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Assessment of Hard Red Spring Wheat Germplasm for Cold Temperature Germination Tolerance

Ulas Cinar
South Dakota State University

ASSESSMENT OF HARD RED SPRING WHEAT GERMPLASM FOR COLD TEMPERATURE GERMINATION TOLERANCE

BY

ULAS CINAR

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Karl Glover, PhD

Dissertation Advisor Date

David Wright, PhD

Head, Department of Agronomy,

Horticulture and Plant Science

Department Date

Kinchel C. Doerner, PhD

Dean, Graduate School Date

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ABBREVIATIONS

AOSA	Association of Official Seed Analysts
ANOVA	Analysis of Variance
AYT	Advanced Yield Trials
CI	Confidence Interval
CTGT	Cold Temperature Germination Tolerance
EROS Data center	Earth Resources Observation and Science Data Center
FAOSTAT	Food and Agriculture Organization of the United Nations
HRSW	Hard Red Spring Wheat
LCL	Lower Confidence Level (α=0.05)
LT	Low Temperature
MN	Minnesota
MT	Montana
ND	North Dakota
SD	South Dakota
SDSU	South Dakota State University

UCL	Upper Confidence Level (α=0.05)
USDA-NRCS	United States Department of Agriculture-Natural Resources Conservation Service
USDA-NASS	United States Department of Agriculture-National Agricultural Statistics Service
WSFS	World Summit on Food Security

ABSTRACT

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When planted early in the season, hard red spring wheat (HRSW; *Triticum aestivum* L.) can help for both vegetative growth and yield providing maximum agronomic productivity. The north-central Great Plains growing region is considered best for developing varieties that germinate in sub-optimal temperatures. Within limited regions, spring wheat planting typically occurs between mid-April and late May, when soil temperatures are 8 °C to 14 °C. Early season planting may result in freezing stress, while late season planting can result in heat and drought stress. Our study tested the germination rate of hard red spring wheat (HRSW) over a range of low temperatures within a laboratory environment. Ten HRSW populations were selected and four replications of 100 randomly chosen seeds of each genotype were tested at a series of temperatures (5°C, 7°C, 9°C, 11°C, 13°C, and 15°C). The purpose of this study was to review information on cold temperature germination tolerances for the HRSW populations and develop a recommendation for early season planting of HRSW. As a result of this study, we found out that SD4011/BARLOW showed the highest germination rate at 5°C, whereas SD4330 was recorded as a highest germinating entry at the 5 °C to 15°C temperature range. The importance of this study is to help predict how cooler growing temperatures might affect planting dates and improve crop productivity in anticipation of climate warming which poses a significant threat to area farmers.

According to USDA-NRCS, soil temperature data from the EROS Data center for SD five-year averages of soil temperatures showed that between first recorded 5°C and 11°C soil temperatures have approximately two weeks of differences. Planting may be completed up to two weeks earlier if a HRSW cultivar capable of germinating in cooler soils is used.

INTRODUCTION

Hard red spring wheat (HRSW; *Triticum aestivum* L.) is an important crop in North America. The majority of HRSW production in the United States takes place in the states of Minnesota (MN), Montana (MT), North Dakota (ND) and South Dakota (SD; USDA-NASS, 2016) where approximately 255.8 million bushels of spring wheat with an estimated value of $1.232 billion was produced. According to 2016 growing season records, South Dakota produced 47.3 million bushels of spring wheat with an estimated value of $215 million (USDA-NASS).

Planting of HRSW typically begins in early- to mid-April and continues through late May. The time range is largely dictated by when the soil temperature reaches a certain level and when moisture conditions decrease to a point where planting equipment can operate efficiently. The optimum soil temperature range for sowing HRSW is 8 °C to 14 °C (Sacks et al. 2010). If sowing temperatures are beneath this range, germination, emergence, and rates of seedling vitality can quickly decrease (Rinalducci et al., 2011).

This research was conducted primarily to evaluate cold temperature germination tolerance (CTGT) through measuring seedling germination rates of HRSW genotypes at various temperatures within and surrounding the optimum range. Of particular interest were temperatures on the low end of the range, and below, because if producers were able to plant cultivars that are able to successfully germinate and establish themselves at low soil temperatures, then the growing season could be extended. This study may provide useful information to spring wheat breeders for selection purposes and also help agronomists and farmers know which cultivars can be planted earlier.

LITERATURE REVIEW

Wheat (*Triticum aestivum* L.) is the most widely cultivated cereal crop in the world, and accounts for approximately 20% of caloric and protein intake in the human diet (FAOSTAT, 2016). According to United States Department of Agriculture (USDA 2017), world wheat production will be roughly 737 million metric tons. The United States is projected to produce approximately 56.12 million metric tons, and is therefore expected to be the fifth-largest global wheat producer, following the European Union, China, India, and Russia (USDA 2017). Of the wheat produced in the USA, hard red spring wheat (HRSW) accounts for approximately 20% of the total, and is produced primarily in the Northern Plains states of North Dakota, Montana, Minnesota, and South Dakota (USDA ERS). Generally, HRSW contains high levels of protein with excellent end-use quality and high water absorption capacity (Khan and Shewry 2009; U.S. Wheat Associates 2014). Flour produced from HRSW is often used for producing high-quality bread products where strong gluten characteristics are required, such as with pizza crust, though HRSW flour is also very often blended with lower protein flour to improve its functionality (USDA-ERS). During the 2016 growing season, South Dakota was estimated to produce 47.250 million bushels of spring wheat (USDA, 2016) valued at $214.988 million (USDA-NASS, 2016).

Several studies have reported that wheat productivity must improve further in order to meet future world demands (Reynolds et al. 2012). Among other means, this could be accomplished through improvements in a number of physiological processes (Reynolds et al. 2009; Sukumaran et al. 2017). Growth and development of wheat is influenced by temperature and drought conditions (Widyawati et al.2015). Pradhan et al.

(2012) found that drought and high temperature caused significant losses to wheat yield. Hucl and Baker (1989) found that earlier planting dates resulted in greater tiller numbers and development when compared with delayed planting dates. A more-recent study also noted that a mere seven-day difference in an earlier planting date affected protein content and nitrogen efficiency (Subedi et al. 2007). To minimize exposure to adverse conditions, growers usually sow HRSW as early as possible when excessive soil moisture around planting time is not an issue. Early planting imparts a production advantage, as more time then generally exists between seedling emergence and the typical hot and dry growing conditions that often exist from roughly mid- to late-June until the crop is harvested in July or August. Planting too early, however, can result in a production disadvantage because low soil temperatures prevent HRSW seeds from germinating. If sown while soil temperatures are too low for germination, seeds are inactive. If a significant precipitation event occurs while it is too cold for seeds to germinate, as an example, they are then subject to rot and other difficulties that would result in lower than anticipated production, or entire fields may require replanting.

A physiological process that could help minimize exposure of HRSW to drought and heat stress is cold temperature germination tolerance (CTGT). The optimal soil temperature for sowing HRSW is thought to be within the range of 8°C and 14°C (Sacks et al., 2010) and high correlations have been noted between standard germination test scores and similar ratings collected under field conditions (Khah et al. 1986; Kolasinska et al. 2000).

The objective of this study was to measure seedling germination rates of HRSW genotypes at specific low temperatures in order to determine respective levels of CTGT.

Information and methods derived from this research could be useful for breeders to use in selecting from within segregating populations for the development of new cultivars. Additionally, through the screening methods utilized, breeders and agronomists could develop cultivar-specific planting recommendations as some may possess significantly higher levels of CTGT.

MATERIAL AND METHODS

Seed Preparation

Ten HRSW genotypes were selected for inclusion in this study based on data collected from previous work conducted in 2014 (Jenkins). One of the genotypes was 'Forefront' (Glover, et al, 2013) a cultivar developed and released by the South Dakota State University (SDSU) HRSW breeding program. A second genotype, SD4330, was an $F_{4:7}$ experimental breeding line that was under consideration for eventual release as a cultivar, and therefore included in the 2015 advanced yield trial (AYT). Each of these genotypes was genetically fixed for obvious visible traits and were selected as experimental checks with differing levels of CTGT. Specifically, Forefront was found to have a lower level of CTGT than SD4330, which was among those with the highest levels of CTGT (Jenkins, 2014). The remaining eight genotypes were $F_{4:5}$-derived lines, that had not undergone the same level of phenotypic purification as the checks and were chosen because they were created through crossing parents with various levels of CTGT. All seed utilized in this study was harvested in early-August 2015 from yield trial plots grown near Aurora, SD. After harvest, seeds were stored in the SDSU seed house at -20°C until prepared for germination tests.

To prepare for germination tests, 400 grams of each genotype were gathered and cleaned with a Seedburo J10/64" round screen (Seedburo Inc., Chicago, IL USA). Broken seeds, weed seeds, and other debris was removed through this process. Cleaned seed was then passed through a Carter Day Fractionating Aspirator (Carter-Day Company, Minneapolis, MN USA) to remove any insect damaged kernels.

Germination Testing

Germination tests were conducted according to methods published by the Association of Official Seed Analysts (AOSA 2014). One hundred randomly chosen seeds of each genotype were spaced equally via a vacuum planter onto two layers of germination paper, which was presoaked with deionized water. A third presoaked sheet was then placed over the seeds, and the sheets were rolled to a size of approximately one-quarter of their original width. This procedure was replicated four times for each genotype. All four rolls of each genotype were then banded together and placed into a plastic bucket for incubation (Percival Mtg., Ames, IA, USA). A digital thermometer placed in tap water was used to insure proper temperatures in the chamber. ± 0.5 °C.

After placement in the incubator, seeds were germinated for three weeks at the 3°C, and 5°C temperatures, while the 7°C, 9°C, 11°C, 13°C and 15°C tests were conducted for two weeks. At the completion of each test, paper rolls were removed from the incubator and seeds were evaluated for germination and growth. To evaluate CTGT levels, germinated normal seedlings (AOSA, 2014) were counted and converted to percentages.

Data Analysis

Jenkins (2014) found that at 3°C, germination was generally weak with high rates of abnormal seedlings. Though at 5°C, significantly more normal seedlings were obtained and germination percentages among replicate rolls were similar. Although the 3°C treatment was carried out in these tests, the 5°C treatment was the lowest to be considered alone and served as an independent parameter for analysis. The second parameter to be analyzed was the mean of all temperature treatments. Statistical analyses of both parameters were carried out using SAS-JMP version 12.0.1 (SAS Institute, 2015) using analysis of variance. Entry effect mean separation was performed by using an F-protected LSD with $P \leq 0.05$. Analysis of variance was also conducted among temperature treatments.

RESULTS

Only radicles were observed at 3°C for three weeks, so this treatment was removed from analysis as having no germination. The 5ºC temperature analysis of variance accounted for 73% of variability, while the model described 71% of the variability for the CTGT parameter created by combining data from each of the temperature treatments. Analysis of variance of germination rates at 5ºC revealed that significant differences existed among the genotypes, although the range from highest to lowest only spanned the difference from 93.0 to 88.3% (4.7%). Genotypes with the highest levels of CTGT were the $F_{4:5}$-derived lines SD4011/BARLOW and SD4305/SD4165, along with the $F_{4:7}$-derived line, SD4330 (Table 1). Those with the lowest rates of CTGT were Forefront, SD4189/SD3997, and SD4178/SD4189 (Table 1). Results were very similar with respect to CTGT measured with data from averaging all of the temperature treatments. Specifically, SD4011/BARLOW and SD4330 had significantly higher CTGT levels than all others. The level of CTGT for the $F_{4:5}$-derived line SD4178/SD4189 was significantly lower, however, it remained among those with the highest means (Table 2). Among genotypes with the lowest CTGT, Forefront and SD4189/SD3997 were again in this group, as was the case when the 5ºC temperature treatment was considered (Table 2).

Levels of CTGT for all genotypes were measured from 3ºC to 15ºC in increments of 2ºC. Because data from the 3ºC treatment was discarded, six temperature treatments remained for consideration, and an analysis of variance was conducted to determine whether levels of germination were significantly different among the temperature treatments. Although the highest temperature tested (15 ºC) did not have the absolute highest mean rate of germination, Table 3 reveals that higher temperatures were generally noted to produce higher rates of germination, and differences in germination rates between high and low temperatures were statistically significant.

DISCUSSION

The HRSW genotypes included in this study were evaluated for CTGT at 3ºC to 15ºC in increments of 2ºC. Because of low germination rates, observations collected at the 3ºC treatment were removed from consideration. Two parameters were subjected to analysis; the first was CTGT data collected at 5ºC, while the second was the rate of CTGT observed by calculating the average germination rate of each genotype for all temperatures (5ºC to 15ºC). Analysis of both parameters revealed that genotypes differed with respect to their levels of CTGT (Tables 1 and 2). Since statistically significant differences were present among genotypes tested at 5ºC, yet little or no germination took place at the 3ºC temperature treatment, it appears as though the lowest feasible temperature for screening CTGT is somewhere between 5ºC and 3ºC.

The number of genotypes tested in this study (n = 10) was likely too small to provide an accurate estimation of how well results were correlated with respect to the two CTGT parameters that were measured. Examination of Tables 1 and 2, however, reveals that results were generally similar, especially on the low and high ends. This suggests that when germplasm screening takes place, it may be most efficient to simply conduct trials at a temperature of 5ºC. To eventually improve levels of CTGT, however, it may be that the 5ºC temperature should be the maximum and additional large pools of germplasm should be screened in an attempt to identify those with better levels of CTGT. Doing so successfully would allow growers to effectively increase the duration of a growing season and thereby increasing yields of HRSW.

REFERENCES

AOSA. (2014). Association of Official Seed Analysts. Available online: http://www.aosaseed.com/aosa_rules_for_testing_seeds

Crespo-Herrera, L. A., Crossa, J., Huerta-Espino, J., Autrique, E., Mondal, S., Velu, G., Vargas, M., Braun, H. J., and Singh, R. P. (2017). Genetic Yield Gains In CIMMYT's International Elite Spring Wheat Yield Trials By Modeling The Genotype × Environment Interaction. *Crop Science* 57, 789.

FAOSTAT. (2010). Food and Agriculture Organization of the United Nations. Available online: http://faostat.fao.org/site/377/DesktopDefault.aspx?PageID=377#ancor

FAOSTAT. (2016). Food and Agriculture Organization of the United Nations. FAOSTAT data. Available online: http://www.fao.org/faostat/en/#data/QC

Glover, K. D., Rudd, J. C., Devkota, R. N., Hall, R. G., Jin, Y., Osborne, L. E., and Hareland, G. A. (2013). Registration of 'Forefront' wheat. Journal of Plant Registrations, 7(2), 184-190. DOI: 10.3198/jpr2012.07.0007crc.

Gregory, P. J., and George, T. S. (2011). Feeding nine billion: the challenge to sustainable crop production. *J Exp Bot* 62, 5233-9.

Hucl, P., and Baker, R. J. (1989). Tiller Phenology and Yield of Spring Wheat in a Semiarid Environment. Crop Sci. 29, 631-635. doi:10.2135/cropsci1989.0011183X002900030016x.

Jenkins, S. (2014). Assessment of Hard Red Spring Wheat Germplasm for Germination in Sub-optimal Temperatures, Plant Science Department, South Dakota State University.

Khah, E. M., Ellis, R. H., and Roberts, E. H. (1986). Effects of laboratory germination, soil temperature and moisture content on the emergence of spring wheat. The Journal of Agricultural Science. 107(2), 431-438.

Khan, K., and Shewry P. R. (2009). Wheat: Chemistry and Technology, 4th edition. Khan K, Shewry PR, eds. AAAC International, Inc. St. Paul, MN, USA. 54, 63-64.

Kolasinska, K., Szyrmer, J., and Dul, S. (2000). Relationship between Laboratory Seed Quality Tests and Field Emergence of Common Bean Seed. Crop Sci. 40, 470-475. doi:10.2135/cropsci2000.402470x.

Lanning, S. P., Hucl, P., Pumphrey, M., Carter, A. H., Lamb, P. F., Carlson, G. R., Wichman, D. M., Kephart, K. D., Spaner, D., Martin, J. M., and Talbert, L. E. (2012). Agronomic Performance of Spring Wheat as Related to Planting Date and Photoperiod Response. *Crop Science* 52, 1633.

Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., and Foley, J. A. (2012). Closing yield gaps through nutrient and water management. *Nature* 490, 254-7.

Pradhan, G. P., Prasad, P. V. V., Fritz, A. K., Kirkham, M. B., and Gill, B. S. (2012). Response of Aegilops species to drought stress during reproductive stages of development. *Functional Plant Biology* 39, 51.

Ray, D. K., Mueller, N. D., West, P. C., and Foley, J. A. (2013). Yield Trends Are Insufficient to Double Global Crop Production by 2050. *PLoS One* 8, e66428.

Reynolds, M., Foulkes, J., Furbank, R., Griffiths, S., King, J., Murchie, E., Parry, M., and Slafer, G. (2012). Achieving yield gains in wheat. *Plant Cell Environ* 35, 1799-823.

Reynolds, M., Foulkes, M. J., Slafer, G. A., Berry, P., Parry, M. A., Snape, J. W., and Angus, W. J. (2009). Raising yield potential in wheat. *J Exp Bot* 60, 1899-918.

Rinalducci, S., Egidi, M. G., Karimzadeh, G., Jazii, F. R., and Zolla, L. (2011). Proteomic analysis of a spring wheat cultivar in response to prolonged cold stress. *Electrophoresis* 32, 1807-18.

Sacks, W. J., Deryng, D., Foley, J. A., and Ramankutty, N. (2010). Crop planting dates: an analysis of global patterns. *Global Ecology and Biogeography*, 19, 607-20.

SAS Institute (2015). SAS user's guide: Statistics. SAS Inst., Cary, NC.

Smith, C. W. (1995). Crop production: evolution, history, and technology. John Wiley and Sons, New York. Print. ISBN: 978-0-471-07972-9.

Subedi, K. D., Ma, B. L., and Xue, A. G. (2007). Planting Date and Nitrogen Effects on Grain Yield and Protein Content of Spring Wheat. *Crop Science* 47, 36.

Sukumaran, S., Crossa, J., Jarquin, D., Lopes, M., and Reynolds, M. P. (2017). Genomic Prediction with Pedigree and Genotype x Environment Interaction in Spring Wheat Grown in South and West Asia, North Africa, and Mexico. *G3 (Bethesda)* 7, 481-495.

USDA ERS. (2013). United States Department of Agriculture- Economic Research Service. Available online: https://www.ers.usda.gov/webdocs/publications/43783/39923_eib116.pdf?v=41516

USDA-NASS. (2016). United States Department of Agriculture-National Agricultural Statistics Service. Available online: https://www.nass.usda.gov/

USDA. (2017). United States Department of Agriculture- World Agricultural Production. Available online: https://apps.fas.usda.gov/psdonline/circulars/production.pdf

U.S. Wheat Associates. (2016). Available online: http://www.uswheat.org/cropQuality/doc/B4274BB5C43BBF9A85258050006FB3EA/$File/HRS2016.pdf?OpenElement#

Widyawati, N., Kurnia, T. D., and Murdono, D. (2015). Dynamization Performance of Thirteen Wheat Genotypes during Three Planting Season for Adaptation in Tropical Lowland. *AGRIVITA Journal of Agricultural Science* 37, 115-122.

TABLES

Table 1. Mean, least significant difference (LSD) groupings, and ranges for cold temperature germination tolerance levels of 10 hard red spring wheat genotypes tested at 5 ºC.

Level	LSD Group					Mean	Minimum	Median	Maximum
SD4011/BARLOW	A					93.0	92	93	94
SD4330	A					92.5	92	92	94
SD4305/SD4165	A	B				92.2	91	92	94
SD4078/SD4178		B	C			91.3	91	91	92
SD4243/SD4078			C			91.0	90	91	92
SELECT/SD4333			C			90.7	90	91	91
SD4189/SD4076			C	D		90.5	89	91	91
FOREFRONT				D	E	89.5	89	89	91
SD4178/SD4189					E	89.2	88	89	91
SD4189/SD3997					E	88.8	86	89	90

Table 2. Mean, least significant difference (LSD) groupings, and ranges for cold temperature germination tolerance levels of 10 hard red spring wheat genotypes tested using averages of observations collected from 5 ºC to 15 ºC.

Level	LSD Group					Mean	Minimum	Median	Maximum
SD4330	A					94.6	92	94.5	98
SD4011/BARLOW	A					94.5	92	94.5	97
SD4305/SD4165		B				93.6	91	94	96
SELECT/SD4333		B				93.1	89	93	96
SD4189/SD4076		B				93.1	89	93.5	96
SD4078/SD4178		B	C			93.0	90	93	95
SD4178/SD4189			C	D		92.2	88	92	96
FOREFRONT				D		91.9	89	92	96
SD4243/SD4078				D	E	91.5	89	91	95
SD4189/SD3997					E	90.9	86	91	95

Table 3. Mean, least significant difference (LSD) groupings, and ranges for rates of germination of hard red spring wheat genotypes at various temperatures from 5 ºC to 15 ºC.

Temperature	LSD Group			Mean	Minimum	Median	Maximum
13	A			94.3	92	94	96
15	A			94.2	89	94	97
11	A			94.1	89	94	98
9		B		92.4	86	91	94
7			C	91.2	86	91	95
5			C	90.9	90	93	96