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Edible Grain Legumes

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ABSTRACT

Edible grain legumes, including dry bean (*Phaseolus vulgaris* L.), dry pea (*Pisum sativum* L.), chickpea (*Cicer arientinum* L.), and lentil (*Lens culinaris* Medikus), have served as important sources of protein in the human diet for thousands of years. In the United States, these crops are consumed nationally and produced for export markets. The objectives of this study were to examine yield gains in edible grain legume crops over the past 25 yr. Genetic gain in dry bean during the past 30 yr based on common trials was 13.9 kg ha^{-1} yr^{-1} (0.77% yr^{-1}) and 17.4 kg ha^{-1} yr^{-1} (0.85% yr^{-1}) for navy and pinto bean cultivars, respectively. Data from national yield trials on research sites indicates that yield gains were 0.4, 0.7, 0.9, and 1.7% for pinto, navy, black, and kidney beans, respectively. The results also suggest that dry bean cultivars have not reached a yield plateau for most market classes. Continued introgression of germplasm from other races of common bean should provide new sources of genetic diversity to enhance yield in the future. Over the past 25 yr, the production of cool season food legumes (pea, lentil, and chickpea) in the United States has increased dramatically; however, yields of dry pea in the United States have decreased by 0.3% per year, lentil yields have increased by only 0.1% per year, and chickpea yields have increased by 2.8% per year. Pea and lentil production has increased dramatically in Montana and North Dakota, but the cultivars grown in this region were originally developed in the U.S. Pacific Northwest (PNW) and Canada and are likely not well adapted for Montana and North Dakota. Several currently grown cultivars are at least 20 yr old, but new cultivars have been released that are superior to these older cultivars.

Abbreviations: CDBN, Cooperative Dry Bean Nursery; NGP, Northern Great Plains; PNW, U.S. Pacific Northwest.

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Dry edible bean is arguably the most important grain legume in the human diet and has been characterized as the almost perfect food (Broughton et al., 2003; Câmara et al., 2013). Dry beans were widely cultivated in Mexico and the United States during pre-Columbian times. Kaplan (1965) reported that dry beans found at an archeological site in the southwestern United States were cultivated 2300 yr ago and that they likely originated from Middle America. New World settlers cultivated dry beans from European introductions in the eastern United States and from landraces of small red, pink, pinto, and great northern beans in the western United States that were cultivated by Native Americans. The early landraces were grown on small acreages in the United States until state and federal governments initiated improvement programs during the late 1800s and early 1900s. The first large-scale production of dry edible beans in the United States occurred in Orleans County, NY in 1839 (Bowen, 1898). New York State became an important producer of dry beans and maintained its dominance until the early 1900s when Michigan became the leading producer (http://www.agmrc.org/commodities__products/grains__oilseeds/dry-edible-bean-profile, accessed 15 Oct. 2013). Michigan was the largest producer of commercial dry bean in the United States until 1991 when North Dakota became the top-ranking producer. The leading market classes of dry beans produced in the United States are pinto (~42%), navy or pea (~17%), black (~11%), and great northern (~5%) (USDA-ERS, 2010). Other important market classes produced include light red kidney, dark red kidney, pink, small red, cranberry, and small white, with lesser amounts of specialized market types such as yellow eye, Appaloosa, Anasazi, and others.

Total world production of dry bean increased 65% from the 10-yr period of 1961 to 1970 to 169 million tonnes during 2001 to 2010 (USDA-ERS, 2013). During this time span, U.S. dry bean production increased 71.0% to 11.5 million tonnes and accounted for 5.8% of world production.

U.S. production is limited by many environmental conditions, including heat and drought stress, early fall frost and late spring frost, soil compaction, hail, etc. (Brick and Grafton, 1999). In addition, pathogens that cause rust (*Uromyces appendiculatus* Pers:Unger), common bacterial blight [*Xanthomonas axonopodis* pv. *phaseoli* (Smith) Dye], bacterial brown spot [*Pseudomonas syringae* pv. *syringae* (van Hall)], halo blight [*Pseudomonas syringae* pv. *phaseolicola* (Burkholder)], white mold [*Sclerotinia sclerotiorum* (Lib.) de Bary], and soilborne fungi that causes root rots can further reduce yield of beans (Brick and Grafton, 1999).

Basis for Yield Improvement in Dry Beans

In recent years, scientists in developing countries and the United States have made major advances in dry bean disease resistance, stress tolerance, and increased yield (Kelly, 2004). Agronomic and biotechnological tools have contributed to these achievements. Dry bean breeding programs in the United States were initiated to improve specific market classes and production systems in their region. Because environmental conditions such as nighttime temperatures, rainfall pattern, relative humidity, and soil types are so different among production areas, genetic improvements in one region have little more than academic interest to colleagues working with different market classes in other regions. For example, gains made in breeding pinto beans for the irrigated semiarid production zones of southern Idaho have little application to breeding small seeded determinate navy or Andean kidney beans for the high humidity, rainfed conditions of the midwestern United States. As a result, breeders in each region developed individual strategies and focused on specific market classes for local production. Breeders in the 1960s through the 1990s became known for the specific market class of dry bean on which they focused: M.W. Adams in Michigan focused on navy bean; D.H. Wallace in New York focused on kidney bean; D.R. Wood in Colorado focused on pinto bean; D.P. Coyne in Nebraska focused on great northern bean; M.J. Lebaron and J.J. Kolar in the PNW focused on pinto bean; D.W. Burke in Washington focused on small red and pink beans; and F.L. Smith in California focused on pink bean. A summary of the achievements and limitations of contemporary bean breeding programs was recently reviewed by Beaver and Osorno (2009).

In the early 1900s, breeding programs at Cornell University focused largely on disease resistance, including the earliest work on the genetic race structure of anthracnose [*Colletotrichum lindemuthianum* (Sacc. & Magnus) Lams.- Scrib.] and differential responses of this pathogen to host genotypes (Burkholder, 1918). Breeding efforts also focused on physiological traits and improving yield through efficient partitioning of plant metabolites (Wallace et al., 1993).

Breeding programs in Michigan extend back to the early 1900s (Michigan State University, 2009), and those at the University of Idaho were initiated in 1925 (Singh et al., 2007). Research in Michigan focused largely on improving plant architecture and yield (Adams, 1982; Kelly, 2000). In the intermountain west, breeders focused largely on developing resistance to a range of pathogens, including rust, white mold, bacterial blights, plant viruses, and root pathogens (Singh and Schwartz, 2010). Exchange of germplasm among programs was limited to major disease resistance traits because more complex traits such as yield, plant architecture, and energy partitioning were not directly transferable because of genotype × environment interactions among commercial seed classes. Fundamental concepts such as yield component compensation, first described by Adams (1967), prevented breeders from combining the high pod load potential of small seeded navy beans with very large seed size of a kidney bean (White and Gonzales, 1990). In addition, breeders were constrained by differences in growth habit, maturity, and seed traits demanded by the market place. Not only do these traits limit access to broader genetic variability, but they also lock breeders into genetically narrow breeding populations that limit yield gains (Kelly et al., 1998).

Singh (1982) classified plant architecture of dry bean germplasm into four classes, including Type I upright bush with determinate plant growth, Type II upright with indeterminate growth, Type III semi-vine with indeterminate growth, and Type IV strong climbing vine with indeterminate growth. Breeding for upright Type II architecture has been an important component of breeding pinto bean cultivars since 1980 because upright growth habit provides a level of disease avoidance for some fungal pathogens such as white mold (Park, 1993) and enables the crop to be direct harvested, thus reducing seed loss during cutting and field curing. Early breeding efforts to develop upright architecture in pinto beans utilized navy and black bean germplasm from race Mesoamerica. The pinto cultivar Sierra was the first pinto bean cultivar released with improved architecture (Kelly et al., 1990), followed by additional cultivars with upright architecture (Osorno et al., 2010; Brick et al., 2011). Improvements in yield have also been achieved in some cases by extending maturity by 10 to 14 d. Upright plant architecture usually requires more time to produce a larger plant that sets pods on later nodes in contrast to early season highly efficient bush navy cultivars and semi-vine pinto landraces that lack upright plant structure.

Michigan released the first U.S. navy bean cultivar Robust in 1915 as a selection from locally grown landraces, followed by Michelite, the first cultivar bred and released by Down and Thayer (1938). Later, mutation breeding was used to introduce determinate bush growth habit into the traditional prostrate semi-vine indeterminate growth habit of Michelite (Down and Andersen, 1956). The navy bean cultivar Sanilac released in 1957 was the first bush navy bean cultivar that had the advantage of an erect bush habit combined with early maturity, white mold avoidance, and harvest ease, but it initiated an era of underperforming navy bean cultivars through the 1980s that lacked adequate genetic variability to generate future yield gains (Andersen et al., 1960). The narrow base of genetic variability in navy beans was corrected by introducing genetic variability from black beans from Central America (Adams, 1982), and yields have increased 50% over the last three decades (Kelly and Cichy, 2012). Early cultivars from these crosses lacked canning quality, but this has been corrected, along with refinements in maturity, lodging resistance, and partitioning, such that over 75% of the bean crop in Michigan is currently direct harvested. A valuable spin-off of this work has been the development of new high-yielding locally adapted black bean cultivars, many of which were derived from the same crossing program as navy beans (Kelly and Cichy, 2012).

In Nebraska, early yield gains were achieved in the great northern market class by selection for a more vigorous vine that produced higher biomass than traditional landraces. These gains came at a cost of increasing the risk of white mold due to denser plant canopies that retained humidity (Steadman, 1983). Major breeding efforts were focused on improving levels of resistance to white mold and seedborne bacterial diseases, including common bacterial blight, halo blight, and bacterial wilt [*Curtobacterium flaccumfaciens* pv. *flaccumfaciens* (Hedges) Collins & Jones]. Resistance introgressed from tepary bean (*P. acutifolius* A. Gray) in the tertiary gene pool has led to a number of new cultivars with high levels of resistance to common bacterial blight. Current gains in yield are being achieved through interracial crosses to improve architecture (Coyne, 1980), disease avoidance from white mold, and water use efficiency as water restrictions expand in the western United States (Urrea et al., 2009).

In New York, breeding efforts focused on improving physiological traits and efficient partitioning of nutrients and energy in light red kidney beans. The early cultivars were highly photoperiod sensitive and as a result produced plants with large vegetative biomass that were inefficient in partitioning energy to the seed. Wallace (1985) and colleagues developed the Redkloud cultivar that was photoperiod neutral, matured 2 wk earlier, and outyielded the older Redkote cultivar. ‘Redkloud’ was widely used as a parent, but the processing industry did not prefer it because of its dark seed coat color. Progress in breeding light red kidney bean was made at Sacramento Valley Milling Co. and the University of California, Davis with the releases ‘Sacramento’ in 1976 and ‘California Early Light Red Kidney’ (‘CLERK’) in 1989. These cultivars replaced the low-yield and long-season cultivar California Light Red Kidney. The cultivars Sacramento and CELRK are still predominant cultivars because of their excellent seed quality and early maturity.

Root pathogens caused by *Fusarium*, *Rhizoctonia*, and *Pythium* species were the major constraint to bean production in the PNW where the USDA program in Washington led efforts to introgress resistance to these pathogens into a wide array of pink, small red, and pinto seed types. The main source of resistance came from a small black seeded bean introduction 'N203' (PI 203958) collected by Oliver Norvell in Mexico (Wallace and Wilkinson, 1965). Introgression of resistance was challenging given the diversity and unadapted nature of the source material. Screening for resistance was conducted in infertile soils with limited irrigation that were infested with several different root pathogens (Burke and Miller, 1983). As a result, many of the lines and cultivars derived from these beans carry high levels of root rot resistance and have a yield advantage when grown in regions where root rots are a problem. In addition, many of these materials are recognized for higher levels of drought resistance that are, in part, due to improved root systems. In the early 1980s, a number of the pinto lines from this program were released as cultivars, and the germplasm was used to establish the bean breeding program at North Dakota State University. This germplasm and material mostly from the Michigan State University program have allowed the release of several pinto and navy cultivars that have excellent adaptation to the harsh conditions in North Dakota such as disease pressure, short growth cycle, frost, and flooding. Viral diseases, principally *Bean common mosaic virus* and *Beet curly top virus*, are also problematic in the PNW because of high insect populations that vector the pathogen. Resistance breeding was actively pursued and improved germplasm from this region continues to provide valuable resistance sources. Despite these disease problems, bean yields in the central basin of Washington are among the highest in the country and set the standard as some of the highest yields found.

Pinto bean production has long been associated with Idaho, largely because of the high-quality seed produced, the general overall adaptation of race Durango bean types, and favorable weather combined with adequate irrigation water. The landrace Common Pinto is well adapted to the region because of its overall robustness and favorable growing conditions. The breeding program at the University of Idaho has a long history of releasing improved pinto, great northern, pink, and small red cultivars (Singh et al., 2007). The preferred growth habit has been the early-season, semi-vine, Type III growth habit cultivars that respond well to cool nighttime temperatures, furrow irrigation, and low humidity. During harvest, plants are cut at maturity and allowed to dry in the field for 3 to 5 d before threshing to ensure even drying and excellent seed quality. The focus of the breeding program in Idaho has been largely on multiple disease resistance, yield improvement, and adaptation to western growing conditions.

Pinto beans have been produced in Colorado since the early 20th century. Production systems are similar to Idaho, but foliar diseases such as rust, bacterial diseases, and Fusarium wilt (*F. oxysporum* Schlechtend:Fr. f. sp. *phaseoli* J. B. Kendrick & W. C. Snyder) are more problematic (Brick et al., 2006). The program at Colorado State University (CSU) was initiated in 1948 and has focused on breeding for rust resistance, improved seed quality, upright architecture, and staying ahead of the emerging races of the rust pathogen (http://beans.agsci.colostate.edu/, accessed 13 Nov. 2013). Wood and Keenan (1982) developed the first rust resistant pinto cultivar Olathe and the first bush pinto bean cultivar Ouray (Wood and Keenan, 1982). Ouray was never widely grown because its determinate growth habit lacked the yield potential of indeterminate cultivars. In recent years, the program at CSU has incorporated upright Type II architecture in the cultivars Croissant and Long's Peak to improve plant structure and further enhance yield potential (Brick et al., 2011). In addition, CSU has a breeding program for rainfed pinto production in the Four Corners region of Colorado, New Mexico, Arizona, and Utah. The cultivars Fischer (Fisher et al., 1995), Cahone, and San Juan Select were released for this region. Although 'Fisher' is recognized for its drought tolerance in the Four Corner's region, it has shown little adaptation elsewhere.

Several breeding methodologies have been reported to improve dry beans. Interracial hybridization between beans from races Durango and Mesoamerica have been used to improve pinto, great northern, small red, and pink beans (Singh et al., 1993). Urrea and Singh (1994) compared breeding methods for beans and found that the pedigree breeding produced lines with the highest mean yield, followed by the mass selection. They suggested that early generation testing and selection should be used to more efficiently manage populations from interracial crosses. Urrea and Singh (1995) reported on the use of recurrent and congruity backcrossing for wide interracial hybridization in common bean.

The development of cultivars with multiple disease and pest resistance has been achieved in many bean breeding programs. Pinto rust resistant breeding lines BelDakMik-RMR 14 to BelDakMik-RMR 23 carry pyramided resistance to all known races of rust in the United States and resistance to all strains of *Bean common mosaic virus* and *Bean common mosaic necrotic virus* (Terán et al., 2009). Resistance to anthracnose in common bean is conditioned by at least nine major independent genes, *Co-1* to *Co-10* (Kelly and Vallejo, 2004). Molecular markers linked to the majority of *Co* genes have been reported that provide the opportunity to enhance disease resistance through marker-assisted selection (MAS) and gene pyramiding (Kelly and Vallejo, 2004). Miklas et al. (2006) highlighted examples of breeding using molecular markers that revealed the role and success of MAS in gene pyramiding. They discussed the ability to rapidly deploy resistance genes via marker-assisted backcrossing, enabling simpler detection and selection of resistance genes in the absence of pathogens, which lead to simplified breeding of complex traits. Marker-assisted selection has been well documented to speed up the selection process or reduce the selection cost during early generations of breeding program (Yu et al., 2000).

Yield Gains in Dry Bean: On-Farm Yields vs. Potential Yield

Several authors have discussed the difference between on-farm yields and potential yield (also known as realized yield) (Bingham, 1967; MacKey, 1979; Evans and Fisher, 1999). On-farm yield estimates are taken from production statistics and takes into consideration all factors affecting crop production, including cultivar potential, the environment, management practices, biotic factors, and their interactions. Potential yield trials primarily focus on the expression of the genetic potential under optimum or near optimum environmental and management conditions as achieved in trials conducted on research stations or where management practices are carefully applied in a selected environment (site) to allow plants to express their yield potential. The difference between on-farm yield and potential yield is known as the "yield gap" (Fisher et al., 2009; Godfray et al., 2010; Licker et al., 2010; Neumann et al., 2010). In most cases, the yield gap develops because of the impact of biotic and abiotic factors such as water regime, soil physical and chemical conditions, disease and pest pressure, weed competition, suboptimum plant stands, and harvest loss, as well as other factors that reduce on-farm yield. Crop management and other agronomic practices also play a crucial role (Duvick and Cassman, 1999). Economic factors such as fluctuations in commodity prices, marketing, and availability of seed stocks may also influence the pace in which yield gains are achieved. Plant breeders primarily focus on increasing potential yield while also attempting to optimize the interaction between genotype, environment, and agronomic practices to increase on-farm yield and reduce the yield gap.

During the last 20 yr, much of the pinto bean production moved from the western United States into the Midwest and Northern Great Plains (NGP). These ecogeographic regions are very different; consequently, cultivars originally developed for the western region did not perform well when grown in the latter areas. Such differences have been shown to impact estimates of yield gains as shown in the three major crops rice (*Oriza sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.) by using high-resolution geospatial databases and statistical tools (Ray et al., 2012).

Reliable estimates of on-farm yields can be obtained from surveys and statistical sources. Estimating potential yield is more challenging because of the difficulty of finding an optimum environment that would ensure little or no limitations for production resources. Potential yield is often estimated using data obtained from field experiments at research stations where environmental and management practices are maximized but are still not optimum for genetic expression of potential yield. Weather alone as a factor guarantees variation in yield expression below genetic optimum for every crop, and management practices cannot be applied to fully compensate for environmental variability.

For this section, production data from the USDA-NASS (2013) were used to estimate on-farm yields, and data obtained from the Cooperative Dry Bean Nursery (CDBN) was used to estimate potential yield. The CDBN has been grown every year since 1950 with an average of 10 locations each year across the most important dry bean production regions in North America (http://www.ars.usda.gov/pandp/docs.htm?Docid=21679, accessed 15 Nov. 2013). Different market classes are included in this trial with pinto, navy, black, and kidney beans the most frequent. For our comparisons, only data between 1981 and 2012 have been used to provide estimates of potential yields during the last 30 yr.

The earliest year in which on-farm yield values are available from the USDA-NASS is 1909 (USDA-NASS, 2013). Overall, on-farm yield across all market classes of dry bean grown in the United States show a seed yield increase of 12.9 kg ha^{-1} yr^{-1} (2.4% yr^{-1}) between 1909 and 2012 (Fig. 5–1). Potential yield data from the CDBN also show a positive trend with an average seed yield increase of 7.3 kg ha^{-1} yr^{-1} (0.5% yr^{-1}) during the last 31 yr (data not shown). Interpreting these results is difficult because of the large genetic diversity among market classes, yield potential, disease resistance, seed characteristics, and other traits. Therefore, we evaluated individual yield gains among four market classes, namely pinto, navy, black, and kidney beans during the past ~30-yr period. These four market classes account for approximately 95% of the total U.S. production.

Pinto bean yield gains between 1981 and 2012 showed a positive trend for both on-farm yield and potential yield, with yield gains ranging between 12.2 and 15.2 kg ha^{-1} yr^{-1} (0.4% yr^{-1} for potential yield) (Fig. 5–2). There was a yield gap between on-farm and potential yield, which suggests that the genetic poten-

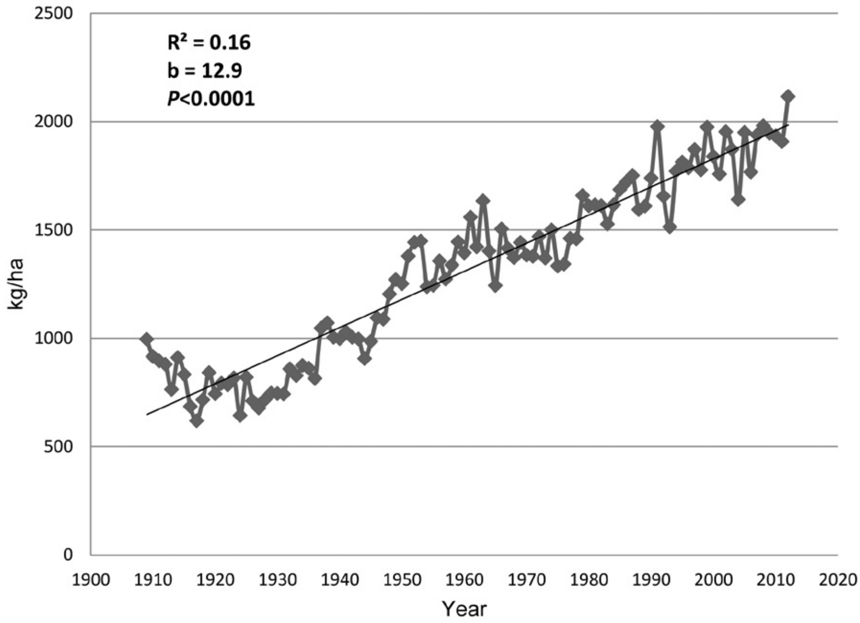

Fig. 5–1. On-farm seed yield averaged across dry bean market classes in the United States between 1909 and 2012 using production data from USDA-NASS.

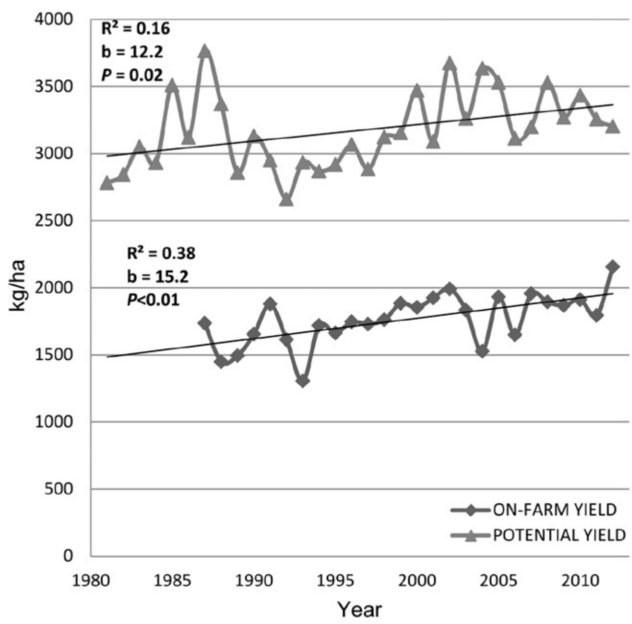

Fig. 5–2. On-farm yield and potential yield of pinto beans from 1981 to 2012 in the United States using production data from both USDA-NASS and the Cooperative Dry Bean Nursery.

tial of pinto bean cultivars was not fully expressed in on-farm trials. Pinto bean can be greatly affected by foliar bacterial and fungal diseases, root pathogen, and weed competition, which may explain a portion of the differences observed between on-farm and potential yield. Because the CDBN sites are often selected to represent high-yielding environments with adequate fertilization and optimum cultural practices, it is not surprising that potential yield was higher than on-farm yields. The gap between potential yield and on-farm yields clearly demonstrates that there are opportunities to improve production and management practices to increase on-farm yields and more fully exploit the genetic yield potential of new cultivars.

Navy and black beans show similar yield gains, which is not unexpected because they have similar genetic background (race Mesoamerica) and plant growth characteristics. Navy bean had yield gains between 18.5 and 25.9 kg ha^{-1} yr^{-1} (0.7% yr^{-1} for potential yield) (Fig. 5–3), which is greater than pinto bean. Black bean show a more variable range in yield gains between the on-farm and potential yield, with 5.7 and 24.3 kg ha^{-1} yr^{-1}, respectively (0.9% yr^{-1} for potential yield) (Fig. 5–4). These results may reflect more variation among cultivars and production regions in the black bean market class. Because fewer black bean cultivars are tested each year in the CDBN in comparison to other market classes, the results may have higher variability across years and locations. In addition, black bean cultivars had a larger yield gap than navy bean. On-farm results indicate that black bean may be reaching a yield plateau, which suggests that opportunities to improve production and management practices may be needed to increase on-farm yields for black bean.

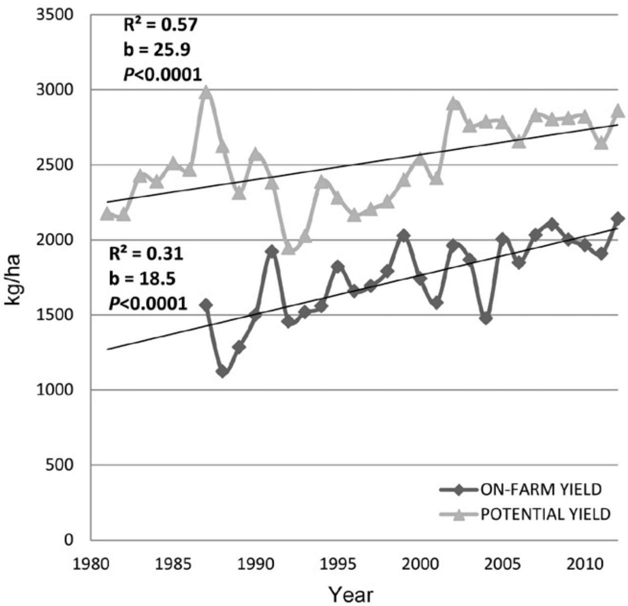

Fig. 5–3. On-farm yield and potential yield of navy beans from 1981 to 2012 in the United States using production data from both USDA-NASS and the Cooperative Dry Bean Nursery.

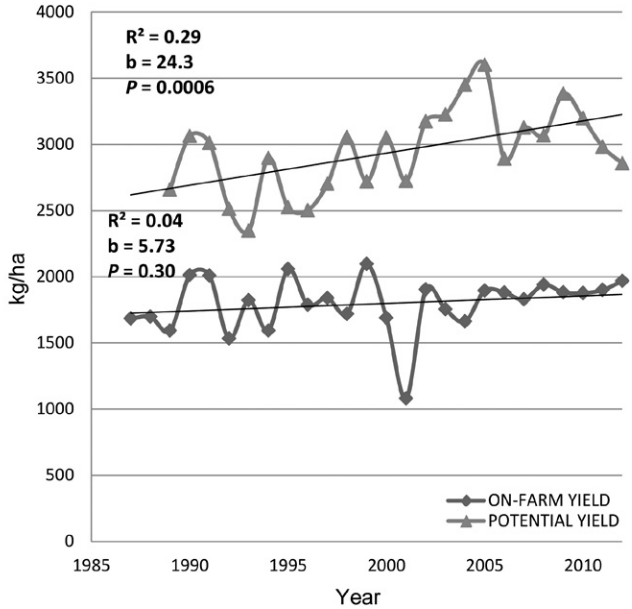

Fig. 5–4. On-farm yield and potential yield of black beans from 1987 to 2012 in the United States using production data from both USDA-NASS and the Cooperative Dry Bean Nursery.

Combined data from both light and dark red kidney bean show a yield increase between 19.1 and 39.9 kg ha^{-1} yr^{-1} (1.7% yr^{-1} potential yield) (Fig. 5–5). This is the highest gain among all market classes, which is surprising given the challenges associated with production and genetic improvement of kidney bean. Yield gains in kidney bean have been a challenge because they have a narrow genetic base and high susceptibility to biotic and abiotic factors (Beaver and Osorno, 2009; Kelly and Cichy, 2012). In addition, kidney bean has the smallest yield gap among those compared. The small difference between on-farm and potential yield in kidney bean may result from the fact that producers of kidney bean tend to manage the crop better than for other market classes because market prices are typically higher than for other market classes.

Yield Gains as Measured in Common Dry Bean Trials

Nuland and Taylor (1996) reported that yield levels of dry bean have increased 4.0 kg^{-1} ha^{-1} yr^{-1} from 1940 to 1994. They analyzed yield data from four major bean-producing counties in the United States to compare yield changes due to the introduction of new cultivars. They reported that changes in yield were largely driven by the introduction of new cultivars that possessed novel genes for resistance to pathogens. Singh et al. (2007) conducted studies on yield gain by using common trials in Idaho in which yield ranged between 2904 kg ha^{-1} for pinto cultivar UI 111 released in 1945 and 3921 kg ha^{-1} for cultivar Bill Z released in 1986 (Wood et al., 1989). This yield difference represents a 35% gain in 52 yr for these cultivars. Common trials that test cultivars released over time in the same environment have

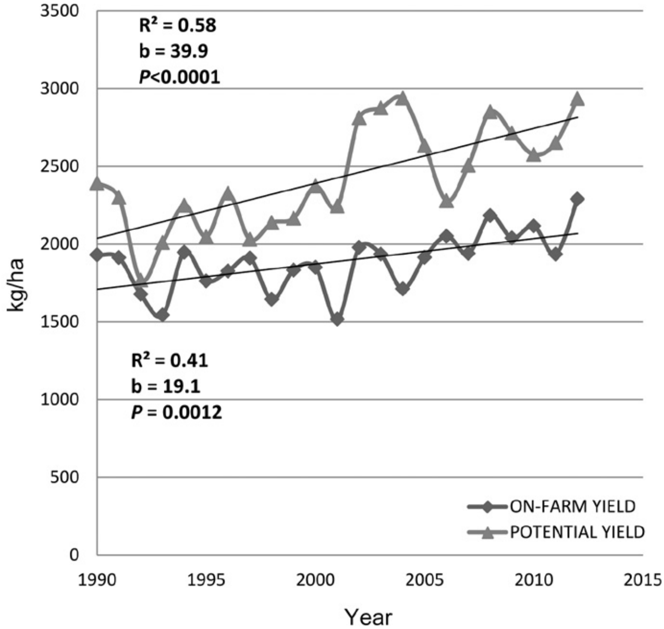

Fig. 5–5. On-farm yield and potential yield of kidney beans from 1990 to 2012 in the United States using production data from both USDA-NASS and the Cooperative Dry Bean Nursery.

been suggested by Cox et al. (1988) and others to specifically measure the genetic contribution of yield gain over time without confounding environmental or cultural effects. The results of trials reported in this report were conducted by four participants in the Bean Coordinated Agriculture Project in Colorado, Michigan, North Dakota, and Nebraska during 2011 and 2012. The trials included cultivars released since 1956 for navy bean and since 1965 for pinto bean. Field trials at all sites were managed following standard recommendations for tillage, herbicides, and insecticides. In Colorado, the trials were grown on the Agricultural Research Development and Extension Center in Fort Collins. The trials were furrow irrigated and received 506 mm of rainfall plus irrigation during the growing seasons in 2011 and 464 mm in 2012. Yield levels were normal in both years, with growing degree days 6% higher in 2012 than 2011. In Michigan, trials were grown near Frankenmuth in 2011 and 2012. In 2011, plots received 206-mm rainfall during the growing season and 263 mm in 2012. Growing degree days were 8 and 10% higher than normal for 2011 and 2012, respectively. In North Dakota, plots were grown at the Carrington Research Station under limited irrigation in 2011 (395-mm rainfall + irrigation during the growing season), and in 2012 plots were grown in a growers field near Hatton under rainfed conditions (257-mm rainfall). In Nebraska, plots were planted in a grower's fields near Mitchell and irrigated with an overhead sprinkler both years. Total rainfall + irrigation was 390 and 411 mm in 2011 and 2012, respectively. The 2012 season was warmer than 2011, with the maximum temperature 2°C higher during the growing season. Seed yield was measured using standard field plot practices at each location. Depending on the protocols used by each breeding program, seed yield was measured in two or four row plots, 5 to 7 m long. Two replicates per location were used in 2011, and three replicates per location were used in 2012. Plant maturity was the number of days from planting to visually estimated 30% pod discoloration (yellow to brown), seed weight (g 100 seed^{-1}) was measured by weighing 100 random seeds from each replicate, and plant canopy height was measured from the soil surface to the uppermost plant part by using a meter stick. Analysis of variance was used to determine interactions between location and cultivar, and linear regression was used to estimate genetic progress over time by regressing the four response variables on the year of cultivar release. Years and replicates were considered random model factors and location and cultivars considered fixed factors. A combined analysis of variance over locations was used independently for navy and pinto bean cultivars with replicates nested in locations and years.

Seed yield increased for both navy and pinto bean cultivars over the time periods of cultivar release (Fig. 5–6a, 5–6b, and 5–6c). For both navy and pinto beans, the analysis of variance indicated that the main effects of cultivar and the location × cultivar interaction were significant ($P < 0.001$); however, the main effects of location were not. The analysis indicated that navy cultivars released since 1956 had a similar linear response across the Midwest region (Michigan and North Dakota) and western region (Colorado and Nebraska); therefore, the response was summarized over both regions (Fig. 5–6a). The overall regression of yield on year of release indicated that mean seed yield in navy cultivars increased from 1832 kg ha^{-1} in 1956 to 2558 kg ha^{-1} in 2008. The regression equation indicated that yield increased 13.9 kg ha^{-1} yr^{-1} ($P = 0.003$) and the regression equation accounted for 54% of the variation in response. Yield response for pinto bean cultivars differed between the Midwest and West regions. In the Midwest (Fig. 5–6b), mean seed yield increase over time was not significant ($b = 2.6$; $P = 0.68$; $R^2 = 0.01$) and likely occurred because most of the pinto cultivars released between 1965 and 2008 were developed by breeding programs located in the western United States. In the West region (Fig. 5–6c), mean seed yield of pinto cultivars increased from 2041 kg ha^{-1}in 1965 to 2880 kg ha^{-1} in 2008. The regression equation indicated that mean seed yield increased 17.4 kg ha^{-1} yr^{-1} ($P = 0.009$) and explained 36% of the variation in yield (Fig. 5–6c). Only the test cultivars Sierra, Stampede, and Lariat were developed by breeding programs in the Midwest, hence the set of cultivars in this study are not representative of progress in yield gains in the Midwest. It is noteworthy that the three cultivars developed in the Midwest fell above the Midwest region regression line (Fig. 5–6b). The average yield increase for navy beans was 0.77% yr^{-1} [13.9 kg ha^{-1} yr^{-1}; and for pinto beans developed and tested in the West, 0.85% yr^{-1} (17.4 kg ha^{-1} yr^{-1})]. These results are similar to the yield increases reported for soybean [*Glycine max* (L.) Merr.] (Specht and Williams, 1984; Voldeng et al., 1997), wheat (Lopes et al., 2012), and dry beans (Singh et al., 2007) and to findings based on on-farm and potential yield data from the USDA-NASS and the CDBN, respectively.

Seed weight, harvest maturity, and plant height were also measured in the common trials. Seed weight is an important criterion that defines market classes for both navy and pinto bean cultivars. In general, navy bean cultivars range in seed weight from 18 to 22 g 100 seed^{-1} and pinto cultivars from 35 to 40 g 100 seed^{-1}. Therefore, breeders do not select for seed weight outside of the range that is commercially acceptable. Consequently, mean seed weight did not change

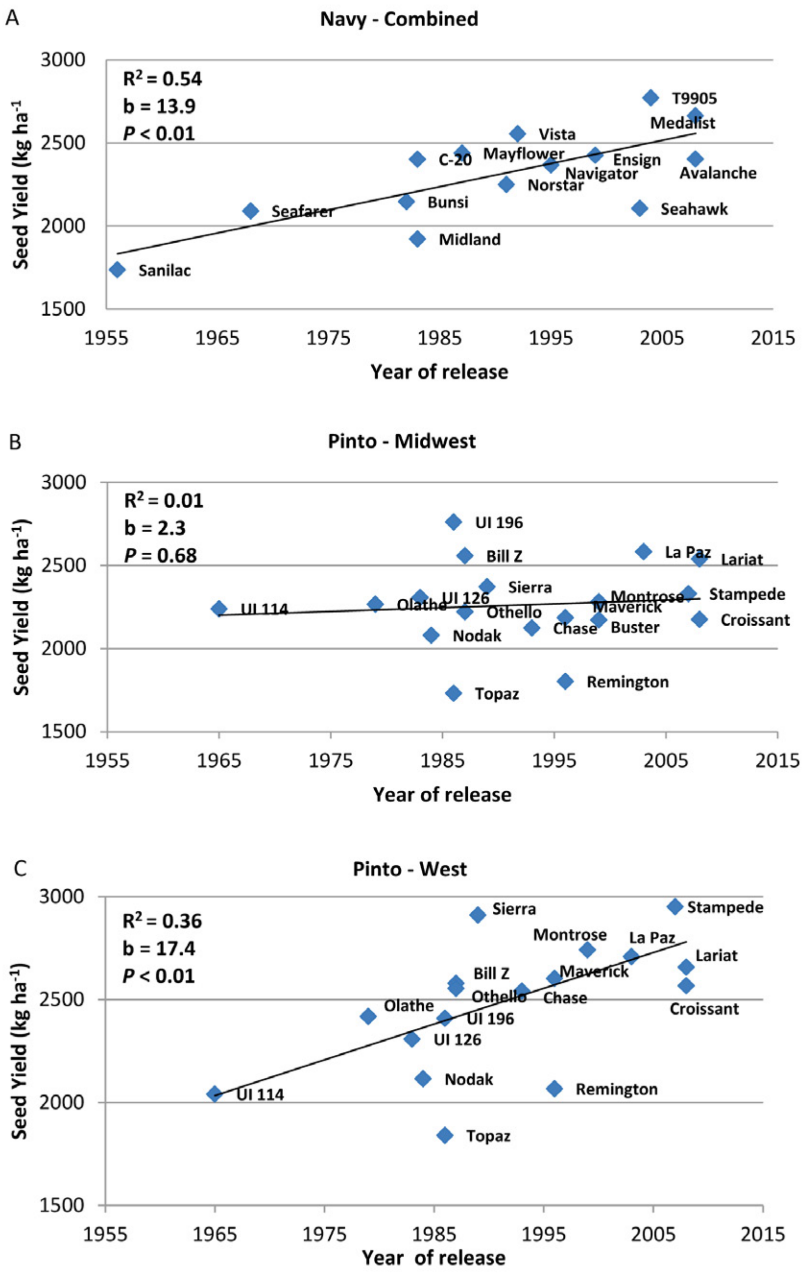

Fig. 5–6. Seed yield (kg ha^{-1}) among (a) navy bean cultivars averaged over Midwest and Western region trials, (b) pinto bean cultivars in the Midwest region, and (c) pinto cultivars in the western region regressed on year of release.

($P > 0.05$) for navy cultivars and only increased 0.09 g yr^{-1} ($P < 0.05$) for pinto bean cultivars over time (Fig. 5–7a and 5–7b). This small increase in seed weight likely reflects some pressure on pinto breeders to increase seed size because a small premium price is placed on large seed in pinto markets. Mean harvest maturity (days to pod maturity) did not change for either navy ($P = 0.61$) or pinto bean cultivars over the time of release ($P = 0.40$) (data not shown). This lack of relationship is not surprising, because dry bean harvest in the United States and Canada must occur in September when the air temperature is high and humidity is low

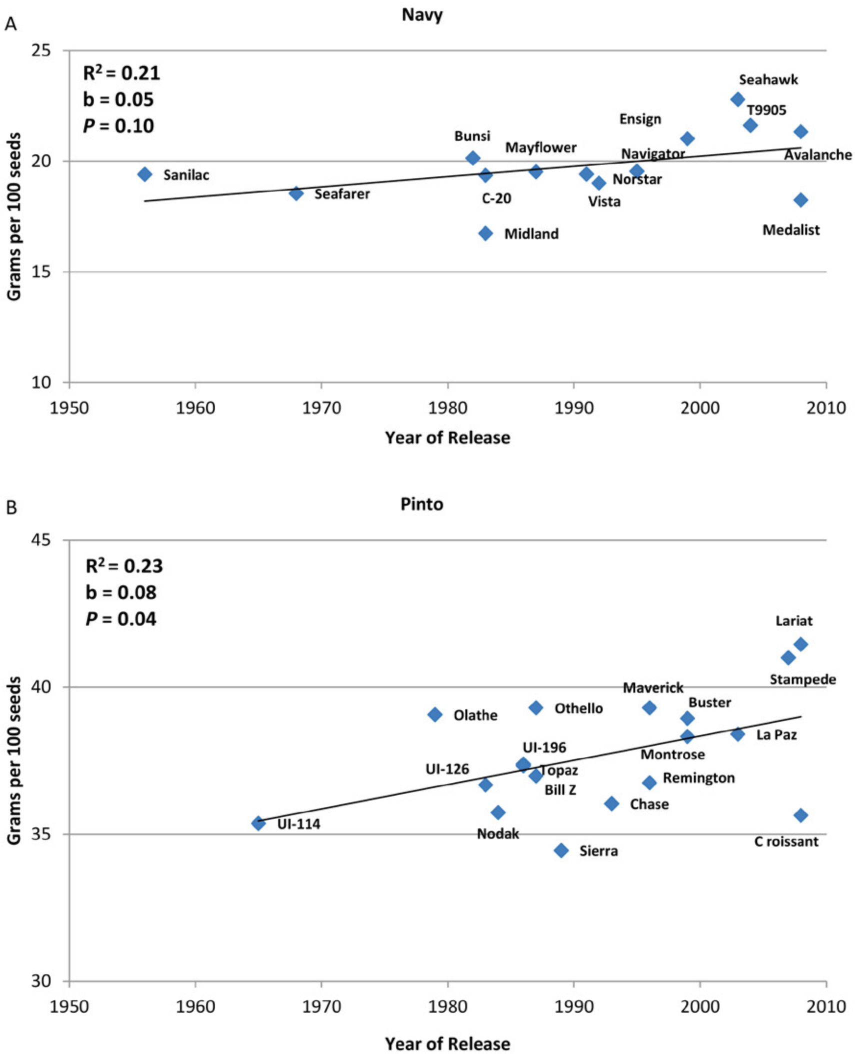

Fig. 5–7. Seed weight (g 100 seed⁻¹) among (a) navy bean cultivars and (b) pinto bean cultivars averaged over Midwest and western region trials regressed on year of release.

to allow the pods to dry for threshing. This drying requirement is important to produce bright colored seed color because high humidity or rainfall on the crop can cause dark or stained seed color and reduce the market value of the crop. In fact, in many regions of the West that produce high-quality dry beans, September is the driest month of the year. In some regions, early harvest is also important to allow producers to timely harvest other full-season crops such as corn, soybean, sugarbeet (*Beta vulgaris* L.), and sunflower (*Helianthus annuus* L.) and to prepare the field for fall planting of winter cereal or oil seed crops. These concerns have prevented breeders from extending plant maturity to increase seed yield as in other crops.

Plant height increased significantly in pinto bean cultivars over time; however, plant height did not significantly increase in navy bean cultivars (Fig. 5–8a) even though the plant height of the earliest released navy bean cultivars Sanilac and Seafarer is well below that of more recent cultivars Medalist and T9905. A few of the more recent navy bean cultivars such as Seahawk and Avalanche have a tendency to lodge, which is reflected in lower plant height. Mean plant height for pinto beans in the Midwest trial (Fig. 5–8b) increased from 38 cm for cultivars released in 1965 to 50 cm for cultivars released in 2008 ($P = 0.02$); for pinto bean in the West trial (Fig. 5–8c), plant height increased from 32 cm for cultivars released in 1965 to 64 cm for cultivars released in 2008 ($P = 0.02$). For navy bean cultivars, mean plant height across regions was not significantly different over the time of release (from 52 cm in 1956 to 57 cm in 2008) ($P = 0.39$). This large difference in response is due to the fact that all navy bean cultivars tested in this research had upright architecture; however, pinto cultivars had prostrate vine architecture before 1980.

Summary and Conclusions Regarding Dry Bean Yields

Genetic gain in dry bean based on common trials was 13.9 kg ha^{-1} yr^{-1} (0.77% yr^{-1}) and 17.4 kg ha^{-1} yr^{-1} (0.85% yr^{-1}) for navy and pinto bean cultivars, respectively. These results are similar to the yield increases reported for soybean (Specht and Williams, 1984; Voldeng et al., 1997), wheat (Lopes et al., 2012), and dry bean (Singh et al., 2007) in previous studies. They are also similar to findings in this report that evaluated potential yield data within market classes from the CDBN trials over the past ~30 yr (0.9% yr^{-1} across market classes). Data from potential yield gains within each market class showed a gain of 0.4, 0.7, 0.9, and 1.7% for pinto, navy, black, and kidney beans, respectively. The fact that similar gains are found by using different sources of data suggest that the results provided here are robust and accurate. The results also suggest that yield increases have been linear since 1956 and suggest that dry bean cultivars have not reached a yield plateau for most market classes. Continued introgression of germplasm from other races of common bean should provide new sources of genetic diversity to enhance yield into the foreseeable future. For navy bean, only seed size has not changed since 1956. Plant height for pinto bean cultivars increased from 34 to 57 cm over time because of the introgression of Mesoamerican germplasm with upright Type II architecture. Seed size increased slightly in pinto bean but did not change in navy bean cultivars over time. In addition to breeding efforts to reduce the yield gap found in all market classes, there is a need to keep improving management practices that allow for higher production efficiency.

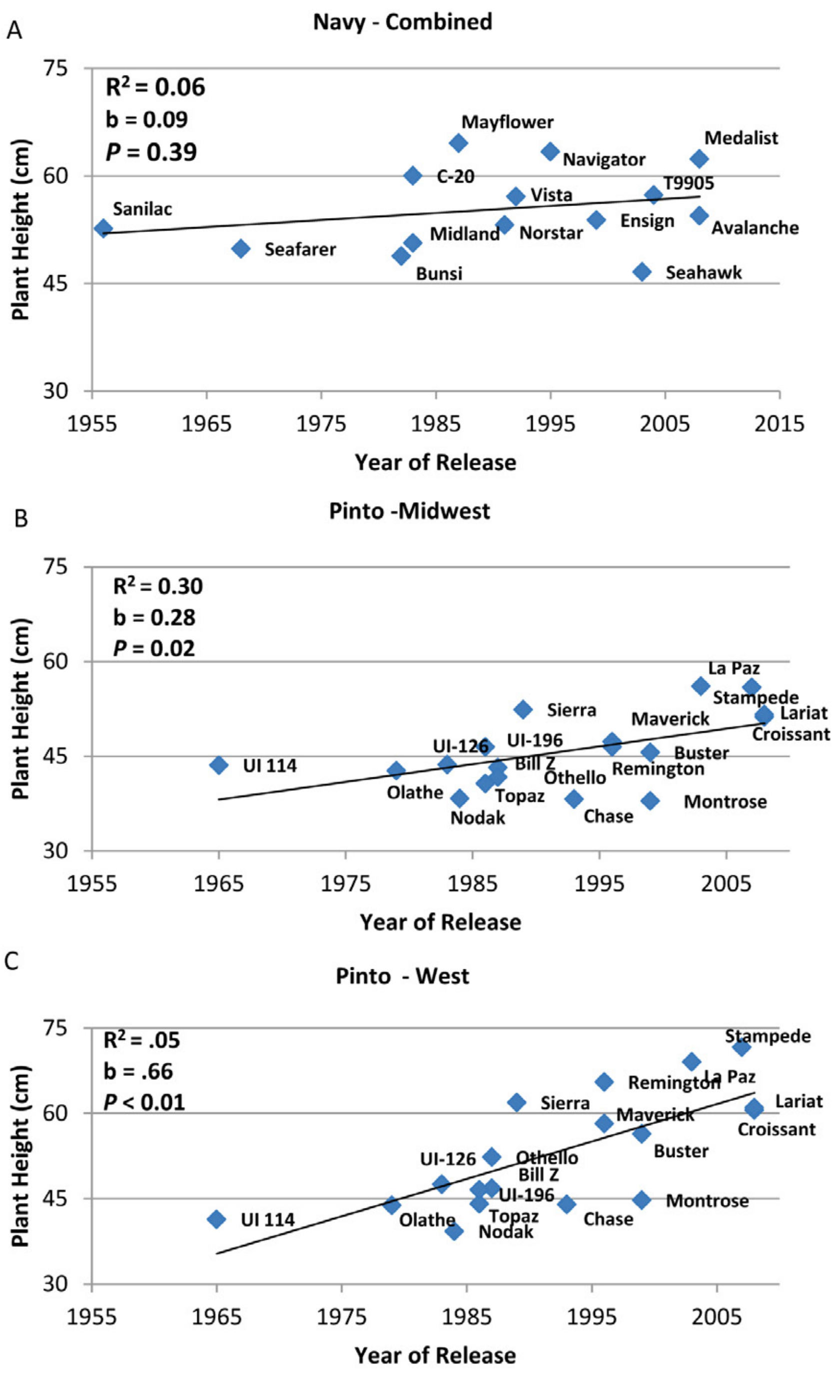

Fig. 5–8. Plant height (cm) among (a) navy bean cultivars averaged over the Midwest and western region trials, (b) pinto bean cultivars in the Midwest trial, and (c) pinto bean cultivars in the West region trial regressed on year of cultivar release.

Yield Gains in Cool Season Food Legumes

Cool season food legumes, including pea, lentil, and chickpea, were among the first crops to be domesticated during the advancement of Neolithic culture that occurred 8,000 to 12,000 yr ago in riparian societies along the Euphrates and Tigris rivers (Ladinsky and Alder, 1976). These crops have been historically grown in rotations with small cereal grains and confer several benefits to small grain production, including disruption of cereal disease cycles and increasing availability of residual nitrogen produced by fixation of atmospheric N by rhizobacteria in root nodules. Cool season food legumes also complement small cereal grains in nutritional qualities, with food legumes having relatively high seed concentrations of lysine and low concentrations of the sulfur-containing amino acids methionine and cysteine, while cereal grains tend to have low concentrations of lysine but high concentrations of sulfur-containing amino acids (Bressani and Elias, 1988).

Dry Peas

Pea was domesticated at least 8000 yr ago in areas of present-day Turkey through Iran (Zohary and Hopf, 1973). Currently, dry pea ranks second only to common bean as the most widely grown grain legume in the world. Global pea production during 2006 to 2010 averaged nearly 9.9 million tonnes, with Canada being the largest producer followed by the Russian Federation, China, India, and France (FAOSTAT, 2013). The National Center for Biotechnology Information (NCBI) currently recognizes *P. sativum* with five subspecies (*abyssinicum, asiaticum, elatius, sativum* and *transcaucasicum*) and *P. fulvum*.

Commercial dry pea production in the United States began in the 1910s in eastern Washington and northwestern Idaho, a region that is known as the "Palouse," as growers tried to identify an alternative rotational crop to oats (*Avena sativa* L.) and barley (*Hordeum vulgare* L.) for dryland wheat production systems. Initial cultivars recommended for the Palouse were the green pea Alaska and the yellow pea Canadian White (Shinn, 1916). By 1926, yield benefits to wheat production using pea rotations were recognized (Schafer, 1926). The PNW continued to be the primary area for producing dry pea until the mid 1990s, when pea production expanded rapidly in the dryland regions of the NGP, especially in eastern Montana and North Dakota.

In the United States, dry pea production consists primarily of yellow and green market classes (FAOSTAT, 2013). Green and yellow peas are typically dried and eaten split or whole and are also used to make flour or for animal feed (Wright, 1985). The largest pea-producing states in the United States now are Montana, followed by Washington, which is closely followed by North Dakota, and finally, Idaho (USDA-NASS, 2013). Although the USDA-NASS does not separate yellow and green peas when reporting dry pea statistics, the U.S. Dry Pea and Lentil Council estimates that 2012 U.S. dry pea acreage consisted of approximately 45% green peas and 55% yellow peas (U.S. Dry Pea and Lentil Council, 2012). The U.S. Dry Pea and Lentil Council estimated that in 2013 approximately 36% of the total U.S. green pea crop was produced in the PNW and 64% in the NGP. However, in 2013 approximately 95% of the total U.S. yellow pea crop was produced in the NGP (U.S. Dry Pea and Lentil Council, 2012).

Over the past 25 yr (1987–2011), the area of peas harvested annually in the United States has increased considerably. During the most recent 4 yr (2008–

2011) of the past 25-yr (1987–2011) period, the average area of peas harvested in the United States was 277,364 ha, which is a 300% increase over the average of 69,356 ha harvested in the United States during the first 4 (1987–1990) of the past 25 yr (USDA-NASS, 2013). The rapid increases over time in the area of peas harvested in the NGP compared with the PNW can be seen in Fig. 5–9. During the recent 4-yr period (2008–2011) the average area of dry pea harvested in the PNW was 42,120 ha, a 38% decrease from the average of 68,141 ha harvested from this region during the first 4 (1987–1990) of the past 25 yr (USDA-NASS, 2013). In contrast, during the most recent 4 yr (2008–2011), the average area of dry pea harvested in the NGP was 232,976 ha, a 472% increase over the average of 40,753 ha for the first 4 yr (1998–2001) for which data are available from NASS for pea production in the NGP.

On-Farm Productivity Trends for Dry Peas

Although both the area harvested and total production of peas in the United States have greatly increased over the recent 25-yr period from 1987 through 2011, yields per hectare have actually decreased by 0.3% per year (Fig. 5–10). This change from an average of 2274 kg ha^{-1} (2031 lb ac^{-1}) during 1987 to 1991 to an average of 2084 kg ha^{-1} (1861 lb ac^{-1}) during 2007 to 2011 represents an average annual yield decrease of 8 kg ha^{-1} (7.1 lb ac^{-1}). Considering the PNW separately, over the past 25 yr pea yields have decreased by approximately 0.4% per year. Dry pea yields in the U.S. Northern Plains have also decreased over time, by approximately 1.5% per year over the past 14 yr for which data are available.

Basis for Yield Improvement in Dry Peas

The biological basis of crop yield is the final result of genetic, environment, and genetic × environment interaction effects that take place in a dynamic system that includes the crop, beneficial and detrimental microorganisms, insect pests, herbivores, and the growing environment. Pea improvement programs must consider a range of traits that impact yield and consumer acceptance. Quality traits of

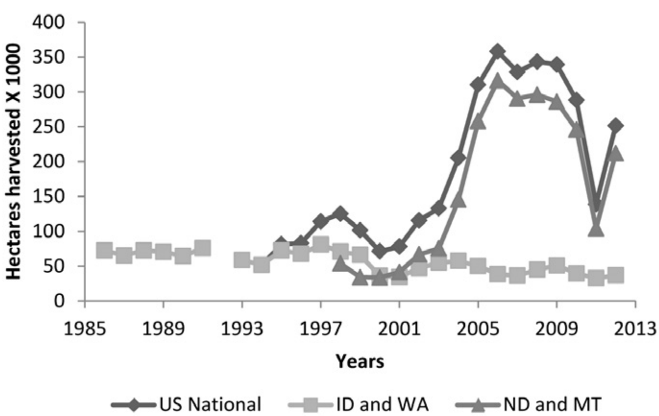

Fig. 5–9. Historical changes in the area (ha) of peas harvested in the total United States, the U.S. Pacific Northwest (Idaho and Washington), and the U.S. Northern Plains (Montana and North Dakota) during 1987 to 2011.

importance to consumer acceptance include cotyledon color, bleaching resistance (green cotyledon only), seed coat and hilum color, seed size and shape, splitting quality, cooking time, and organoleptic characteristics (Hawtin et al., 1988). New cultivars that have improved seed quality traits must also have acceptable yield levels to be grown commercially. Several reproductive traits, including seed size, number of pods per plant, and number of seeds per pod, contribute to yield in pea. A significant positive correlation was observed between grain yield and seed size, number of pods per plant, and plant harvest index, which is the ratio of seed yield per plant divided by total biomass per plant (Sarawat et al., 1994). Significant general combining ability and specific combining ability effects have been detected for yield and several yield components of yield in pea, including pods per plant, plant harvest index, seeds per pod, and seed weight, suggesting these traits are conditioned by both additive and nonadditive genetic variance (Sarawat et al., 1994). A narrow sense heritability (h^2_n) estimate of 0.55 has been calculated for seed yield of dry pea (Timmerman-Vaughan et al., 2005). Several developmental and morphological traits also impact dry pea yield. Early flowering is desirable because high temperatures can occur later in the growing season and reduce pod set. A negative correlation has been observed between days to maturity and grain yield in dry pea (Tar'an et al., 2004). The leaf type of a pea cultivar can also impact havestability. Cultivars with conventional leaves, such as Columbian, tend to have long vines and are susceptible to lodging. Newer cultivars are predominately *afila* leaf types, which are also known as "semi-leafless." *Afila* type plants only produce stipules while producing many more tendrils than normal leaf type plants, which produce stipules, leaflets, and tendrils. The profuse

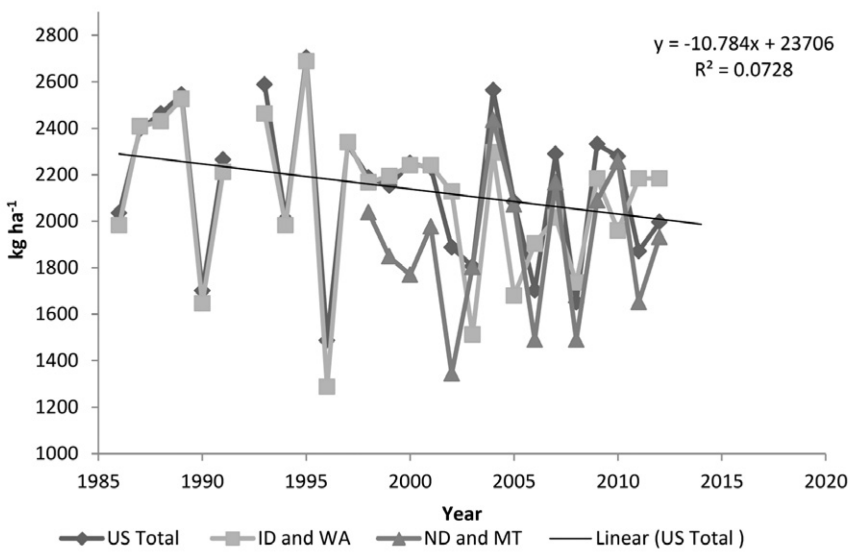

Fig. 5–10. Historical changes in on-farm pea yields (kg ha^{-1}) across the total United States, the U.S. Pacific Northwest (Idaho and Washington), and the U.S. Northern Plains (Montana and North Dakota) during 1987 to 2011.

tendrils that develop from *afila* lines intertwine in the field and serve to support the crop, which reduces lodging and allows for more efficient harvesting.

Pea production in the United States is impacted by several diseases that remain a focus for breeding efforts. Aphanomyces root rot, caused by *Aphanomyces euteiches* Dresch., is the most destructive disease of pea in the United States and can cause complete crop loss when cool and wet spring conditions promote disease development (Pfender, 2000). Fungicides are not effective at controlling this disease and resistance is lacking in commercial dry pea cultivars (Pfender, 2000). Progress in improving levels of resistance in pea to Aphanomyces root rot has been impeded by linkage between resistance genes and loci responsible for undesirable production traits, such as tall plants (*Le*), colored flowers (*A*), and colored seed (*Pl*) (Marx et al., 1972). Heritability estimates for resistance in peas to *A. euteiches* have been less than 0.50 (Pilet-Nayel et al., 2002; Shehata et al., 1983), which suggests environmental variance contributes considerably to disease reaction. Other important diseases of pea in the United States include wilt caused by *Fusarium oxysporum* Schlech. (Haglund, 2000), blight caused by *Mycosphaerella pinodes* Berk. & Bloxam (Bretag and Ramsey 2000), and white mold disease caused by *Sclerotinia sclerotiorum* (Lib.) de Bary (Biddle, 2000).

Pea is a self-pollinated diploid ($2N = 2X = 14$) crop that produces cleistogamous flowers. Commercial dry pea cultivars are pure lines developed either through pedigree, backcross, or modified bulk-pedigree descent breeding approaches (Gritton, 1986). The initial sources of resistance to several soilborne diseases, including Aphanomyces root rot and Fusarium wilt, were PI accessions or pea cultivars developed for canning. PH-14-119 (Kraft et al., 1972), a canning pea with resistance to both Fusarium wilt and Aphanomyces root rot, was crossed with an *afila* type line to produce the pea germplasms 792022 and 792024, the first high-yielding dry pea lines with field tolerance to soilborne diseases of the PNW (Kraft, 1981). The germplasm 792022, PI 180693, and PI 189171 were then used as sources of resistance to develop pea germplasm lines 90-2079 and 90-2131, and 90-2322, which were released based on enhanced resistance to Aphanomyces root rot, Fusarium wilt, and Fusarium root rot (Kraft, 1992). Pea germplasm 90-2031 was subsequently crossed to the cultivar Dark Skin Perfection, and several lines were recently released that have improved resistance to multiple soilborne diseases coupled with desirable seed and plant architecture characteristics (McGee et al., 2012).

Major efforts in the United States to develop improved dry pea cultivars for U.S. production began in the early 1960s by the USDA-ARS in cooperation with Washington State University. These two research programs, one located in Prosser, WA and the other in Pullman, WA, remained the primary public breeding programs in the United States for dry pea until 2008, when a dry pea improvement program began at North Dakota State University. Currently, the majority of dry pea cultivars grown in the United States are derived from private breeding programs. These include green pea cultivars Columbian, Aragorn, and Banner and yellow pea cultivars Delta and Universal.

Yield Gains Measured in Recent Dry Green Pea Cultivar Trials

Only a few new green pea cultivars have been released over the past decade in the United States, and the majority of these cultivars are not intended for human consumption. Specter (McPhee and Muehlbauer, 2007) and Windham (McPhee et al., 2007) are two cultivars of peas that can be sown in the fall and produce grains that are used for animal feed. The recently released cultivar Lynx (McGee et al., 2012) is intended for use as a component of wildlife food plots. The most successful spring green pea cultivars grown in the United States have been developed by private breeding programs and include Ariel (Progene Plant Research 2013a), which was released in 2002 on the basis of its high yield and bleaching resistance, Aragorn (Progene Plant Research 2013b), released in 2007 on the basis of its high yield, large seed size, and early maturity, and Banner (Progene Plant Research 2013c), released in 2008 on the basis of its high seedling vigor, yield, and early maturity. 'Aragorn,' 'Ariel,' and 'Banner' were compared with 'Columbian' for yield and other metric traits to determine what traits have been markedly changed between older and newer materials (Table 5–1). Comparisons are based on the results of field trials conducted at four locations in the PNW (Genesee, ID; Kendrick, ID; Pullman, WA; and Fairfield, WA) during 2011 and 2012. The Pullman, WA trials were at the WSU–Spillman Research Farm, and all other trials were conducted on fields provided by cooperating growers. The average yield of 'Columbian' was significantly less than the average yield of all three newer cultivars. The three new lines had an average yield of approximately 2242 kg ha^{-1} (1996 lb ac^{-1}), which is 35% higher than the observed average yield of 'Columbian.' These results suggest that considerable gains in yield of green peas are being realized though breeding efforts.

Considering selected traits of agronomic importance to pea, 'Ariel' produced significantly smaller seed than 'Columbian,' while the seed sizes of 'Banner,' 'Aragorn,' and 'Columbian' were not significantly different (Table 5–1). 'Columbian' reached 50% flowering in a significantly shorter time than any of the newer cultivars. The early flowering of 'Columbian' is a consequence of its indeterminate pod development compared to the newer entries. 'Columbian' had a significantly lower canopy height and plant height index than any of the newer cultivars, which suggests that gains are also being made through breeding in improving traits associated with harvesting ease.

Table 5–1. Yield and agronomic characteristics of green pea cultivars based on field trials conducted in Washington and Idaho in 2011 and 2012.

Entry	Release	Yield†	Seed size‡	Days to 50% flower‡	Canopy height‡	Plant height index‡¶
		kg ha^{-1}	g 100 $seeds^{-1}$		cm	
Banner	2008	2325 A	19.4 A	54.2 A	55.5 A	0.86 A
Aragorn	2007	2273A	19.8 A	55.0 A	54.6 A	0.89 A
Ariel	2002	2129 A	17.7 B	55.6 A	56.7 A	0.89 A
Columbian	~1980	1666 B	19.7 A	47.8 B	40.4 B	0.49 B
LSD (α = 0.05)		332	0.9	2.9	6.7	0.08

† Based on trials conducted at Pullman, WA; Fairfield, WA; Genesee, ID; and Kendrick, ID in 2011 and 2012 (eight location years).

‡ Based on trials conducted at Pullman, WA in 2011 and 2012.

¶ Plant height index = plant height mature/green vine length.

Lentils

Lentil was domesticated approximately 10,000 yr ago in areas of present-day Syria, Turkey, Iran, and Iraq (Harlan, 1992). Recent taxonomic studies (Galasso, 2003; Sonnante et al., 2003) have identified six species in the genus *Lens*, which includes *L. culinaris* (spp. *culinaris* and spp. *orientalis*), *L. odemensis*, *L. tomentosus*, *L. nigricans*, *L. ervoides*, and *L. lamottei*. Cultivated lentil (*L. culinaris* spp. *culinaris*) is proposed to have been developed from *L. culinaris* spp. *orientalis*, with domestication associated with increases in plant height, number of leaves and total leaf area, along with larger pods and seeds (Cubero et al., 2009).

Global lentil production during 2006 to 2010 averaged nearly 3.6 million tonnes, with Canada being the largest producer, followed by India, Turkey, the United States, and Nepal (FAOSTAT, 2013). Cultivated lentils may be divided into market classes that are based predominately on seed size, the color of the seed coat, and cotyledon color. The majority of lentils produced in the United States are exported, and specific market classes are targeted to distinct global markets (Muehlbauer et al., 2009). Red lentils are typically exported to nations in southwest Asia, including India, Sri Lanka, and Bangladesh. Spanish Brown lentils, which have small seed ($\approx$4 g 100 seed^{-1}), a dark seed coat, and yellow cotyledons, are primarily exported to Spain. A broader market exists for medium and large yellow lentils, which includes the cultivars Brewer (Muehlbauer, 1987) and Riveland (McPhee and Muehlbauer, 2009), and they are exported to Latin America, Europe, and North Africa. Another market class grown in the United States is small yellow lentils, such as the cultivar Eston, which produces small seed ($\approx$4.5 g 100 seed^{-1}) with a green seed coat and yellow cotyledons.

Similar to dry pea, commercial lentil production in the United States began in the1930s in the Palouse region of eastern Washington and northern Idaho (Youngman, 1967). This region remained the primary production area in the United States until the 1990s, when lentil production began to expand to the dryland regions of central and eastern Montana and North Dakota. The largest lentil producing state in the United States is Montana, followed closely by North Dakota, then Washington and Idaho (USDA-NASS, 2013). Currently, approximately 78% of the total lentil production in the United States occurs in Montana and North Dakota, and the remaining 22% is produced in Washington and Idaho (USDA-NASS, 2013). The area of lentils harvested annually in the United States has increased considerably over the past 25 yr (1987–2011) (Fig. 5–11). During the most recent 4 yr (2008–2011) of the 25-yr (1987–2011) period, the average area harvested in the United States was 173,340 ha, a 326% increase over the average of 40,661 ha harvested during the first 4 (1987–1990) of the past 25 yr (USDA-NASS, 2013). The rapid increase over time in the area harvested in the NGP compared with the PNW is evident in Fig. 5–11. During the most recent 4 yr (2008–2011) the average area harvested in the PNW was 44,348 ha, only a 7% increase over the average of 41,411 ha harvested from this region during the first 4 (1987–1990) of the past 25 yr (USDA-NASS, 2013). In contrast, during the most recent 4 yr, the average area of lentils harvested in the NGP was 128,993 ha, a 510% increase over the average of 21,162 ha for the first 4 yr (1997–2000) of data available from USDA-NASS for lentil production in the NGP.

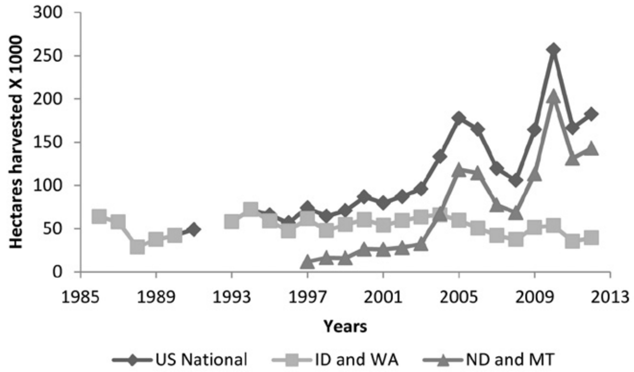

Fig. 5–11. Historical changes in the area (ha) of lentils harvested in the total United States, the U.S. Pacific Northwest (Idaho and Washington), and the U.S. Northern Plains (Montana and North Dakota) during 1987 to 2011.

On-Farm Productivity Trends for Lentils

Although both the area harvested and total production of lentils in the United States has increased considerably over the 25-yr period from 1987 through 2011, lentil yields have been essentially unchanged, increasing only 0.1% per year (Fig. 5–12). This change from an average of 1345 kg ha^{-1} (1201 lb ac^{-1}) during 1987 to 1991 to an average of 1368 kg ha^{-1} (1222 lb ac^{-1}) during 2007 to 2011 represents an average yield gain per year of only 1 kg ha^{-1} (0.9 lb ac^{-1}). In the PNW over the past 25 yr, lentil yields have remained unchanged, decreasing approximately 0.1% per year. Yields in the NGP have decreased by approximately 0.1% per year over the past 14 yr of available data.

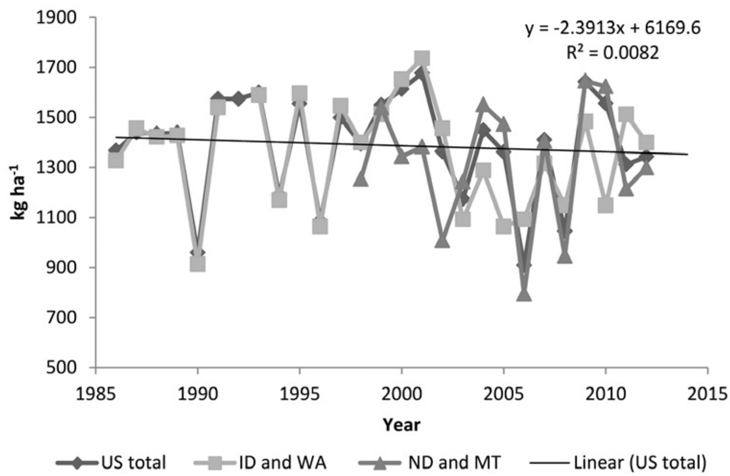

Fig. 5–12. Historical changes in on-farm lentil yields (kg ha^{-1}) across the total United States, the U.S. Pacific Northwest (Idaho and Washington), and the U.S. Northern Plains (Montana and North Dakota) during 1987 to 2011.

Basis for Yield Improvement in Lentil

Successful lentil cultivars must have traits necessary for field production and market acceptance. Critical production traits include yield, plant height, lodging tolerance, pod height, flowering time, number of seeds per pod, and reduced pod dehiscence (Sharma, 2009). Although pod dehiscence serves as a trait to promote survival in wild *Lens* spp., it is a very undesirable trait in cultivated lentil because pod drop reduces yields. Increased plant height, tolerance to lodging, and high pod height facilitates mechanical harvesting and reduces pod damage. Low pod height at harvest causes damage to harvesting combines through contact with rocks and soil along with contamination of harvested grains with soil, rocks, and plant stubble. Inheritance of plant height in lentil appears to be conditioned by both genetic and environmental sources of variance, with narrow sense heritability (h^2_n) estimates for plant height ranging from 0.35 (Khodambashi et al., 2012) to 0.65 (Tullu et al., 2008).

Considerable yield losses in lentil occur annually because of diseases, and cultivar development programs place great emphasis on improving resistance to important diseases. Lentils in the PNW are affected by the soilborne pathogens *Aphanomyces euteiches* Drechsler (Vandemark and Porter, 2010) and *Rhizoctonia solani* Kühn (Porter et al., 2011). Foliar diseases caused by fungi also reduce lentil yields in the United States, particularly in the NGP, where humidity during the growing season averages higher than in the PNW. These include anthracnose caused by *Colletotrichum truncatum* Schwein. (Buchwaldt, 2011) and Stemphylium blight caused by *Stemphylium botryosum* Wallr. (Banniza, 2011). Lentils in the PNW are also impacted by a number of viruses, including *Pea streak virus* and *Bean yellow mosaic virus* (Schwinghamer and Larsen, 2011).

Lentil is a self-pollinated diploid ($2N = 2X = 14$) crop that produces cleistogamous flowers. All commercial cultivars are pure lines that have been developed through a modified bulk-pedigree descent breeding approach (Muehlbauer et al., 2009). The initial seed stocks of lentil introduced into the United States in the 1930s were medium green (Persian) and large green (Chilean) landraces brought from Europe (Youngman, 1967). Harlan (1950) collected lentil accessions in Turkey that were maintained by the USDA Plant Introduction System. Beginning in 1961, these accessions were evaluated in lentil yield trials conducted by Washington State University. During the 1930s through the 1970s, growers in the United States produced their own common seed or purchased common seed from processors.

Commercial lentil cultivars grown in the United States have been developed from PI accessions, landraces, and breeding materials from other countries. The small yellow cultivar Eston is a pure line derived from PI 179307 (Slinkard, 1981). The popular medium yellow cultivar Brewer was developed using a black seeded landrace (no name available) that conferred earlier flowering as compared to the landrace Chilean (Muehlbauer, 1987). The large yellow cultivar Palouse was developed from a population derived from a cross between the Canadian lentil cultivar Laird and the Argentine cultivar Precoz (Muehlbauer, 1992), with large seed size coming from Laird and early flowering coming from Precoz. Laird also served as a parent in the cross used to develop Riveland, an exceptionally large yellow lentil cultivar (McPhee and Muehlbauer, 2009). Richlea, a high-yielding medium yellow lentil developed in Canada, was crossed to PI 297754, which has tolerance to lodging and tall height, to produce the recently released medium yellow cultivar Essex (Vandemark et al., 2011).

Major efforts to develop improved lentil cultivars for U.S. production began in the 1970s by the USDA-ARS in cooperation with Washington State University, located in Pullman, WA. Selections from this breeding program served as sources for the majority of lentil cultivars grown in the United States, including Brewer (Muehlbauer, 1987) and Merrit (Muehlbauer and McPhee, 2004). Currently, the majority of lentil cultivars grown in the United States are derived from either the USDA-ARS breeding program, the lentil breeding program from the University of Saskatchewan, or landraces introduced from Europe.

Yield Gains Measured in Recent Lentil Cultivar Trials

Older lentil cultivars and newer cultivars and advanced breeding lines were compared for yield and other metric traits. The comparisons are based on the results of field trials conducted at three locations in the PNW (Genesee, ID; Pullman, WA; and Fairfield, WA) during 2011 and 2012. All three field sites are located in areas of commercial lentil production. The results are presented in Table 5–2 for three different lentil market classes. For each market class, the breeding lines selected for comparisons were the highest yielding lines across all six location years. The newer cultivars and breeding lines in the small yellow market class were compared to the cultivar Eston (Slinkard, 1981). The results suggest that

Table 5–2. Yield and agronomic characteristics of recent lentil breeding lines and older cultivars based on field trials conducted in Washington and Idaho in 2011 and 2012.

Entry	Release	Yield†	Seed size‡	Days to mature‡	Canopy height‡	Plant height index‡¶
		kg ha^{-1}	g 100 seeds^{-1}	d	cm	
			Small yellow lentils			
Essex	2009	1593 A	4.4 B	94.7	34.4 A	0.93
LC08600005E	Line	1438 AB	4.8 A	94.7	31.0 B	0.90
LC01602273E	Line	1375 AB	3.3 D	92.5	29.1 C	0.90
LC09600054E	Line	1299 AB	3.8 C	93.3	28.4 C	0.96
Eston	1981	1191 B	3.2 D	94.7	28.5 C	0.92
LSD (α = 0.05)		383	0.2	ns	1.8	ns
			Spanish brown lentils			
LC08600116P	Line	1643	5.0 A	94.3	25.5	0.77
LC08600113P	Line	1579	4.5 B	93.3	26.6	0.74
LC0860115P	Line	1556	4.6 B	94.7	26.5	0.77
Pardina	< 1980	1469	4.0 C	92.0	24.8	0.75
Morena	2012	1353	3.9 C	94.7	28.6	0.77
LSD (α = 0.05)		Ns	0.3	ns	ns	ns
			Large yellow lentils			
LC07600541L	Line	1369	7.1 B	96.5	36.5 A	0.91
LC06601734L	Line	1356	7.3 AB	96.5	35.8 A	0.89
LC0860B130L	Line	1352	7.4 AB	96.5	35.4 AB	0.91
Riveland	2009	1239	7.5 A	94.7	35.5 AB	0.89
Brewer	1987	1192	6.2 C	92.0	32.3 B	0.91
LSD (α = 0.05)		Ns	0.4	ns	3.3	

† Based on trials conducted at Pullman, WA; Genesee, ID; and Kendrick, ID in 2011 and 2012 (six location years).

‡ Based on trials conducted at Pullman, WA in 2011 and 2012.

¶ Plant height index = plant height mature/green vine length.

considerable gains in yield have been made over time in breeding for this lentil market class. The recently released cultivar Essex (Vandemark et al., 2011) had significantly higher yields than Eston (Table 5–2). Collectively, Essex and the three USDA-ARS breeding lines had yields that on average were 20% higher than Eston. Three entries produced seed that was significantly larger than Eston. The larger seed size of high-yielding lines compared to Eston is a concern, as it remains to be determined if these differences in seed size will be tolerated by traditional consumers of Eston lentils. The breeding line LC01602273E is currently being considered for release as a new cultivar on the basis of its high yield (15% greater than Eston) and the similarity of its seed size to that of Eston.

Considering selected traits of agronomic importance to lentil, no significant differences between entries were observed for days to maturity or plant height index (Table 5–2). This suggests that yield gains have been realized in newer lentil lines of the Eston market class without any appreciable increase in time needed to reach maturity or decrease in lodging tolerance. The canopy height was significantly greater in the two highest yielding entries than in all other entries.

The performances of newer cultivars and breeding lines of the Spanish Brown market class were compared with the cultivar Pardina (Table 5–2). Pardina is the only cultivar of the Spanish Brown market class that has been grown to date commercially in the United States. No significant differences in yield were detected between 'Pardina' and the four newer entries. The three highest yielding breeding lines had an average yield of approximately 1593 kg ha^{-1} (1423 lb ac^{-1}), which is 8% higher than the yield of 'Pardina.' However, the yield of Morena, a Spanish Brown lentil cultivar recently released by the USDA-ARS, was nearly 9% less than Pardina. 'Morena' was released on the basis of several years of evaluation in the PNW, where it consistently exhibited yields equivalent to or higher than 'Pardina,' along with having a higher canopy height that 'Pardina.' Recently, 'Morena' was found to be susceptible to Stemphylium blight, caused by the fungus *Stemphylium botryosum* Wallr. The disease has historically been a problem for lentil production in Canada and the U.S. Northern Plains (Banniza, 2011) but had not been detected in lentils in the PNW until 2012, when it was detected in seed increase fields of 'Morena' in Washington and Idaho. The low yields observed for 'Morena' are considered to be primarily due to its susceptibility to Stemphylium blight, which is becoming an emerging disease of importance for lentil production in the PNW.

Similar to comparisons among entries in the small yellow market class, no significant differences were observed between 'Pardina' and the newer entries for days to maturity or plant height index (Table 5–2). The three highest yielding breeding lines all produced seed that was significantly larger than 'Pardina.' The cultivar Morena has received very favorable reviews from growers of Spanish Brown lentils, largely due to its seed size, which is not significantly different than 'Pardina.'

The performances of newer cultivars and breeding lines of the large yellow market class were compared with the cultivar Brewer (Table 5–2). No significant differences in yield were detected between 'Brewer' and the four newer entries. The three highest yielding breeding lines had an average yield of 1359 kg ha^{-1} (1214 lb ac^{-1}), which is 14% higher than the yield of 'Brewer.' No significant differences were observed between 'Brewer' and the newer entries for days to maturity or plant height index. 'Brewer' produced significantly smaller seed than any other entry, and its canopy height was also significantly smaller than all other entries. Unlike the small yellow and Spanish Brown market classes of lentil, the medium and large yellow lentil cultivars cultivated in the United States, including Brewer, Merrit, and Riveland, span a range of seed sizes, and new breeding lines that have high yield coupled with larger seed size may be promising for commercial production.

It should be noted that although the advanced breeding lines included in this analysis appear to be promising candidates for release as new cultivars on the basis of their agronomic performance, they still must be examined for other important post-harvest traits that will impact their suitability for commercial production. These traits include how well the seeds can be split, seed water retention and cooking time, and palatability (Bressani and Elias, 1988). Other quality traits of importance to lentil cultivars include protein and carbohydrate digestibility and quantities of antinutritional factors such as trypsin inhibitors and tannins (Bressani and Elias, 1988).

Chickpea

Domesticated chickpea is thought to have been derived 8000 to 10,000 yr ago from initial selections in the progenitor species *Cicer reticulatum* Ladizinsky (Ladizinsky and Adler, 1976), which had a limited distributed throughout southern Turkey (Berger et al., 2003). During the early domestication of chickpea, it was converted from a fall-sown crop to a spring-sown crop in southwestern Asia and southeastern Europe, most likely in response to severe crop losses due to Ascochyta blight [*Ascochyta rabiei* (Pass.) Lab.], the most globally destructive disease of chickpea, both past and present (Abbo et al., 2003; Bayaa and Chen, 2011). Currently, there are 44 different species, 9 annual and 35 perennial, recognized in the genus *Cicer*, of which only one, *C. arientinum*, is cultivated (van der Maesen et al., 2007). Chickpeas can be divided into two major classes, the macrosperma, or "kabuli" class, and the microsperma, or "desi" class (Toker, 2009). Kabuli chickpea seeds are shaped like an "owl head" and are larger and lighter in color than desi type chickpeas, which have a "teardrop" seed shape. Kabuli type chickpeas are cooked and then used for salads, canned and eaten whole, or used to make hummus, whereas desi chickpeas are predominately split and then cooked (Newman et al., 1988).

Commercial chickpea production in the United States began in the 1930s in the San Joaquin Valley of southern California. The first chickpeas grown were large white kabuli chickpeas known as "Spanish White" or "Spanish Common" (Muehlbauer et al., 1982). Chickpea production in California was centered in the San Joaquin Valley, where they were sown in the fall, grown under irrigation, and harvested in March to April. In the 1980s, as demand for pea decreased and large increases in lentil production by Canada restricted lentil prices, chickpea production expanded in the dryland wheat production areas of Washington and Idaho. Currently, U.S. chickpeas are primarily grown in Washington and Idaho, with lesser amounts in Colorado, Montana, Nebraska, North Dakota, and California. Only kabuli chickpeas are produced commercially to any appreciable degree in the United States. Over the 25-yr period from 1987 through 2011, the area of chickpeas harvested annually in the United States has dramatically increased, with the majority of area being in Washington and Idaho (Fig. 5–13). During the

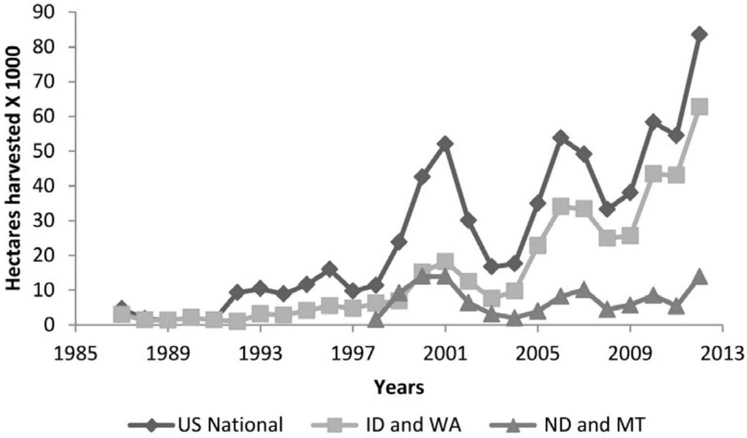

Fig. 5–13. Historical changes in the area (ha) of chickpeas harvested in the total United States, the U.S. Pacific Northwest (Idaho and Washington), and the U.S. Northern Plains (Montana and North Dakota) during 1987 to 2011.

most recent 5 yr (2007–2011) of the past 25-yr (1987–2011) period, the average area harvested in the United States was 46,612 ha, which is a 835% increase over the average of 5580 ha harvested in the United States during the first 5 (1987–1991) of the past 25 yr (USDA-NASS, 2013).

On-Farm Productivity Trends for Chickpeas

Although both the area harvested and total production of chickpeas in the United States have increased considerably over the recent 25-yr period from 1987 to 2011, chickpea yields in the United States on a per acre basis have increased by approximately 2.8% per year over a recent 25-yr period (1987–2011) (Fig. 5–14). This increase translates to a yield gain per year of 26 kg ha^{-1} (23.2 lb ac^{-1}). However, yields have not increased consistently over this time, with the greatest yield increases being observed during 1992 to 1996. These increases were likely due to the introduction of chickpea cultivars with partial resistance to Ascochyta blight and improved fungicides for blight control.

Basis for Yield Improvement in Chickpea

Crop yield in chickpea has several components, including the number of pods per plant, seeds per pod, and seed weight (Kumar and Arora, 1991; Güler et al., 2001). Early generation selection of individual plants has not resulted in improved chickpea yields, so commercial chickpea cultivars are pure lines predominately developed through modified bulk-pedigree descent breeding (Salimath et al., 2007). Large seeded chickpea lines tend to have lower yields than lines with smaller seeds, and these differences are attributed to larger seeded lines having fewer pods per plant and fewer seeds per pod than small seeded lines (Liu et al., 2003). A significant negative correlation was observed between yield and seed weight in kabuli chickpeas, while a significant positive correlation between yield and number of pods per plant was detected (Gowda et al., 2011). Similarly, Cobos et al. (2007) observed a significant negative correlation between seed weight and

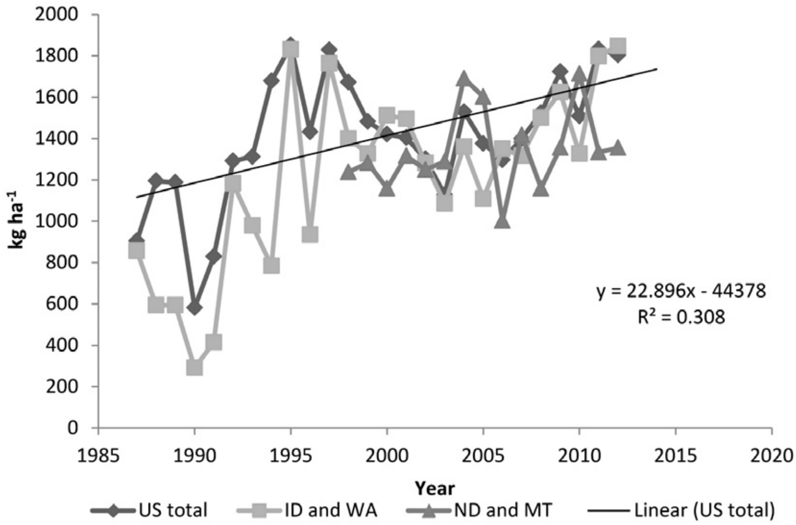

Fig. 5–14. Historical changes in on-farm chickpea yields (kg ha^{-1}) across the total United States, the U.S. Pacific Northwest (Idaho and Washington), and the U.S. Northern Plains (Montana and North Dakota) during 1987 to 2011.

yield in a population derived from a kabuli × desi cross, with a broad sense heritability estimate for yield of 0.14. Dehghani et al. (2010) determined that the total contributions to yield variance in chickpea of environmental effects, genotype effects, and genotype × environment interaction effects were approximately 60, 9, and 23%, respectively. Significant genetic and genetic × environment interaction effects were detected for both yield and seed weight in large seeded kabuli chickpea genotypes (Gowda et al., 2011).

Leaf type may also influence yield in chickpea. Chickpeas have two leaf types, unifoliate and fern type (Muehlbauer and Singh, 1987). Unifoliate leafs are characterized by a single lobate leaf attached to the petiole, while fern leaves are composed of several small serrated leaflets attached to a single petiole. Li et al. (2006) observed that fern leaf type chickpea cultivars had higher yields than unifoliate leaf type cultivars when grown in short season environments in Saskatoon. Higher yields in fern leaf types were attributed to a higher growth rate and greater partitioning of dry matter to seeds than in unifoliate leaf types.

Chickpea yield is also influenced by a range of diseases and abiotic stresses. Devastating crop losses occurred in the PNW in the 1980s because of epidemics of Ascochyta blight (Kaiser and Muehlbauer, 1988). Consequently, improving levels of resistance to Ascochyta blight remains a priority for chickpea breeding in the United States. Two different pathotypes of *A. rabiei* have been reported in the United States, and the evaluation of chickpea lines and cultivars for disease reaction suggests that resistance to each pathotype is inherited independently (Chen et al., 2004). Besides Ascochyta blight, chickpea production in the United States is also impacted by other diseases such as *Bean leaf roll virus* (Larsen and Schwinghamer, 2011) and wilt caused by *Fusarium oxysporum* f. sp. *cicieris* (Jiménez-Díaz et al., 2011).

Two other important traits for chickpea in the United States are early maturity and large seed size. Chickpeas are typically harvested in the United States during August to September to avoid autumn precipitation. However, chickpeas often have not sufficiently senesced by this time to be dry enough for harvesting. Consequently, most chickpea growers in the United States apply a desiccant herbicide, such as glyphosate, to the crop 7 to 10 d before harvesting (McKay et al., 2002). Earlier maturing chickpea cultivars might allow for harvest without using desiccant herbicide. Early maturing cultivars may also permit delayed sowing, which is part of an integrated strategy to manage ascochyta blight (Bayaa and Chen, 2011). Inheritance of maturity in chickpea can be conditioned by both epistatic (Anbessa et al., 2006) and quantitative (Lichtenzveig et al., 2006) gene action.

Large seed size is a critical trait for chickpeas intended for the fresh or canning markets. The USDA-NASS classifies chickpeas grown in the United States as "small" (<9 mm seed diameter) or "large" ($\geq$9 mm) (USDA-NASS, 2013). This trait has considerable economic importance, as large chickpeas have a higher value than small chickpeas. For example, in 2011 the average value for large chickpeas was $\approx$\$39 cwt^{-1} compared with an average of $\approx$\$24 cwt^{-1} for small chickpeas. Previous reports suggest that inheritance of seed size in chickpea is conditioned by both genotype and genotype $\times$ environment effects (Gowda et al., 2011).

Chickpea is a self-pollinated diploid ($2N = 2X = 16$) crop that produces cleistogamous flowers. Current commercial cultivars are pure lines that have been developed through a modified bulk-pedigree descent breeding approach (Salimath et al., 2007). Initially in the United States, the landrace Spanish White was grown in California (Muehlbauer et al., 1982). Spanish White produces a large, very light colored seed that has a high value. Direct selections from Spanish White resulted in the cultivars UC-5 and Mission, and these three cultivars were grown during the early years of chickpea production in the PNW (Muehlbauer et al., 1982). However, the incidence of Ascochyta blight began to increase in Washington and Idaho in the early 1980s until an epidemic in 1987 resulted in nearly complete loss of the chickpea crop in this region (Bayaa and Chen, 2011). Chickpea accessions from ICARDA were screened for reaction to Ascochyta blight in the field in Washington, and resistant lines were identified (Kaiser, 1991). The resistant kabuli chickpea line FLIP 85–58 was crossed with Surutato 77, a large kabuli chickpea cultivar from Mexico, which had high yield, resistance to Fusarium wilt, and early flowering (Muehlbauer et al., 1982). The FLIP 85–58 $\times$ 'Surutato 77' cross resulted in two sibling line that were released as the cultivars Sanford (Muehlbauer et al., 1998a) and Dwelley (Muehlbauer et al., 1998b). These were the first two chickpea cultivars with appreciable levels of resistance to Ascochyta blight under field conditions. 'Surutato 77' also contributed early flowering and improved Fusarium wilt resistance to 'Dwelley' and 'Sanford.' In 2004, the kabuli chickpea cultivar Sierra was released (Muehlbauer et al., 2004). 'Sierra' was the result of the following three-way cross: Dwelley/FLIP 85–58/Spanish White. FLIP 85–58 provided additional resistance to Ascochyta blight, while Spanish White served as a source of large seed size and light seed color. Currently the majority of kabuli chickpeas produced in the United States are from 'Dwelley' and 'Sierra,' although small seeded chickpeas grown primarily for hummus production include cultivars developed by the University of Saskatchewan, such as 'CDC Frontier,' or local landraces that are commonly referred to as "Billybeans." In 2013 the USDA-ARS released two new large café kabuli chickpea cultivars, 'CA04900843C' and 'CA04900851C,' based on their high yields and large seed size demonstrated in advanced yield trials (Grain Legume Genetics and Physiology Research Unit, 2012).

Yield Gains Measured in Chickpea Cultivar Trials

The chickpea cultivars Dwelley (Muehlbauer et al., 1998b) and Sierra (Muehlbauer et al., 2004) represent the great majority of chickpeas produced in the United States. The performances of Dwelley and Sierra during 2011 and 2012 are compared of two new café kabuli chickpea cultivars approved for release by the USDA-ARS in 2013, CA04900843C and CA04900851C (Table 5–3). 'CA04900851C' has simple leaves like 'Sierra' and 'Dwelley,' while 'CA04900843C' has compound leaves. There were no significant differences among entries for yield, with 'Sierra' averaging 3% less than 'Dwelley,' while yields of 'CA04900843C' and 'CA04900851C' were 16 and 8% greater, respectively, than 'Dwelley.' 'CA04900843C' produced significantly larger seed than the other cultivars. 'CA04900843C' reached 50% flowering significantly earlier than the other cultivars. Differences between 'CA04900851C,' 'Sierra,' and 'Dwelley' were not significant for days to 50% flower or seed size.

Summary and Conclusions Regarding Yields in Cool Season Food Legumes

Over the past 25 yr, the production of cool season food legumes (peas, lentils, and chickpeas) in the United States has increased dramatically, from 240,000 t in 1987 to 570,000 t in 2011 (USDA-NASS, 2013). During this time the production area in the United States has risen considerably, from approximately 125,000 ha in 1987 to over 380,000 ha in 2011. Unfortunately, crop yield per unit of area (kg ha^{-1}) has not seen similar increases over the past 25 yr. Over the past 25 yr, dry pea yields in the United States have decreased by 0.3% per year, lentil yields in the United States have increased by only 0.1% per year, and chickpea yields have increased by approximately 2.8% per year.

Table 5–3. Yield and agronomic characteristics of newly released and older chickpea cultivars based on field trials conducted in Washington and Idaho in 2011 and 2012.

Entry	Release	Leaf type†	Yield‡	Seed size¶	Days to flower ¶	Reaction to Ascochyta blight#
			kg ha^{-1}	g 100 $seed^{-1}$		
CA04900843C	2013	C	2299	62.8 A	55.8 A	1.8
CA04900851C	2013	S	2148	56.5 B	57.5 B	2.0
Dwelley	1998	S	1981	53.2 B	56.3 AB	2.6
Sierra	2004	S	1923	54.3 B	56.0 AB	2.5
LSD (α = 0.05)			ns	3.9	1.6	ns

† C, compound; S, simple.

‡ Based on trials conducted at Pullman, WA; Genesee, ID; and Kendrick, ID in 2011 and 2012 (six location years).

¶ Based on trials conducted at Pullman, WA in 2011 and 2012.

Each plant within a plot was scored on a scale of 0–9 as follows: 1 = healthy plant; 3 = lesions clearly present but plant remains mostly green; 5 = lesions girdle stems, most leaves show lesions; 7 = plant dying but at least three green leaves present, and 9 = dead plant (Chen et al., 2004). The score of the most severely affected plant within a plot was used for the plot score.

Several factors are likely responsible for limited yield gains over the past 25 yr for these crops. Pea and lentil production has increased dramatically over this time, especially in the NGP. The cultivars grown in the NGP were originally selected on the basis of their performance in the PNW and were likely not well adapted for the higher disease pressure and more extreme climatic conditions encountered in the NGP. The continued efforts of the cool season food legume breeding program at North Dakota State University should develop new cultivars adapted for the NGP. The further evaluation in the NGP of plant materials from other breeding programs should also identify promising plant genotypes for the NGP.

Another likely factor restraining yield gains in cool season food legumes is the limited availability of new cultivars. Although private breeding efforts, in particular those of Progene Plant Research (Othello, WA), have produced several green pea cultivars, including Banner, Ariel, and Aragorn, there have been few new cultivars of cool season food legumes. 'Dwelley,' released in 1998 and 'Sierra,' released in 2004, dominate the U.S. chickpea market. The Spanish Brown lentil market has been dominated by the cultivar Pardina for over 30 yr. Important large green lentil cultivars including Laird and Brewer have been grown for at least the past 25 yr. However, the areas where these cultivars are cultivated have changed markedly in terms of pressure from diseases, pests, and weeds.

In conclusion, advances over the past 25 yr in the production of cool season food legumes in the United States has been the result of increasing the area of cultivation of these crops as opposed to being due to yield gains that can be attributed to genetic enhancement. Several cool season legume cultivars currently in production were released over 20 yr ago. New advanced breeding lines of peas, lentils, and chickpeas are currently being evaluated that have yields that are superior to commercial cultivars. Continuing efforts to develop pea and lentil lines that are especially adapted to the U.S. Northern Plains will result in improved yields in this emerging area of importance for U.S. cool season food legume production.

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