Agronomic Performance of Spring-Sown Faba Bean in Southeastern Washington

Erik J. Landry, Clarice J. Coyne, and Jinguo Hu*

ABSTRACT
Faba bean (Vicia faba L.) is the world’s fourth most important cool-season pulse crop. Currently commercial faba bean cultivars are unavailable in the United States specifically selected for grain production; therefore, a spring-sown variety trial with 11 populations was conducted for two seasons at two contrasting locations in southeastern Washington. Early seeding was expected to achieve optimal grain yield. In 2012, the warmer Central Ferry, WA, location was sown a month earlier than at Pullman, WA (April vs. May), resulting in earlier flowering, higher grain yield, and an earlier maturity across populations. A drier March–April in 2013 allowed similar sowing dates across locations, synchronizing phenological development and improving grain yields at Pullman. However, at Central Ferry, yield was reduced due to high temperatures (>35°C) and subsequent flower and pod shedding. The National Plant Germplasm System (NPGS) accession W6 12023 and the Extra Precoce Violetto × Hiverna/2 F3:5 breeding population were the highest yielding populations and earliest to flower and mature in 2012 and 2013, respectively. Across 4 site-years, W6 12023 proved to have superior general adaptability with a high mean plant yield (22.6 g plant−1). Yield data compared favorably to other spring sown pulses currently grown in the region; therefore, a multi-environment trial with early maturing spring-type cultivars is warranted.

The agroecosystem benefits of cool season pulses in rotation with cereals mainly supports agronomic sustainability via improvement of cereal yield through residual N, residue management, weed control, and by providing a disease break (Veseth, 1990). Other benefits of pulse integration into a cereal dominated cropping system include: increased microbial diversity, soil sanitation, improvement of soil structure, and soil moisture retention (Jensen et al., 2010).

Faba bean could support the sustainability of cereal-cool season pulse cropping systems in the United States, as previously shown in Europe and Australia (Champ, 2001; Kopke and Nemecek, 2010). Most studies have supported the benefits of biological N fixation and residual N to a proceeding cereal (McEwen et al., 1990). Herridge et al. (1994) has shown faba bean to have one of the highest N2 fixing capacities when compared to other cool season pulses. Although, the extent of this capacity has not been conclusively determined here in the inland Pacific Northwest, a positive N economy would be expected based on studies throughout the northern Great Plains (Walley et al., 2007). Jensen et al. (2010), based on available literature, estimated that the global average N fixation of faba bean was 153 kg shoot N ha−1, which was much higher than average lentil (Lens culinaris Medik.), pea (Pisum sativum L.), or chickpea (Cicer arietinum L.) rates.

Thomas et al. (2010) examined different crop rotations that would improve the sustainability of dryland grain production in Australia and found that even though faba bean provided agroecological services, chickpea was economically advantageous providing a higher gross margin of return. According to Australian Pulse Marketing News (Pulse Australia, 2013) prices for faba bean and chickpea were similar. However, it is uncertain if faba bean production in southeastern Washington would have an agronomic or economic competitive advantage compared with countries, such as Australia, Canada, France, or the United Kingdom, that export pulses (FAOSTAT, 2014). There are limited markets for human consumption of faba bean in the United States; however a regional source of protein rich animal feed could supplement feed pea and canola (Brassica napus L.) oil cake.

The purpose of this research was to evaluate spring-sown faba bean across two contrasting environments in southeastern Washington. Assessment of phenological development and the level of experimental grain production would identify key areas of additional research necessary for the development of this crop.

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Abbreviations: NPGS, National Plant Germplasm System; RCB, randomized complete block.
weeds and Thio-Sul (NH4)2S2O3; Texas Sulfur Co., Texline, 2,6-dinitro-N,N-dipropyl-p-toluidine; Dow Chemical, a following a randomized complete block (RCB) experimental

The 2013 season, at both locations, was cooler mesic Oxyaquic Argixeroll), is higher elevation (790 m), and mesic pachic Ultic Haploxeroll and fine-silty, mixed, superactive, has a Palouse–Thatuna silt loam (fine-silty, mixed, superactive, F

Fisher's Least Significant Differences (LSD) test at .05.

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<thead>
<tr>
<th>Populations</th>
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<th>100 seed weight</th>
<th>Flowering plants</th>
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</tr>
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<td>48</td>
<td>23</td>
</tr>
<tr>
<td>Hiverna/2‡</td>
<td>Germany</td>
<td>46</td>
<td>19</td>
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<td>52</td>
<td>38</td>
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<td>W6 12024</td>
<td>Bulgaria</td>
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<td>25</td>
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<td>F3½</td>
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† Seed obtained from Dr. Wolfgang Link, Georg-August-University.
‡ na, not applicable.

Materials and Methods

A spring-sown variety trial with 10 European breeding lines, cultivars, and USDA accessions (Table 1) was conducted for two seasons (2012 and 2013) across two locations (Central Ferry [CF] Research Farm in Central Ferry, WA [46°39’5.1” N, 117°45’45.4” W]; Washington State University’s Whitlow Farm [WF] in Pullman, WA [46°44’3.2” N, 117°7’25.8” W]) following a randomized complete block (RCB) experimental design with three blocks. Treflan (trifluralin, α,α,α-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine; Dow Chemical, Indianapolis, IN) was applied pre-emergence to control monocot weeds and Thio-Sul (NH4)2S2O3; Texas Sulfur Co., Texline, TX) to reduce bird damage to seedlings. Warrior (Lambda-cyhalothrin, [1a(S*),3a(Z)]-cyano(3-phenoxyphenyl)methyl-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropane carboxylate; Syngenta, Greensboro, NC) was used to control pea leaf weevil (Sitona lineatus) as necessary. Field sites characterized extremes in elevation, moisture, and temperature (Table 2) of southeastern Washington, as well as field management. The CF location has a Chard silt loam soil (coarse-loamy, mixed, superactive, mesic Calcic Haploxeroll) and is characterized as low elevation (198 m), warmer temperature, less rainfall, and was irrigated with subsurface drip irrigation (10 min d−1), while WF has a Palouse–Thatuna silt loam (fine-silty, mixed, superactive, mesic pachic Ultic Haploxeroll and fine-silty, mixed, superactive, mesic Oxyaquic Argixeroll), is higher elevation (790 m), and dryland managed. The 2013 season, at both locations, was cooler and drier in April than in 2012, but warmer for the remainder of the year. The weather in 2012 was very similar to the 30 yr average; however, 2013 temperatures during the main growing season were above average at both locations.

Plot dimension varied by location due to irrigation constraints at CF, but area was 2.7 m2. Plots at WF had four rows, while CF had two. Rows were spaced ~35 cm apart at each location. Plot dimensions were 1.5 by 1.8 m at WF and 0.75 by 3.6 m at CF, with a 40 cm space separating plots within blocks at both locations. A Hege 120 Planter (Hege Company, Waldenburg, Germany) was set for 48 seeds per plot, equivalent to 80 to 120 kg of seed ha−1 depending on seed size. Seeding date varied according to prevailing weather. For 2012, sowing was 4 April at CF and 7 May at WF, whereas in 2013, sowing was 26 March at CF and 3 April at WF. Furthermore, in 2013, Striker, one of the smallest yielding and latest flowering 2012 populations, was replaced with a F3½ population derived from a cross between cultivars Extra Precoce Violetto and Hiverna/2 (spring-type × winter-type) in an attempt to distinguish late flowering populations from early.

Phenological development was partitioned to characterize vegetative and generative stages. The percentage of flowering plants and early branching and height measurements were taken at early bloom (2012: 16 July at WF and 11 June at CF; 2013: 10 June at WF and 7 June at CF), late branching and height were measured before leaf shedding (2012: 19 September at WF and 17 July at CF; 2013: 26 August at WF and 10 July at CF), and harvest was between the 409 and 410 maturity stage (Knott, 1990). Number of branches and height measurements were based on 20 representative plants from each plot. The percentage of flowering plants was based on plot stand counts averaged across blocks and locations. Plot yield was converted to kg ha−1 and g plant−1 was based on stand counts at harvest. Yield adaptability (h), based on g plant−1, was estimated according to Finlay and Wilkinson (1963) as the regression coefficient of an individual population on the mean site year yield across testing locations. A further stability identifier “ecovariance” (W2) was computed and transformed into a variation coefficient (VCW2) according to Stelling et al. (1994) to weight variation according to yield.

Phenological characteristics and yield components least squares means (LS-means) and Pearson correlation coefficients were compiled and analyzed using ANOVA with PROC MIXED and PROC CORR (SAS Institute, 2008), respectively. Population, location, and year were treated as fixed effects and block was set as a random effect within the model following an RCBD. Treatment mean comparisons were assessed based on Fisher’s Least Significant Differences (LSD) test at P = 0.05.

Table 1. Faba bean populations tested, their country of origin, 100 seed weight (g), and percentage of total flowering plants across two locations (Whitlow Farm and Central Ferry Research Farm) for two seasons (2012–2013).

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Table 3. Early branching and height, late branching and height, yield per plant, and plot yield (kg ha⁻¹) marginal least squares-means across nine faba bean populations grown at Central Ferry Research Farm (CF) and Whitlow Farm (WF) for 2 yr (2012–2013). Letters separate significantly different LS-means (P ≤ 0.05).

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Early branch no.</th>
<th>Late branch no.</th>
<th>Early height cm</th>
<th>Late height cm</th>
<th>Plant yield g</th>
<th>Plot yield kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF</td>
<td>2012</td>
<td>2.0b</td>
<td>3.4d</td>
<td>28.0b</td>
<td>83.8b</td>
<td>21.0b</td>
<td>2650.8a</td>
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<tr>
<td>CF</td>
<td>2013</td>
<td>2.8a</td>
<td>3.4c</td>
<td>41.6a</td>
<td>55.3c</td>
<td>7.3c</td>
<td>799.8d</td>
</tr>
<tr>
<td>WF</td>
<td>2012</td>
<td>2.0b</td>
<td>3.8b</td>
<td>40.5a</td>
<td>90.2a</td>
<td>24.5a</td>
<td>2041.0c</td>
</tr>
<tr>
<td>WF</td>
<td>2013</td>
<td>1.1c</td>
<td>2.1d</td>
<td>26.8c</td>
<td>85.4b</td>
<td>22.1b</td>
<td>2418.6b</td>
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</table>

**RESULTS**

There was a significant year × location effect for all dependent variables; therefore, data were analyzed separately by year. Both Striker and the F3:F5 populations were removed before the combined analysis and were only included within their respective year of cultivation.

The date of transition from vegetative to generative phase was consistently early flowering across seasons and locations and was earlier at WF in 2012, likely due to a later seeding date than in 2013. An earlier seeding date for WF in 2013 improved the alignment of late flowering between the two locations. The W6 12023 accession was consistently early flowering it may be informative across locations within each year (Fig. 1). Since the W6 12023 accession was consistently early flowering in 2013, was, however, the tallest at flowering and among the shortest at harvest. The F3:F5 population, also early flowering in 2013, was, however, the tallest at flowering and among the shortest at harvest.

Grain yield components, that is, plant and plot yield, were also inconsistent across locations and growing seasons (Table 3). There was a severe incidence of pea enation mosaic virus at WF in 2012 as compared to 2013. Heavily infected barren plants were culled before harvest at an average of 16% across locations; Central Ferry Research Farm (CF) and Whitlow Farm (WF). Values (± SE) are derived from the mean of 20 plants per replication (n = 3) averaged across field locations; Central Ferry Research Farm (CF) and Whitlow Farm (WF).

Branching and height at flowering did not necessarily predict height and branching at maturity. Correlations between early and late branch number were consistently positive for each year (2012: \( r = 0.59 \); 2013: \( r = 0.87 \), \( P < 0.0001 \)), whereas early and late height was positive in 2012 (\( r = 0.32 \), \( P = 0.02 \)) and negative in 2013 (\( r = -0.08 \), \( P < 0.0001 \)), likely as a result of environmental stress at CF in 2014. Both branching and height at maturity were higher across populations in 2012 than in 2013 and plants were generally taller at WF than CF across years (Table 3).

Populations had similar height and branch numbers averaged across locations within each year (Fig. 1). Since the W6 12023 accession was consistently early flowering it may be informative to compare this population against the others tested. In 2012, W6 12023 was the tallest population at flowering, but shortest at harvest, across locations. In 2013, W6 12023 did follow this same trend, although not as strong as in 2012, because of environmental stress at CF in 2013. The F3:F5 population, also early flowering in 2013, was, however, the tallest at flowering and among the shortest at harvest.
because of the incidence of virus at WF, yield per plant was not necessarily indicative of plot yield.

There were only slight differences among populations for their plot yields in 2012 and 2013 (Fig. 2). Côte d’Or/2-3 and W6 12023 had the smallest and greatest plot yields in 2012, respectively. However, poor production across populations in 2013 at CF reduced the resolution of differences between populations. Other than the reduction in plant height and yield at CF in 2013, mean 100 seed weight was significantly lower (43.3 g 100 seed⁻¹) than across other site years (53.8 g 100 seed⁻¹), indicating abiotic stress during seed production.

The significant location × population interaction for per plant yield may help to resolve discrepancies observed at the whole plot level (Fig. 3). Per plant yield of each population was plotted against site means (average per plant yield across populations). Further, regression coefficients (bᵢ) and their respective ecovalence coefficient of variation (VCWᵢ²) were calculated. Similar to plot yield, Côte d’Or/2-3 and W6 12023 had the smallest and greatest mean per plant yield across location and year (data not shown). Côte d’Or/2-3 had a bᵢ of 0.55 and a VCWᵢ² of 31.8, while W6 12023 had a bᵢ of 1.16 and a VCWᵢ² of 13.8. These data indicate that W6 12023 was more responsive or dynamically stable than Côte d’Or/2-3 over the growing environments tested, possibly through avoiding heat stress.

The F₃:5 population had the greatest per plant and plot yields in 2013. Further, the yield per plant was above average for stability with a bᵢ of 0.52. Therefore, the F₃:5 population fit the static concept of phenotypic stability and also appeared to avoid heat stress through early maturity. Since the F₃:5 was only tested in 2013, it would be important to confirm how this population is more responsive or dynamically stable than Côte d’Or/2-3 over the growing environments tested, possibly through avoiding heat stress.

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**DISCUSSION**

Faba bean has faced neglect by researches in the United States due to yield instability and market saturation from other cool season pulses (D.F. Bezdicek, personal communication, 2012). Our data has confirmed the environmental yield instability facing faba bean production; however, collaboration between developed breeding programs in Europe, Australia, and Canada with USDA pulse breeders and germplasm could improve the regional visibility of the world’s fourth most important food legume (FAOSTAT, 2014). Stability trials in Europe have suggested that wide adaptation can be bred for once stable genotypes are identified (Link et al., 1996). The presented research suggests selection for early flowering and more determinant maturity are two traits that would improve the stability of yield, that is, adaptation, of spring-sown faba bean in southeastern Washington.

Mean plot yield of populations across site years ranged from 1257.2 to 2897.7 kg ha⁻¹, or an average across populations of about 2000 kg ha⁻¹, comparing favorably with a faba bean variety trial in Oregon (James et al., 1984), the average yield of chickpea in Washington State of 1800 kg ha⁻¹ (NASS, 2013), and the global average yield of faba bean at just over 1600 kg ha⁻¹ (FAOSTAT, 2014). Yet there was no clear differentiation between individual population yields, apart from the W6 12023 accession and the F₃:5 population, which were both notably earlier flowering and maturing than the other populations tested. The W6 12023 accession proved to have the greatest per plant yield across site years with one of the smallest VCWᵢ², while, Côte d’Or/2-3 was the smallest yielding and had the greatest VCWᵢ². Further, the F₃:5 population tested in 2013 had an above average stability (low bᵢ) coupled with the greatest mean yield across locations. Therefore, both the W6 12023 accession and the F₃:5 population would be candidates for future testing.

Key issues for successfully developing spring-sown faba bean include identification of adapted cultivars, optimizing seeding date, and management of pests and weeds. Based on the comparisons between the winter-type populations tested here and adjacent observational plots with more spring-type materials, faba bean has an extensive variation for timing of flowering and maturity. Comparing the winter bean cultivar Webo to other spring bean, Herzog (1989) did not observe a significant developmental delay when spring sown. However, direct comparisons were not made and could have been influenced by the location or year of observation. Winter-type faba bean shows a vernalization response and is typically later flowering and maturing than spring-type stocks under a given temperature and photoperiod regime (Evans, 1959).

Future studies exploring the sowing date × cultivar interaction for growth and yield of spring-sown faba bean in southeastern Washington will help to establish an optimal seeding date.
(Thompson and Taylor, 1977). It appears early spring seeding generally outperforms later through earlier flowering, higher branching, less pod shedding, and earlier maturity. The earlier 2013 seeding at the dryland managed WF location resulted in earlier flowering and maturity, likely contributing to greater plot yields than in 2012. A modest improvement in yield per plant compared with the gain in plot yield at WF in 2013 suggests that the incidence of virus in 2012 was an important factor affecting plot yield. Due to limited site year testing further studies on earlier sowing dates using spring genotypes would be advisable.

Heat (Bond et al., 1994) and associated moisture stress once flowering (Lawes, 1978) were limited yield potential at the irrigated CF location. Flower abortion, pod shedding, reduced seed size, stunting, and early maturity (i.e., “fire” see Khan et al., 2007) observed at CF in 2013, commonly attributed to drought stress (Kambal, 1969; Link et al., 1999), were likely the result of a high water demand due to low humidity and temperatures above 35°C. Therefore, genotypes with a prolonged vegetative phase would not be recommended where average temperatures exceed 10°C at sowing or ≥35°C at flowering, even if irrigation is available. The exceptional performance of the F2:F3 population under adverse conditions at CF in 2013, however, should indicate the possibility for improving adaptation where early developmental heat stress is likely.

Based on these yield data and its nutritional and agronomic values (Guillon and Champ, 2002; Crépon et al., 2010), the potential of faba bean should be explored further. Future research should focus on manipulating seeding date, testing additional field locations, and selecting early flowering and maturing spring-type materials. Spring-sown cultivars in Canada and Europe yield on average >3000 kg ha−1 (Rowland et al., 1982) and can exceed 5000 kg ha−1 across a broad range of environments (Dantuma et al., 1983). Ultimately, selecting adapted material with optimized growth and development will depend on screening a diverse germplasm within the agroecosystems of intended production.

ACKNOWLEDGMENTS

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