Cultivar, Planting Date, and Row Spacing Effects on Mungbean Performance in Virginia

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Abstract. Mungbean [*Vigna radiata* (L.) R. Wilczek, Fabaceae] is one of the most important food legume crops in Asia. It is also gaining importance in other parts of the world such as Australia and Canada. The United States imported mungbean worth ≈22 million dollars during 2014. To establish domestic production and to determine if mungbean can be produced in rotation with winter wheat (*Triticum aestivum* L.), replicated experiments were conducted during 2012 and 2013 using two cultivars (Berken and TexSprout), two planting dates (early and late July), and two row spacings (37.5 and 75 cm). Cultivar and planting date effects on seed yield were not significant, however, narrow row spacing resulted in significant higher seed yield and concentration of protein over the wider row spacing (1.76 vs. 0.86 Mg·ha⁻¹ yield and 24.9% vs. 23.7% protein). Early planting resulted in lower sugar and oil concentrations over late planting (4.4% vs. 5.5% sugar and 1.24% vs. 1.99% oil). Average mungbean values for seed yield, seed size, and concentrations of protein, sugars, and oil were 1.31 Mg·ha⁻¹, 7.08 g/seed¹⁰⁰, 24.3%, 4.91%, and 1.59%, respectively. Low harvest index values (17% to 25%) indicated that potential exists for improvement in mungbean seed yield. The results indicated that mungbean can be easily produced in rotation with winter wheat in the mid-Atlantic region of the United States.

Mungbean [*V. radiata* (L.) R. Wilczek], a member of the Fabaceae family (also known as the Leguminosae family) along with the common pea, chickpea, soybean, alfalfa, and other crops, is a native of India–Burma (Myanmar) region of Asia and is grown principally for its protein-rich edible seeds for use as food or livestock feed. This plant and its production strategy are very similar to that of soybean. The seeds have potential as human food (cooked beans or sprouts) and livestock feed. The plant is a good nitrogen fixer and can also be used as forage or hay (Oplinger et al., 1990).

Mungbean is one of the most important food legume crops in Asia. It is also gaining importance in other parts of the world such as Australia and Canada. The United States imported 12,731, 13,474, and 13,672 Mg of mungbean during 2012, 2013, and 2014, respectively (ERS, 2015). Even though previously limited research has indicated that mungbean has potential as a short-duration summer crop in mid-Atlantic region of the United States (Bhardwaj et al., 1999), only limited information is available about mungbean production in this region.

Vigna species including mungbean have potential for introduction or increased production in the United States and this introduction or expansion of the culture of *Vigna* species in the United States would create new opportunities and provide alternative crops for American farmers, give American consumers access to new and novel foods, and increase the biodiversity of crops used in American agriculture given that these species are suited for production in many areas with heat and drought stresses too extreme for the successful production of other legume crops (Fery, 2002). In addition, Fery (2002) indicated that all of the economic *Vigna* species have great potential as a supplemental or alternate source of legume protein for the nation's food supply.

Mungbean needs 90–120 frost-free days to mature and should have great potential as a short-duration crop for production in rotation with winter wheat. Winter wheat (*T. aestivum* L.) is a major crop in the mid-Atlantic region. Winter wheat was harvested from ≈277,328, 273,279, and 312,955 ha in four mid-Atlantic states (Delaware, Maryland, Pennsylvania, and Virginia), during 2011, 2012, and 2013, respectively (NASS, 2014). In the mid-Atlantic region of the United States, winter wheat is generally harvested in the first week of July and the next crop is planted in about mid-October. This results in short growing period for a double-crop soybean crop. Double-crop soybean tends to yield 10% to 30% less than full-season soybean. Over half of the soybean acres in the mid-Atlantic states are double-cropped after small grains. This information indicates that an opportunity exists to enhance farm economies in the mid-Atlantic region if a successful mungbean

crop can be produced in rotation with winter wheat.

Our objectives were to determine if mungbean can be produced as a short-duration summer crop in this region and to characterize effects of cultivars, planting dates, and row spacings on seed yield, seed size, and concentrations of protein, sugars, and oil in mungbean seeds.

Materials and Methods

This study was conducted at Randolph Farm of Virginia State University located near Petersburg, VA (37°15' N, 77°31' W). The plant material consisted of two mungbean cultivars: Berken (small seeded cultivar, PI-662968) and TexSprout (large seeded cultivar, PI-536545). These cultivars were planted at two planting dates (early and late July) during each of 2012 and 2013. The planting dates during 2012 were 7 July and 27 July whereas planting dates during 2013 were 8 July and 23 July. The planting dates of 7 July and 8 July were considered early-July whereas planting dates of 23 July and 27 July were considered late-July for analyses. We used two inter-row spacings for this study: 37.5 cm and 75 cm.

The experiment during each year was designed as a split-plot with planting dates as main plots, cultivars as subplots, and row spacings as sub-subplots. Each plot consisted of four rows spaced either 37.5 or 75 cm apart with 150 cm distance between plots. Each experiment consisted of four replications per planting date. The rows were 3.6 m long. About 100 seeds were planted in each row with a tractor-driven research planter. The seed depth was ≈2 to 3 cm. These plots received 30 kg·ha⁻¹ of NPK. The soil type was Abel sandy loam (fine-loamy, mixed, thermic Aquatic Hapludult). Experimental area received a preplant incorporated treatment of Trifluralin herbicide at the rate of 1 L·ha⁻¹. The plots were manually weeded once. All plots were harvested on 24 Oct. during 2012 and on 31 Oct. during 2013, and data on seed yield and seed size were recorded.

All seed samples were analyzed for protein, total soluble sugars, and oil concentrations (AOAC, 1995). Crude protein content was determined by multiplying N content by a factor of 6.25. The N content of mungbean seeds was determined by digesting 1 g of ground seed with 20 mL mixture of sulfuric acid and hydrogen peroxide (1:1 v/v), followed by colorimetric determination using NH₃ Nessler reagent at 425 nm. Total soluble sugars of dried and finely ground mungbean seeds (1 g) were determined colorimetrically with glucose as a standard after extraction with 80% aqueous ethanol using phenol-sulfuric acid method (Dubois et al., 1956).

Total sugars in whole mungbean seeds were extracted from defatted ground sample and analyzed by high-performance liquid chromatograph (HPLC) following the methods optimized by Johansen et al. (1996). Triplicate of 1.0 g of the defatted sample was placed in 25 mL centrifuge tube and suspended in 2 mL

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of 99% (v/v) ethanol then heated in a boiling water bath for 5 min. The sample was placed in the fume hood until all ethanol had evaporated. Sugars were then extracted from the defatted sample with 10 mL of deionized water containing 5 mg trehalose internal standard at room temperature in a horizontal shaker at 200 rpm for 60 min. The suspension was then centrifuged at 13,000 rpm for 10 min, and 500 µL of the clear supernatant was filtered through a syringe nylon membrane filter (25 mm diameter, 0.2 µm; Waters Associates, Inc., Milford, MA). An aliquot of 20 µL of the filtered sugars extract were auto-injected into a Waters Alliance 2695-HPLC System equipped with Waters refractive index detector (Waters 2414 RID; Waters Associates, Inc.). Sugars in the extracts were identified by comparing their retention times with standards. The total sugar concentration was expressed as g/100 g oil-free meal.

The oil was extracted from 1 g of ground seed at room temperature by homogenization for 2 min in 10 mL hexane/isopropanol (3:2, v/v) with a Biospec Model 985-370 Tissue Homogenizer (Biospec Products, Inc., Racine, WI) and centrifuged at 4000 g for 5 min, as described by Hamama et al. (2003) and Bhardwaj and Hamama (2005). The oil extraction was repeated for each sample for three times to ensure full oil recovery, and the three extractions were combined. The hexane-lipid layer was washed and separated from the combined extract by shaking and centrifugation with 10 mL of 1% CaCl₂ and 1% NaCl in 50% methanol. The washing procedure was repeated, and the purified lipid layer was removed by aspiration and dried over anhydrous Na₂SO₄.

Data on seed yield, seed size, and concentrations of protein, sugar, and oil were analyzed using version 9.4 of SAS (SAS Institute, 2014) using a split-plot design. Cultivars, planting dates, and row spacings were considered fixed factors whereas years and replications were considered random factors. Mean squares were tested against appropriate error terms. Duncan's multiple range test was used for mean separation with a significance level of 0.05.

Results and Discussion

As expected, effects of years on seed yield and concentrations of seed protein, seed sugar, and seed oil were significant (Table 1). However, effects of years on seed size were not significant. Planting date effects were only significant for concentrations of total sugars and oil. We had expected that cultivar difference would not be significant given that this study only involved two cultivars, however, cultivar effects were significant for seed yield, seed size, and concentration of seed protein but not for concentrations of seed sugar and seed oil. Similarly, row spacing effects were significant for seed yield, seed size, and concentration of seed protein but not for concentrations of seed sugar and seed oil. Results of analysis of variance (Table 1) indicated that most of the interactions were not significant, thus, allowing direct comparisons of main effects. The values

for R^2 varied from 76% to 99% whereas values for cv varied from 3 to 30 indicating that experimental conduct was acceptable.

Both cultivars performed similarly for seed yield and concentration of seed protein, seed sugar, and seed oil (Table 2). Seed size was significantly lower (–21%) for 'Berken' as compared with that of 'TexSprout'. This study included only two cultivars; however, inclusion of a wide array of cultivars is expected to result in significant cultivar differences for most traits. The seed yields in this study are similar to results of our preliminary previous studies where seed yields of 'TexSprout' and 'Berken' were 1.53 and 1.31 Mg·ha^{–1}, respectively (Bhardwaj et al., 1999).

Plantings done in early and late July during both 2012 and 2013 did not differ significantly for seed yields, seed sizes, and concentrations of seed protein (Table 2). However, late plantings resulted in increased concentrations of sugar and oil. We are interested in producing mungbean as a grain crop in rotation with winter wheat in Virginia and the mid-Atlantic

region of the United States. Our results indicated that it is possible to produce a successful mungbean crop, which is planted after traditional harvest of winter wheat in early July. Four mid-Atlantic states (Delaware, Maryland, Pennsylvania, and Virginia) produce an average of 283,400 ha of winter wheat each year during 2012, 2013, and 2014 (NASS, 2014), which indicates at great potential for mungbean production in this region. Average seed yield in the current study was 1.31 Mg·ha^{–1}. Based on this average seed yield, U.S. mungbean production on ≈4000 ha should be sufficient to meet current U.S. import needs of mungbean, which, on an average, during 2012, 2013, 2014 have been ≈13,292 Mg·ha^{–1} (NASS, 2014). Therefore, enhanced domestic production of mungbean cannot only meet current demands but may also increase consumption as mungbean is considered to be an excellent human food (Nair et al., 2013). Enhanced mungbean production in the United States can also result in substantial exports to countries such as India,

Table 1. Analysis of variance for selected sources for seed yield, seed size, seed protein, seed sugar, and seed oil of two mungbean cultivars (Berken and TexSprout) when planted in early and late July during 2012 and 2013 using 37.5- or 75-cm row spacings near Petersburg, VA.

Source	df	Seed yield ^z (Mg·ha ^{–1})	Seed size ^z (g/seed ¹⁰⁰)	Protein ^y (%)	Sugar ^y (%)	Oil ^y (%)
Year (Y)	1	15.46**	5.68	53.8**	12.6**	14.0**
Replications (R)	3	1.38*	2.27	0.94(1)	0.12(1)	0.01(1)
R*Y (error _a)	3	0.82	9.21	1.28(1)	0.05(1)	0.00(1)
Planting date (PD)	1	0.10	8.83	0.17	8.33**	3.30**
Y*PD	1	2.86**	0.12	0.09*	1.14	1.06**
Y*R*PD (error _b)	6	0.71	2.56	0.08(2)	0.07(2)	0.00(2)
Cultivars (C)	1	1.39*	38.8*	5.93**	0.05	0.01
PD*C	1	0.02	1.22	1.01	0.19	0.00
Y*C	1	0.65	2.33	0.93	0.74	0.01
Y*PD*C	1	0.33	7.35	0.09	0.01	0.00
Y*R*PD*C (error _c)	12	1.96	7.98	0.18(4)	0.10(4)	0.00(4)
Row spacings (RS)	1	12.00**	44.7**	10.42**	0.05	0.03
Y*RS	1	0.04	22.7*	7.26*	0.12	0.08*
PD*RS	1	0.03	10.4	0.15	0.01	0.04
C*RS	1	0.04	0.47	1.29	0.00	0.00
Y*PD*RS	1	0.03	16.5	3.69*	0.01	0.06
Y*C*RS	1	0.09	0.16	0.71	0.09	0.00
PD*C*RS	1	0.14	0.41	0.01	0.01	0.01
Y*PD*C*RS	1	0.17	4.29	0.01	0.01	0.00
Residual error	24	0.15	4.49	0.67(8)	0.39(8)	0.01(8)
R^2 , %		91.8	75.7	94.9	90.0	99.5
cv, %		29.6	29.9	3.37	12.8	7.12
Mean		1.31	7.08	24.3	4.91	1.59

*, **Significant at 5% and 1% levels, respectively.

^zData from four replications. [error(a), error(b), and error(c) are based on split-plot ANOVA.]

^yData from two replications. The df, if different from that in second column, is presented in parenthesis.

Table 2. Cultivar, planting date, and row spacing effects on seed yield, seed size, seed protein, seed sugar, and seed oil of two mungbean cultivars (Berken and TexSprout) when planted in early and late July during 2012 and 2013 using 37.5- or 75-cm row spacings near Petersburg, VA.

	Seed yield (Mg·ha ^{–1})	Seed size (g/seed ¹⁰⁰)	Protein (%)	Sugar (%)	Oil (%)
Cultivars					
Berken	1.47 a ^z	6.25 b	24.7 a	4.92 a	1.59 a
TexSprout	1.15 a	7.92 a	23.9 a	4.90 a	1.60 a
Planting dates					
5 July	1.34 a	6.83 a	24.2 a	4.38 b	1.24 b
27 July	1.29 a	7.36 a	24.4 a	5.51 a	1.99 a
Row spacings					
37.5 cm	1.76 a	7.98 a	24.9 a	4.90 a	1.55 a
75 cm	0.86 b	6.19 b	23.7 b	4.92 a	1.64 a

^zMeans followed by similar letters within factors were not different according to Duncan's multiple range test at 5% probability level.

which is currently unable to meet its current domestic mungbean demand (Saxena, 2012).

Effects of narrow and wide row spacings did not affect concentrations of sugars and oil in our study (Table 2). However, our results indicated that closer row spacing (37.5 cm) resulted in significantly higher seed yield (+104%), significantly larger seeds (+29%), and significantly higher concentration of protein (+5%). As indicated previously in our work (Bhardwaj et al., 2004) related to white lupin (*Lupinus albus* L.), we evaluated only the inter-row spacings without adjusting for plant density to have results directly applicable to a production system where changing row spacing might be easier than changing the number of seeds per row. In essence, the population densities in our experiments were effectively reduced by widening of the rows, therefore, our results are only applicable to the given row spacings. These results, however, indicate that narrow rows with similar plant density may be conducive to higher mungbean seed yields. We speculate that narrow row spacings might also be conducive to better weed control in mungbean fields.

Mungbean Seed Yield and Harvest Index

Harvest index (ratio of seed weight to total dry weight including plant and seed weights) can be a useful tool in efforts aiming to increase crop yields. The dramatic increases in grain yields during the second half of 20th century have been largely due to increased harvest index (Sinclair, 1998). Since the introduction of the term “harvest index” by Donald (1962), it has been suggested that grain yields can be improved either by increasing the biomass yield without changing harvest index or by increasing both biomass and harvest index (Donald and Hamblin, 1976; Sharma and Lewis, 1986). More recently, it has been established that partitioning efficiency (harvest index) is determined by the amount of biomass energy allocated to vegetative vs. reproductive structures (Zhu et al., 2010) and that harvest index is strongly autocorrelated with yield in soybean (Koester et al., 2014).

We only recorded harvest index during 2012 experiments. The results indicated that harvest index in mungbean was significantly affected by cultivars and planting dates and not by row spacings. The harvest index values were 25.4% and 17.2% for TexSprout and Berken cultivars, respectively. The harvest

index values were 26.5% and 15.4% for early July and late July plantings, respectively. Our results also indicated that harvest index for pods (ratio of seed weight to total pod weight including pod and seed weights) was also significantly higher for ‘TexSprout’ (75%) than that for ‘Berken’ (66%). These observations indicate some possible strategies for improvement in mungbean seed yields. Given that harvest index values of up to 60% have been reported in soybean (Koester et al., 2014) and existence of genetic variation for harvest index in mungbean (significant differences between cultivars), it could be speculated that increases in harvest index might be a practical strategy for increasing mungbean seed yields.

Our results provide a justification for enhanced mungbean production in the United States, especially in the mid-Atlantic region.

Conclusions

Results of experiments conducted over 2 years indicate that mungbean can be easily produced in the United States, especially in the mid-Atlantic region, with an average yield of 1.3 Mg·ha⁻¹ and preferably using a 37.5-cm row spacing. It was observed that mungbean can be produced in rotation with winter wheat by planting in late July and harvesting in late October.

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