

Oklahoma Hard Red Winter Wheat

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Contributor: Pilja Vitale

Wheat breeding continues to be an important component of agricultural innovations in the Great Plains region of the US. Over the past century, Oklahoma's wheat yields have increased but the productivity gains have been offset in part due to increased yield variability. The shift to improved wheat varieties has resulted in increased susceptibility to plant disease and pest pressure. While a few varieties introduced over the past few decades have dominated the wheat seed market, recent trends indicate producers are adopting a more diverse range of wheat varieties. Producers' concerns have expanded beyond demands for high yielding varieties to include more market oriented needs to increase protein content and test weight.

wheat varieties

seed

wheat breeding

1. Wheat Production and Breeding in Oklahoma: Past and Present

Wheat production has been an important part of Oklahoma's history dating back to its territorial period during the US land expansion of the 19th century. Winter wheat (*Triticum aestivum* L.) has been the dominant type of wheat produced in Oklahoma over the past century. The following describes the lineage of Oklahoma's wheat production since statehood in 1912.

Wheat Yield, Planted Acreage, and Production

Oklahoma wheat yields have increased significantly (329 percent) over the past century, from a time-trend average of 7.9 bu/acre in 1895 to 33.9 bu/acre in 2018 (**Figure 1**). The large yield increase is explained by the development of modern farming techniques and advances in breeding compared to traditional farming methods and wheat varieties utilized at the turn of the 20th century. Recent trends, however, show that the long-term trend in increased wheat yields has been accompanied by substantial yield variation (**Figure 1**). Since 1981, annual inter-year yield variation has continued to widen, reaching its largest ever proportion over the past few years. Yield variability introduces risk into producers' decision making criteria, resulting in a shift to more stable yet typically less profitable farm enterprises ^[1]. Reducing yield variability has been one of the most important objectives for wheat producers and is expected to remain at the forefront of the wheat breeding research agenda, since climate change is expected to greatly exacerbate yield variability ^{[2][3]}. Wheat breeding will hence need to explicitly address future climatic forecasts in developing varieties to better tolerate hotter, drier conditions that are expected to prevail well into the 21st century ^{[4][5][2][6][7][8][9][10][11]}.

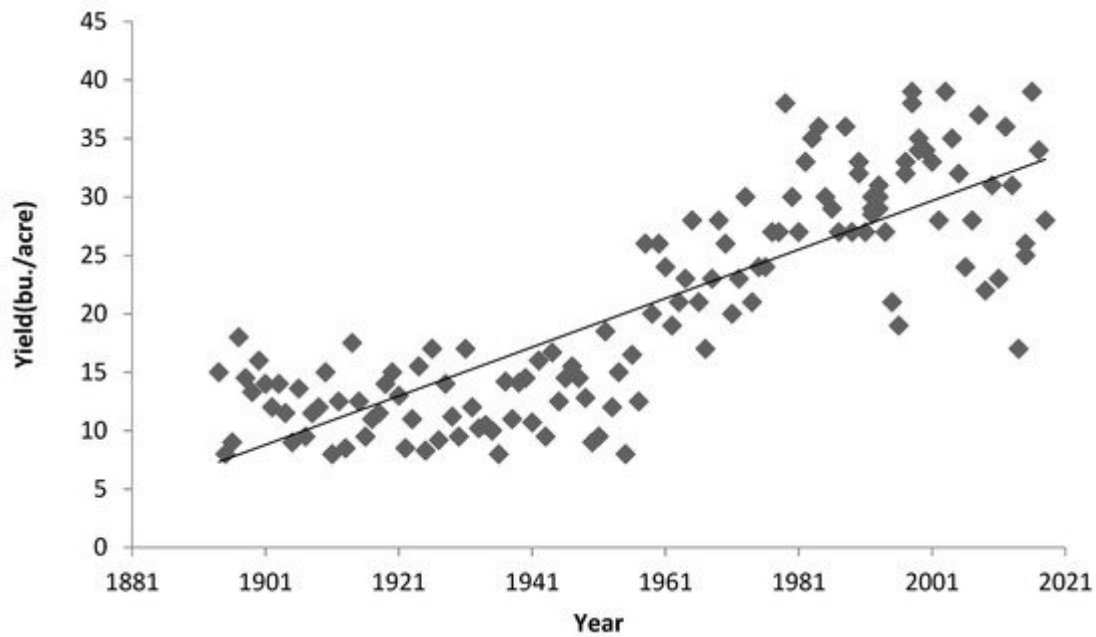


Figure 1. Wheat yields in Oklahoma from 1881 to 2018. Source: USDA-NASS Quickstats (2018) [\[12\]](#).

Oklahoma's wheat planted acreage has decreased substantially since 1990 (**Figure 2**). In large part, the area decline can be explained by decreasing returns per acre from downward long-term price trends. Rival crops that compete with wheat for farmland have better weathered long-term price declines and have experienced greater productivity growth, e.g., soybeans, corn, and sorghum [\[13\]](#). Government policy has also contributed to decreased wheat acreage [\[14\]](#). In 1996, newly enacted "Freedom to Farm" laws removed base acreage requirements for government farm payments, reducing incentives for planting wheat [\[15\]\[16\]](#). The mid 90s shift to more liberal policies, enabling producers to increase returns by shifting to alternative crops such as sorghum and millet, had thus an unintended consequence of reducing wheat acreage.

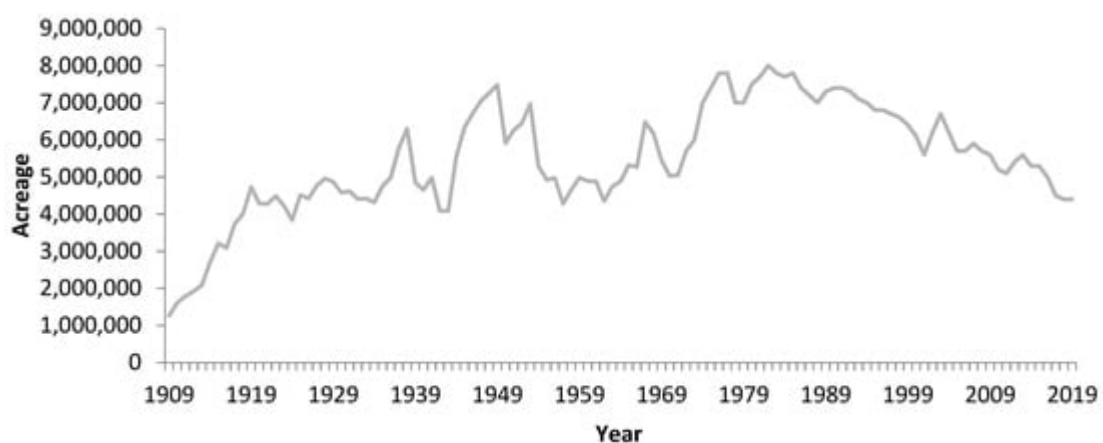


Figure 2. Wheat planted acreage in Oklahoma from 1909 to 2018. Source: USDA-NASS Quickstats 2018 [\[12\]](#).

The ongoing decline of wheat acreage indicates a need to increase demand for wheat based products, including a shift towards developing premium wheat products that can compete with rival crops and emerging health food trends such as local foods and organically grown crops. Over the past couple of decades, US per capita

consumption of both soft and hard wheat has declined by 9.4% due to perceived health concerns from gluten based products, including obesity and links to celiac disease ^{[17][18]}. Recent studies have argued, however, that obesity cannot be directly linked to any particular food, rather it is a general outcome of inactive lifestyles and overeating ^[19]. The negative trends in wheat consumption could be reversed if consumer perceptions were reshaped by information campaigns that raised awareness over the benefits of a health-conscious whole wheat diet that has been associated with significant reductions in risks for obesity related diseases such as type 2 diabetes and heart disease ^[19]. Such public awareness by the wheat industry should refute claims that modern genetic research has created an unnatural protein (gliadin) that promotes obesity by stimulating appetite, resulting in increased caloric consumption ^{[20][21]}.

2. Main Findings: Oklahoma's Legacy of Wheat Varieties

Oklahoma wheat producers have adopted new wheat varieties in an ongoing basis over the past several decades. The following is a review of the legacy of wheat varieties that have been developed over the past century.

2.1. History and Current Status of Oklahoma's Wheat Varieties

In its formative years of agriculture at the turn of the 20th century, Oklahoma's producers grew several wheat varieties. The more popular of the varieties grown during the formative period were brought to the US by European immigrants, primarily German Mennonites, who settled in the newly opened frontier lands of the US Great Plains ^{[8][22]}. As research and development grew in significance with the 1897 Hatch Experiment Station Act, agronomists identified a handful of the more promising wheat varieties. The awkwardly named Turkey variety, which actually originates from Russia, quickly became the region's dominant wheat variety ^{[23][24][25]}. By the end of World War I, Turkey had become the most popular variety and stayed so during the following couple of decades, 1920–1940 (United States Department of Agriculture—USDA 2012, USDA 2018). When Turkey was the most dominant wheat variety planted, it was planted on the majority of Oklahoma's wheat acres (70 percent).

Following Turkey's popularity in the early decades of the 20th century, the Triumph series became the dominant wheat variety in Oklahoma following the end of World War II until the 1980s ^{[26][27]} (USDA 2012, USDA 2018). Triumph reached its maximum adoption in 1964, when nearly two-thirds of Oklahoma's wheat acreage (65 percent) was planted in Triumph ^{[26][27]} (USDA 2012, USDA 2018). It continued as one of Oklahoma's most enduring wheat varieties, remaining in active use as late as 2004 (0.3 percent). A third wheat variety, Jagger, became the region's dominant wheat variety throughout the 1990s and into the first decade of the 21st century ^{[26][27]} (USDA 2012, USDA 2018). At its peak, Jagger occupied nearly half of Oklahoma's wheat acreage (42.3 percent) in 2004. While other varieties have since surpassed its popularity, Jagger is still planted on Oklahoma wheat farms up to the present day.

Those popular varieties (Turkey, Triumph, and Jagger) represented traditional breeding objectives for the Great Plains, i.e., high yielding varieties that are well suited for dual purpose wheat ^[28]. Over the past couple of decades, however, a wider range of wheat varieties have been developed to address specialized needs of producers.

Gallagher, for example, is a high yielding variety suitable for dual purpose wheat and was specifically bred for Hessian fly (HF) resistance by Oklahoma Genetics, Inc. [29]. Gallagher has been one of the most popular varieties over the recent past. In 2019, Gallagher was planted on 19.8 percent of Oklahoma's wheat acreage [26][27] (USDA 2012, USDA 2018). Duster has been another popular variety, although over the past few years it has lost its market share, declining from 14.1 to 2.6 percent over the five-year period from 2015 to 2019 [17][30] (USDA 2019, OSU 2019). Most of Duster's lost market share is due to its inferior milling and baking quality compared to Gallagher [31].

The relatively low market share of the most popular varieties over the past couple of decades is explained by recent trends in wheat production and the increased number of new varieties available for producers to address specific needs. Prior to the 20th century, one wheat variety dominated market share with overall shares ranging between 30–70 percent of planted area. However, with the recent trends in more specialized breeding, no single wheat variety has been able to capture seed markets with the same level of dominance occupied by previous varieties (Turkey, Triumph, and Jagger). Dominant varieties in today's markets occupy typically less than 20 percent of the seed market, with a collection of other less known and/or specialized wheat varieties occupying between 30 to 40 percent of market share. Such recent trends illustrate how wheat varieties are continually diversified by breeders to satisfy specific producer needs.

2.2. Oklahoma's Wheat Breeding Institutions: Contemporary Strategies and Perspectives

Recent trends in breeding strategies targeting specialized needs of producers have generated a diverse portfolio of wheat variety options. Oklahoma's wheat producers can now choose from dozens of wheat varieties from both the public and private sector (Table 1). The predominant type wheat remains hard red winter wheat, which is grown on virtually all of Oklahoma's acreage (97.1 percent), with the remaining acreage (2.9 percent) in soft red winter wheat (Table 1). Public seed companies have an overwhelming market share among identified winter wheat varieties, accounting for 78.6 percent of identified seed sales in the 2019 production season (Table 1). The private seed market is noticeably smaller, comprising a 21.4 percent market share of identified seed sales in 2019 (Table 1). Over the past few years, the most popular varieties, by planted acres, were released by the Oklahoma State University (OSU) breeding program, accounting for 69.9 percent of identified seed sales in the 2019 production season (Table 1). This punctuates the successful breeding program established by OSU and reinforces the importance of maintaining adequate public investments in wheat breeding in the Great Plain states, such as Oklahoma, which combine to form the major wheat producing region in the USA.

Table 1. Oklahoma hard red wheat variety Planted by Institution: 2019 production season.

Sector	Institution ¹	Wheat Type	Planted Acreage (Percent)
Public	OSU	Hard red	43.3
	TAM	" "	3.1
	KSU	" "	2.5
Private	WB	" "	7.5

Sector	Institution ¹	Wheat Type	Planted Acreage (Percent)
	SY	" "	4.9
	LCS	" "	0.9
Not Specified	Not Specified	Hard (various types) ²	4.6
" "	" "	Hard (unidentified names and type) ³	29.2
" "	" "	Soft (various types) ⁴	3.0
Total			100.0

the limited

interest of the private sector is likely due to the lower returns from the wheat seed industry compared to the more lucrative corn, soybean, and cotton seed markets. In particular, genetically modified corn, soybean, and cotton ¹ OSU refers to Oklahoma State University, TAM to Texas A&M University, KSU to Kansas State University, WB to Westbred Company, SY to Syngenta, and LCS to Limagrain Cereal Seeds. ² Hard winter wheat in this category contains various varieties from either the public or private sector and originating from other institutions. ³ Hard from the public domain. In 2019, Oklahoma's wheat had only 13.3 percent of its total wheat acres planted in winter wheat in this category contains unknown varieties from either the public or private sector and from varieties released by private companies (**Table 1**). ⁴ Soft wheat in this category is from an unidentified sector and institution. Source: USDA-

NASS Oklahoma Wheat Variety Report, April 2019 ^[30] Oklahoma's wheat breeding program has traditionally targeted developing high yielding varieties ^{[32][33]}. The impact of Oklahoma's breeding strategies targeting high yielding wheat varieties has been substantial, contributing in large measure to the three-fold wheat yield increase Oklahoma has experienced over the past century (**Figure 1**). The importance of cattle production in the mixed farming systems employed by most of Oklahoma's producers has led to the development of varieties that perform optimally as dual purpose wheat ^[34]. Oklahoma is one of the largest cattle producers in the US, and most wheat producers also produce cattle. Substantial co-benefits are generated from dual purpose wheat, i.e., producing wheat as both a forage, prior to first hollow-stem development, and as a revenue producing crop through subsequent grain harvest.

Over time, breeding has evolved in response to increased pest and weed pressure by introducing varieties resistant to insects such as greenbug (GB), HF, and Russian wheat aphid (RWA) ^{[35][36][37]}. The prevalence of foliar diseases in Oklahoma's wheat production has been addressed though the development of cultivars with increased resistance to wheat rust and mildew related diseases ^[38].

OSU wheat breeders have focused on a variety of crop management and agronomic constraints of wheat producers in their state, e.g., nutrient efficiency, drought management, and crop rotation ^{[34][36][38][39]}. Other winter wheat varieties have addressed weed pressure additional agronomic issues such as awn suppression and increasing coleoptile length ^{[40][41][42]}.

2.2.1. Environmental Issues: Adaptation to Local Conditions

Societal concerns on protecting the environment have led to an awareness among all agricultural stakeholders to promote the prudent use of inputs, particularly environmentally sensitive inputs, which leave large carbon footprints or degrade flora and fauna in sensitive ecosystems ^{[43][44][45][46][47]}. An objective of Oklahoma's breeding over the

past few decades has been to maximize crop efficiency by matching plant growth characteristics and performance to local environmental conditions. Achieving such peak efficiency requires developing varietal lines that require the minimal use of water, soil preparation, fertilizers, chemicals, and other inputs while maintaining production performance standards [48]. Drought avoidance and tolerance has also been a targeted objective of Oklahoma's breeding strategies given the low rainfall conditions that prevail throughout much of the state [42].

Breeders often focus on developing varieties that are the most nitrogen efficient [39][49][50]. Addressing nitrogen has co-benefits to both producers through reduced fertilizer costs and the environment through less runoff into local watersheds. Modern advances in crop genetics enable breeders to utilize biotechnology, such as molecular markers, to identify existing varieties that are well adjusted to local conditions by scoring their performance based input and output efficiency measures. Based on recent USDA data, in the major Oklahoma wheat producing regions (Panhandle, Northeast, other Northcentral districts), circa 50 percent of wheat was planted in local varieties that had no commercial attachment. This illustrates the extent to which producers in many areas of the state do not use well known commercial varieties, i.e., those developed by either public or private institutions. Such areas could provide future opportunities to apply genetic engineering tools to improve crop efficiency, promote improved environmental stewardship, and address climate change concerns.

2.2.2. Milling, Processing, and Consumer Oriented Issues in Selective Breeding Strategies

The primary use of wheat throughout most of the world, including in the US, is providing staple and other baked foods such as breads, pastas, cakes, and snack items. Millers and bakers are thus the main purchasers of wheat at the farm gate, whereas end users of wheat are consumers of bread and other wheat products. Through purchasing power, consumers typically have the loudest voice when determining taste, nutritional, and other characteristics of wheat. US wheat, including Oklahoma wheat, has been consumed in both domestic and international markets. In 2014, domestic use was 47 percent while international use was 53 percent [51]. Domestic demand has remained more or less stable but has experienced modest declines based on population changes and consumer preferences. Like most staple foods, wheat has been less responsive to wheat prices and household incomes. Recent domestic wheat demand is declining due to consumer awareness of gluten free foods and low-carbohydrate diets. Most of US wheat has been used in bread flour, which has declined in demand, although exports from world wheat demand have increased. Wheat breeders and policy makers should be aware of recent trends in domestic consumer demand. New breeding efforts could be designed to provide a healthier perception of wheat and develop a more diversified line of wheat varieties that can provide flours better adapted to a wider range of foods appealing to more lifestyles, such as noodles, pasta, and tortillas.

An emerging trend over the past decade is the growth of niche (specialized) markets that satisfy the parochial needs of wheat producers. Over the past few years, uptake rates of wheat varieties in niche markets have increased by almost 10 percent in Oklahoma. Recent breeding has responded by addressing traits and characteristics to satisfy consumer preferences and market demands on wheat quality, including mill-ability, bake-ability, taste and texture characteristics, and optimizing protein content [52][53][54]. This trend towards niche varieties is in response to wheat producers shifting preferences toward varieties that have been adapted to local conditions

through significant input from wheat producers familiar with regional constraints. This trend will likely continue for the next few years due to the ongoing dynamics in pest and disease pressure on wheat production as well as future challenges from consumers' shifting preferences towards more diverse healthy diets and climate change. This includes prospects for developing varieties more responsive to organic farming methods and other health related production trends. Wheat breeding institutions should continue the trend towards specialization and developing niche varieties by releasing more locally adapted wheat varieties to meet producers' and consumers' ongoing needs specific to sub-regional areas.

2.2.3. Oklahoma’s Preferences for Wheat Varieties: Great Plains Regional Comparisons

Preference for high yielding varieties continues to be the most desired trait among Oklahoma winter wheat producers [33]. Compared to other states in the Great Plains, Oklahoma wheat producers have less preference for other traits, such as insect resistance, which often hold the greatest importance in other wheat producing regions [55]. Wheat breeders have developed varietal lines that provide resistance to HF and some biotypes of greenbug (GB) and other pests such as the Russian wheat aphid (RWA) [35][36][37]. Breeding resistance into varieties is challenging, however, because bio-types with variable levels of virulence exist for both of these aphid species [56][57][58]. According to farm survey data reported in **Table 2**, Oklahoma wheat producers adopted the lowest number of insect resistant winter wheat varieties compared to surrounding states in the Great Plains region (**Table 2**). United States Department of Agriculture (USDA) annual surveys, conducted from 2000 to 2010, found that varieties listed as RWA resistant were seeded on less than 0.1 percent of the wheat acres across the region, with use in Colorado reported at 20 percent. Acreage seeded to varieties listed as GB resistant ranged from 1.1 percent to 5 percent [59]. In Oklahoma, none of its wheat area was planted in GB resistant varieties.

Table 2. Adoption rate (percent of total area) of resistant varieties to aphid by state.

State	2002	Year 2003	2004	2005
Colorado (CO)	42.5	44.2	51.2	49.4
Kansas (KS)	0.0	0.0	0.0	0.0
Nebraska (NE)	0.7	2.2	3.1	2.2
Oklahoma (OK)	0.0	0.0	0.0	0.0
Texas (TX)	27.5	39.1	38.9	31.0
Wyoming (WY)	0.3	2.6	10.1	1.9

2.3. Future Wheat Breeding Strategies

Source: Ph.D. Thesis, Vitale 2013 [55]
Over the last 100 years, wheat has been the most important crop to producers in Oklahoma. Wheat's role has, however, been modestly declining over the recent past. Into the 21st century, the role of wheat will depend on a complex nexus among wheat breeders, producers, and consumers. Breeders will remain challenged to meet the dynamic changes expected in in response to climate change, shifting consumer preferences towards healthy

foods, and enabling environmentally friendly production practices. Future breeding can generate substantial productivity gains by catching up to the new technology that row crops such as corn, cotton, and soybean have benefitted from over the past couple of decades. It is also very important to maintain the strong government support that has fostered the Oklahoma wheat industry to date.

2.3.1. Climate Change and Wheat Variety Development

Climate change is an increasing concern for sustaining wheat production into the 21st century [60][4][61][62]. Wheat is anticipated to be one of the more susceptible food crops, along with potato, to climate change [5]. Winter wheat is produced over an extended agricultural calendar and is exposed to harsh weather conditions from the cold of late fall to heat of early summer. Statistical modeling has determined that winter wheat yields are better explained by extremes of temperature fluctuations rather than average temperatures [5]. Based on historical data, winter wheat yields in the Southern Great Plains have been negatively impacted by higher temperatures, which have risen between 1–2 °F over the past century [5]. The effect of the higher temperatures, through increased number of extreme daily temperatures, has had an overall negative effect on wheat yields. According to model results, days of either extreme heat (above 34 °C) or cold (below 34 °C) have significant, negative effects on winter wheat yield estimated at –7.6 percent and –9.0 percent.

Climate change is expected to primarily impact temperature and precipitation, but in many parts of the world it will also affect humidity and wind. Three climate change models (HadCM3:A2a, B2a, GGa1) predict hotter, drier weather in the Southern Great Plains, with temperatures rising an average of 4.8 °C along with a 9.0% decline in precipitation [63]. Using a crop growth simulation model (WEPP), crop yields were found to be positive in two of the three HadCM3 models with increases of 2.7 percent (A2a) and 5.4 percent (GGa1) and a yield declines of –4.7 percent in the B2a model [63]. The positive wheat yield increases in the climate change models are explained by the dramatic increase in CO₂ levels predicated in the A2a and GGa1 models, where CO₂ levels were predicted to increase by 148 percent and 80 percent. The climate change analysis presents the potential for unintended optimism for future wheat production, with the possibility of greater CO₂ levels offsetting the negative effects of higher temperature and reduced precipitation.

Recent evidence from surveys and interviews suggest that producers consider flexibility in choosing a variety that is best suited to their local condition as the most important option to mitigate climate change [5][8]. Currently, Oklahoma wheat breeders are developing varieties for improved drought and heat tolerance with several already released (e.g., Duster, Gallagher, and Lonerider) [64]. Climate change also is expected to bring severe floods, cooler temperatures, and other climatic shocks. Since those conditions cannot be tested in the field, researching such aspects of climate change requires high investments for developing wheat varieties that can adjust to weather shocks and extreme variability including high temperature, strong winds (lodging), dramatic temperature changes, and severe flooding [7]. Oklahoma is fortunate, since harsh weather and climatic variability, including high winds, drought, and winter freezes, have already been incorporated in breeding efforts over the past several decades. Hence, breeders are expected to be able to use existing varietal lines as starting points for a new range of wheat varieties designed specifically for adaptation to climate change. Oklahoma should continue developing a wide

scope of new wheat varieties to match future climate change weather scenarios, which are expected to include more extreme events compared to historic weather patterns.

2.3.2. Selective versus Hybrid Wheat Breeding and Research in Oklahoma

Wheat breeding began researching hybrid varieties nearly a century ago, following the scientific and agronomic procedures used in developing other hybrids, notably corn [65]. After nearly five decades of research and development, the first hybrid wheat varieties were released by Cargill in the USA and DeKalb in Australia in the early 1980s [66]. Hybrid wheat has continued to be relatively more costly for seed companies to produce compared to other hybrids such as corn, due to genetic differences that make it more difficult to develop sterility and cross pollination that requires additional agronomic management [67]. Due primarily to their relatively higher seed cost and limited yield advantage, hybrid wheat varieties have not been an economical alternative to open pollinated varieties for producers in many parts of the world including the Southern Plains [68].

Biotechnology has been applied for wheat breeding, including molecular genetics and genetic engineering to provide improved variety selection and introduce new plant characteristics [65]. The private sector has pursued biotechnology for wheat and has developed genetically modified (GM) wheat varieties such as Roundup Ready® wheat (RRW) [69]. Analogous to its corn and soybean counterparts, RRW contains a genetic trait making it resistant to glyphosate based herbicides, enabling post emergence weed control. Applications for its commercial release were submitted but eventually withdrawn by Monsanto in 2004 due in part to pressure from anti-GM groups that publicly lobbied against its release [70]. Concerns over its limited profitability, lack of support from producer groups, and segregation issues between GM and non-GM wheat along marketing chains also likely impacted their decision [70][71].

An impediment to biotechnology is the more complex chromosome of modern winter wheat, a complex hexaploid rather than a simple diploid or tetraploid [72]. This chromosomal characteristic has made it more difficult to apply biotechnology to wheat varieties compared to other crops such as corn and soybean [72]. Despite greater technological barriers, successful breeding programs such as OSU should continue incorporating biotechnology into their R&D programs to improve wheat quality into the 21st century, even though genetically modified varieties are not likely to be commercially viable. For example, transgene hybrid-systems, which generate non-GM seed, are being approved for cultivation as non-GMOs in some crops could be applied in wheat [73]. This could include extending research on introducing other GM traits including fusarium resistance, protein enhancements, and drought tolerance, but are yet to be commercially released in the US due in part to the negative perceptions associated with GM labelled foods [70][71].

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