	WA7697/A9622	WA7697//WA7665/RULO	3
20579	**97X230**	2002 SR Entry#	40	WA7697/A9622	WA7697//WA7665/RULO	3
20580	**97X230**	2002 SR Entry#	17	WA7697/A9622	WA7697//WA7665/RULO	3
20581	**97X230**	2002 SR Entry#	125	WA7697/A9622	WA7697//WA7665/RULO	3
20582	**97X230**	2002 SR Entry#	107	WA7697/A9622	WA7697//WA7665/RULO	3
20583	**97X230**	2002 SR Entry#	287	WA7697/A9622	WA7697//WA7665/RULO	3
20584	**97X230**	2002 SR Entry#	328	WA7697/A9622	WA7697//WA7665/RULO	3
20585	**97X230**	2002 SR Entry#	215	WA7697/A9622	WA7697//WA7665/RULO	3
20586	**97X230**	2002 SR Entry#	130	WA7697/A9622	WA7697//WA7665/RULO	3
20587	**97X230**	2002 SR Entry#	20	WA7697/A9622	WA7697//WA7665/RULO	3
20588	**97X230**	2002 SR Entry#	154	WA7697/A9622	WA7697//WA7665/RULO	3
20589	**97X230**	2002 SR Entry#	136	WA7697/A9622	WA7697//WA7665/RULO	3
20590	**97X230**	2002 SR Entry#	315	WA7697/A9622	WA7697//WA7665/RULO	3
20591	**97X230**	2002 SR Entry#	243	WA7697/A9622	WA7697//WA7665/RULO	3
20592	**97X230**	2002 SR Entry#	208	WA7697/A9622	WA7697//WA7665/RULO	3
20593	**97X230**	2002 SR Entry#	96	WA7697/A9622	WA7697//WA7665/RULO	3
20594	**97X230**	2002 SR Entry#	169	WA7697/A9622	WA7697//WA7665/RULO	3
20595	**97X230**	2002 SR Entry#	15	WA7697/A9622	WA7697//WA7665/RULO	3
20596	**97X230**	2002 SR Entry#	21	WA7697/A9622	WA7697//WA7665/RULO	3
20597	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20598	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20599	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20600	**Barley**	2002 Winter		Barley	Barley	3
20601	**97X230**	2002 SR Entry#	270	WA7697/A9622	WA7697//WA7665/RULO	3
20602	**97X230**	2002 SR Entry#	72	WA7697/A9622	WA7697//WA7665/RULO	3
20603	**97X230**	2002 SR Entry#	146	WA7697/A9622	WA7697//WA7665/RULO	3
20604	**97X230**	2002 SR Entry#	199	WA7697/A9622	WA7697//WA7665/RULO	3
20605	**97X230**	2002 SR Entry#	42	WA7697/A9622	WA7697//WA7665/RULO	3
20606	**97X230**	2002 SR Entry#	148	WA7697/A9622	WA7697//WA7665/RULO	3
20607	**97X230**	2002 SR Entry#	32	WA7697/A9622	WA7697//WA7665/RULO	3
20608	**97X230**	2002 SR Entry#	19	WA7697/A9622	WA7697//WA7665/RULO	3
20609	**97X230**	2002 SR Entry#	232	WA7697/A9622	WA7697//WA7665/RULO	3
20610	**97X230**	2002 SR Entry#	53	WA7697/A9622	WA7697//WA7665/RULO	3
20611	**97X230**	2002 SR Entry#	250	WA7697/A9622	WA7697//WA7665/RULO	3
20612	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20613	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20614	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20615	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3
20616	**PS279**	2002 Increase		SU92/3*Omar	SU92/3*Omar	3