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Planting Date, Irrigation, and Row Spacing Effects on Agronomic Traits of Food-grade Soybean

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Abstract

A niche market for food-grade soybean varieties has emerged in the United States in recent years. However, knowledge of optimal management practices for new varieties of food-grade soybean in the southern United States is currently lacking. Therefore, the objectives of the study were: 1) to determine favorable production practices for current specialty soybean cultivars; 2) to determine heritability of major agronomic traits in multiple environments; and 3) to determine correlations among these traits in specialty soybean. Several agronomic traits of eight soybean genotypes, representing tofu, natto, and conventional varieties currently available in the southern United States, were assessed with three variables: planting date (April, May, and June), irrigation treatment (irrigated and dryland), and row spacing (narrow and wide). Yield, seed size, maturity, plant height, lodging, shattering, and stand count were measured after maturity. Among planting dates, the May planting resulted in the greatest yield and height; whereas varieties planted in April were the shortest and produced the lowest yield. June plantings resulted in longer days to maturity. Irrigation improved yield and extended days to maturity. Row spacing did not have a significant effect on yield, seed size, maturity, or plant height. Among all environments, seed size was highly heritable, and yield heritability was relatively low. Yield and maturity were negatively correlated, yield was positively correlated with height, and maturity was positively correlated with seed size. These results can be used to optimize specialty soybean seed production in the southern United States.

Keywords: Food-grade soybean; Irrigation; Row spacing; Planting date; Seed size

Abbreviations: ESPS: Early Soybean Production System; CSPS: Conventional Soybean Production System; WR: Wide-row Spacing; NR: Narrow-row Spacing; G: Genotype; P: Planting Date; R: Row Spacing; I: Irrigation; E: Environment; R: Replication

Introduction

Soybean is the second most-planted crop in the United States, and approximately 31 million hectares of soybean were planted in 2013 [1]. Most of the soybean production is located in the upper Midwest; however, the southern region of the Mississippi River Delta contains a large portion of United States soybean production due to the region's favorable environmental conditions. Furthermore, Arkansas contained over 51% of the total land planted to soybean among the three delta states (i.e., Mississippi, Louisiana, and Arkansas) [2]. Although the vast majority of the soybean in the United States is grown for general purpose (e.g., livestock feed), a niche market in food-grade soybean varieties has been gaining popularity.

Food-grade soybean varieties, unlike highly processed conventional varieties, are grown to produce traditional soy foods, such as natto, soymilk, tofu, and edamame. Soyfood has been consumed in Asian countries for more than 1,000 years; additionally, the prevalence of soybean in Western diet has increased tremendously in recent years [3]. Many people around the world have incorporated more soy food into their diets for nutritional and health benefits [4]. Increased demand within the United States for soy foods has created a niche market for soybean growers interested in producing new food-grade soybean varieties, which they can sell at a premium [5]. Specific characteristics of food-grade soybean varieties, such as seed size and quality (e.g., seed color), vary according to the intended soy food produced. Generally, food-grade soybean is grouped into small- (e.g., natto) and large- (e.g., tofu and soymilk) seeded varieties based on seed size; whole-bean (e.g., edamame, natto, and temph) and ground-bean (e.g., soymilk, tofu, miso, and soy sauce) varieties, based on processing requirements; and fermented (e.g., temph, soy sauce, miso, and natto) and non-fermented (e.g., soymilk, tofu, and edamame) varieties based on fermentation requirements [6]. As soy food consumption rises in the United States, southern states that have favorable climates for soybean production are incorporating an increasing amount of food-grade soybean varieties into production. However, new varieties of food-grade soybean require different combinations of management practices (e.g. planting date, irrigation scheme, and row spacing) for optimal production.

Achieving the correct planting date is one of the most important factors in producing optimal soybean yields. Optimal planting dates vary by variety, cropping system, and environmental conditions. Planting prior to or later than the optimal planting date can greatly reduce soybean yield and quality since photoperiodism controls not only the number of days to flowering, but also the amount of time available for vegetative plant growth and development. Recommended planting dates for soybeans in Arkansas range from April 25 to June 30 for maturity group V lines [2]. Soybeans planted prior to this optimum range often lose yield from poor emergence due to inadequate soil temperature or, when planted after the optimal range, from failure to fully develop [2].

Recognized planting periods for soybean are divided into three

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groups in the mid-south: Early Soybean Production System (ESPS), Conventional Soybean Production System (CSPS), and double-crop soybean production systems. Under ESPS, soybean is planted in late April with the intention of achieving an early harvest or to avoid summer drought stress during seed fill. However, soil temperature and excessive rainfall can inhibit plant growth during this early planting window, which can lead to severe yield reductions [2]. Planting in the CSPS occurs mid-May to early June, which coincides with beneficial soil temperatures that promote rapid seed emergence; however, the shorter growing period under the CSES may prevent maximum yields from being obtained [2]. In a double-crop production system, soybean production is preceded by a winter grain, primarily winter wheat in the mid-south. Therefore, planting dates for double-crop soybean systems typically occur in mid-June, following wheat harvest. If planting after wheat harvest is not expedient and occurs after June 15, a 1- to 2% loss in yield per day could result [2]. Furthermore, if planting is delayed after July 1, yield losses greater than 2% per day could occur [2]. Some yield loss may be mitigated if optimal management practices (e.g., row spacing and irrigation scheme) for the specific soybean variety are implemented [7].

Although choosing the optimal planting date can reduce water stress on soybean during seed fill, irrigation is often required during the soybean growing season. Water stress, which often coincides with high temperatures, is one of the leading causes of yield loss in the humid southern United States [8]. For this reason, approximately 80% of soybean production in Arkansas includes some type of irrigation scheme [9,10]. However, when water is unavailable or the implementation of an irrigation system is too costly, producers rely solely on rainfall to meet the water demand of the crop. When irrigation is not implemented, soybean planted in the CSPS or double-crop system is more likely to require pre-bloom irrigation than soybean planted in the ESPS [2]. Additionally, periods of drought stress in the southern United States often occur during the months of July and August, when soybean planted under CSPS begin seed fill, one of the highest periods of plant-moisture demand [8]. Although irrigation can be absolutely essential to producing optimal yields for high economic return, optimization of other management practices (e.g., variety choice, planting date, and row spacing) can mitigate some of the potential yield loss associated with dryland production.

In addition to planting date and irrigation scheme, row spacing can have a substantial impact on food-grade soybean yield. Soybeans planted in narrow-row (NR) spacing (i.e., 30 to 40 cm), opposed to traditional wide-row (WR) spacing (i.e., >70 cm), can produce greater yields which are mainly attributed to greater light interception [11]. Greater yields in NR than WR spacing have been achieved when soybean was planted earlier [12-14] and later than optimum dates [13,15,16]. Doster [17] determined that 17-, 36-, or 45-cm row spacing out-yielded 76 cm rows by 6 to 18%. Costa et al. [18] and Leuschen et al. [19] both compared 25-cm rows to 76-cm rows and found 21% and 8 to 14% yield advantages for the 25-cm row spacing, respectively. In addition to greater light interception and potential yields, NR spacing promotes rapid canopy closure, which can effectively reduce weed seedling growth, compared with WR spacing [20]. Although NR can reduce weed establishment by early canopy formation, WR spacing allows for post cultivation, band application of herbicides, and the use of readily available equipment from other crops (e.g., cotton). Since NR spacing prevents post cultivation, weed control prior to canopy formation is reliant on costly herbicide applications. In order to increase yield and net returns, many producers are switching to NR spacing. However, some producers are limited by equipment availability and must plant wider rows. Genotype usually affects the suitability of soybean varieties to row spacing due to differential plant height and maturities; however, Board et al [21] proposed that yield performance of different varieties may not be affected by row spacing among late planted soybean.

The effects of planting date, irrigation scheme, and row spacing on food-grade soybean production in the southern United States are still relatively uncertain. Therefore, the objectives of this study were to determine optimal management practices for several types of food-grade soybean; heritability of yield, seed size, plant height, and maturity of food-grade soybean; and correlations between specialty soybean yield, seed size, plant height, and maturity.

Materials and Methods

Eight MG V food-grade soybean varieties were chosen to represent three different soy food categories: small, conventional, and large seed-size. Camp, MFS-591, V97-3000, and B-3 represented small seeded soybean varieties, which would typically be used in natto production. SS-516 produces medium-sized seed and represented a soybean variety that would be used to produce larger natto. Hutcheson produces medium-sized seed and was used as a conventional check for yield and agronomic comparisons. V99-5089 and MFL-552 were large-seeded varieties and represented soybean used for tofu, soymilk, and edamame production (Table 1).

The field experiment was conducted during the 2002, 2003, and 2004 growing seasons at two locations: the Arkansas Agricultural Research and Extension Center (AAREC) in Fayetteville, AR and a research field in Weiner, AR. This study was conducted in silt-loam soil at both locations: Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudults) at AAREC and Henry silt loam (coarse-silty, mixed, active, thermic Typic Fragiaqualfs) at the field in Weiner, AR. Prior to planting each year, fertilizer was applied according to soil test recommendations [2]. Three planting dates were used to study the effects of planting date on seed yield and other agronomic traits: the first plantings were conducted in late April each year in order to simulate ESPS; the second plantings occurred in mid-May, or optimal planting time for MG V cultivars, to simulate CSPS; and the third planting each year was made in early-June, similar to planting dates used for double-cropping soybeans following wheat. This study also consisted of two row spacing widths, 38.1 and 76.2 cm for NR and WR spacing, respectively. The soybean at each field site was either irrigated using an irrigation scheduler or grown under dryland (i.e., non-irrigated) conditions. Each field study was conducted using a strip-split-split plot design with three replications of each planting-date, irrigation,

Variety	Seed Size (g 100 seed^{-1})	Soyfood type	Source	Characteristics
Hutcheson	13.7	Conventional check	U of A Foundation	High yield
V99-5089	17.1	Tofu/Soymilk	VA Tech	High sucrose, low stachyose
MFL-552	19.3	Tofu/Soymilk	VA Tech	Large seed size, high protein
V97-3000	9.0	Natto	VA Tech	Small seed size
SS-516	11.5	Natto	VA Tech	High yield, sugar
B-3	8.1	Natto	Blue Horizon Inc.	Natto quality
Camp	6.7	Natto	VA Tech	High protein, sugar
MFS-591	7.2	Natto	VA Tech	High protein, sugar

Table 1: Soybean genotypes evaluated at two Arkansas Locations in 2002, 2003, and 2004.

row-spacing and seed-size treatment combination. The planting-date factor was arranged as a randomized complete block. The irrigation factor was also arranged as a randomized complete block and was stripped across planting-date treatments. Row spacing was assigned as a split-plot factor, within each planting-date-irrigation treatment combination. Genotypes were randomly assigned as a split-plot factor in each planting-date-irrigation-row-spacing treatment combination.

Stand counts were taken for each plot using a linear stick and converted to number of plants per acre based on row spacing. Maturity was scored as the number of days from planting until 95% of the pods had attained a mature color. Lodging was scored on a scale of 1 (all plants erect) to 5 (all plants prostrate) at maturity. Shattering was also scored at maturity using a 1 to 5 scale with 1 representing all pods intact and 5 representing all pods open. Plant height was measured from the soil surface to stem apex at maturity. Seed yield was determined by harvesting the two center rows of each four-row 6.1-m plot.

One hundred seeds were randomly selected from each plot and evaluated for seed size (g 100 seeds^{-1}) and hilum color (yellow, buff, gray, brown, imperfect black, and black) and rated for green seed (%), mottling (%), and purple seed stain (%).

Analysis of variance (ANOVA), mean separation, and correlation analysis of yield, seed size, maturity, and plant height were conducted using PROC GLM procedure of SAS V9 (SAS Institute, Cary, NC). Means were separated using Fisher's protected LSD at α = 0.05, and Pearson's correlation procedure was used for correlation analyses. Heritability estimates were calculated using the equation:

$$h^2 = \frac{\sigma^2{}_g}{\left(\sigma^2{}_e / RE + \sigma^2{}_{ge} \ / E + \sigma^2{}_g\right)}$$

Where h^2 is heritability, σ^2_g is genetic variance, σ^2_e is experimental error, R is the number of replications, E is the number of environments, and σ^2_{ge} is the variance for G × E interaction [22].

Results and Discussion

Agronomic performance of food-grade soybean

Environment (E) and genotype (G) were highly significant on four major agronomic traits: yield, seed size, maturity, and height (Table 2). The environment contributed 24.8, 3.6, 16, and 23% of the total variation in seed yield, seed size, maturity, and plant height, respectively ($P < 0.001$; Table 2). Genotype accounted for a significant percent of variation on seed size (66.8%), height (20.5%), seed yield (7.9%), and maturity (12.8%; Table 2). Irrigation had a significant effect on yield and plant height (Table 2). Planting date has a significant effect on yield, maturity, and plant height. Row spacing did not have any effect on any major agronomic traits, indicating that specialty soybeans can be equally productive in either narrow or wide rows (Table 2). However, NR spacing might be more profitable due to less herbicide and water costs than WR. Therefore, major agronomic traits may vary from year to year, but selection of proper varieties for a particular production environment is important in achieving high yield, proper seed size, and plant height.

Several agronomic traits were affected by the interactions of environment x irrigation (E x I) and environment x planting date (E x P; Table 2). The E x I interaction contributed 14.9, 7.1, 3.5, and 0.5% of the total variation in yield, maturity, plant height, and seed size, respectively ($P < 0.001$; Table 2). The E x P interaction accounted for 11.1, 0.8, 9.2, and 14% of the total variation of yield, seed size, maturity, and height, respectively ($P < 0.001$; Table 2). These results demonstrate that irrigation and planting dates have varying impacts on major agronomic traits; therefore, cultural management decisions such as irrigation and planting date should be made specifically for each location in a particular year in order to maximize yield potential. The three way interactions of I x P x R, I x G x R, and G x P x R had no significant effect on yield, seed size, maturity, and height, but E x P x R and E x I x P interactions were significant for yield, seed size, maturity, and height; however, these interactions did not account for much of the variation in the major four traits (Table 2). The four way interaction of I x G x P x R was only significant for yield (0.3%; $P < 0.05$) and E x I x P x R was only significant for maturity (0.7%; $P < 0.001$; Table 2). Therefore, producers of food-grade soybeans should be more concerned with the two way interactions of major production variables such as E x I and E x P. The main sources of variation in yield were attributed to environment (24.8%; $P < 0.001$), E x I interaction (14.9%; $P < 0.001$), E x P interaction (11.1%; $P < 0.001$), and genotype (7.9%; $P < 0.001$; Table 2). Seed size variation was attributed mainly to genotype (66.8%; $P < 0.001$) and environment (3.6%; $P < 0.001$; Table 2). Maturity variation was mainly attributed to planting date (16.2%; $P < 0.001$), environment (16%; $P < 0.001$), genotype (12.8%; $P < 0.001$), and E x P interaction (9.2%; $P < 0.001$; Table 2). Variation in height was mainly attributed to environment (23%; $P < 0.001$), genotype (20.5%; $P < 0.001$), E x P interaction (14%; $P < 0.001$), and planting date (12.9%; $P < 0.001$; Table 2). For producers, yield, height, and maturity can be improved through prudent variety and location selection. On the other hand, seed size is relatively independent of environment because it is controlled by genotype (66.8%; $P < 0.001$; Table 2).

A total of five small- and two large-seeded food-grade soybeans were evaluated in six environments and compared to a conventional check (Table 3). The check variety, Hutcheson, had the highest yield and represented the optimal seed size for commercial production (Table 3). Of all six environments, Hutcheson yielded an average of 2936.2 kg ha^{-1} and had a seed size of 13.7 g 100 seeds^{-1}. The larger seed size, represented by V99-5089 and MFL-552, averaged 18.2 g 100 seeds^{-1} and yielded 35% (31.9 to 37.7%) less than Hutcheson (Table 3). The small seeded lines had an average seed size of 8.5 g 100 seeds^{-1} and yielded 4 to 28% less than Hutcheson (Table 3). SS-516 (11.4 g 100 seeds^{-1}) had a smaller seed size than Hutcheson (Table 3), but yielded fairly well (2805.9 kg ha^{-1}) indicating that there is potential for developing high-yielding small-seeded cultivars.

All genotypes had similar maturities, but the large-seeded lines had an early average stand count of 46.1 plants m^{-2}, 11.5 and 12.8% less than the small-seeded and conventional varieties respectively, indicating that producers will need to adjust the seeding rate when growing large-seeded soybean varieties for tofu production. Larger seeds normally have more difficulty in emerging since the hypocotyl in a larger soybean encounters more impedance from the soil during emergence.

Seed quality parameters for all seed sizes were numerically similar and ranged from 2.1 to 2.4; however, the small-seeded lodging scores averaged 1.3, 8, and 1.8% worse than V99-5089, MFL-552, and Hutcheson, respectively (Table 3). Additionally, the small-seeded lines had an average shatter score of 1.2 which is 9% worse than the average shatter scores of the large-seeded and conventional lines (Table 3). One of small-seeded lines, B-3 was the tallest variety and had excessive lodging and shattering, which lowered the average lodging and shattering scores of all the small-seeded lines.

The percentage of green and purple seed varied among the check, small-seeded, and large-seeded soybeans (Table 3). Small-seeded and

Source of Variation†	Yield	Seed Size	Maturity	Height
Environment (E)	24.8 ***§	3.6***	16***	23.0***
Irrigation (I)	4.0***	NS‡	NS	1.0**
E x I	14.9***	0.5***	7.1***	3.5***
Row Spacing (R)	NS	NS	NS	NS
E x R	1.6***	NS	1.0***	0.6***
I x R	NS	NS	NS	NS
E x I x R	0.3**	NS	NS	0.5***
Planting Date (P)	7.5***	NS	16.2***	12.9***
E x P	11.1***	0.8***	9.2***	14.0***
I x P	NS	NS	NS	NS
E x I x P	2.9***	0.3**	2.3***	1.4***
P x R	NS	NS	NS	NS
E x P x R	0.5**	0.3*	0.7***	0.3*
I x P x R	NS	NS	NS	NS
E x I x P x R	NS	NS	0.7***	NS
Rep (E x I x P x R)	2.7**	NS	NS	NS
Genotype (G) †	7.9***	66.8***	12.8***	20.5***
I x G	0.2**	NS	NS	NS
G x P	0.5***	NS	1.6***	NS
G x R	0.2*	NS	NS	NS
G x E	NS	NS	NS	NS
I x G x R	NS	NS	NS	NS
I x G x P	0.5**	NS	NS	NS
G x P x R	NS	NS	NS	NS
I x G x Px R	0.3*	NS	NS	NS

† Eight soybean genotypes
‡ NS, not significant;
*,**, and ***, significant at *P*=0.05, 0.01, and 0.001, respectively.
§ Variance component estimates in percentages of total variances.
¶ Number of days from emergence to full maturity.

Table 2: Analysis of variance and variation percentages for the effects of planting date, irrigation, genotype, row spacing, and the interactions on major agronomic traits across locations and over three years (2002-2004).

conventional lines contained a greater percentage of green seeds and less purple seeds than large-seeded lines (Table 3). Large-seeded lines contained an average of 7.8% seed mottling, which was greater than the small-seeded (6.3%) and conventional (6.1%) varieties (Table 3). The small-seeded line, MFS-591, contained the greatest average percent of green seeds (16.1%) among the lines included in this study (Table 3). Small-seeded varieties, on average, contained very small percentages of green (8.0%), purple (1.0%), and mottled (6.3%) seed. Therefore, the genotypes selected for soybean production in this study appeared to be fairly well adapted to southern environments.

Effect of planting date on agronomic traits of food-grade soybean

All eight genotypes used in this study were MG V varieties and the recommended planting date for MG V in Arkansas is mid-May [2]. Comparing three planting dates, April, May, and June, revealed that the May planting date produced significantly greater yields in all three genotypic groups when compared with the April planting (Table 4). Soybean yields from May plantings were numerically, but not significantly, greater than those from June plantings, except for two varieties, V99-5089 and SS-516, which produced significantly greater yields in May (Table 4). Greater yields following the May planting date may be due to the maturity group of the studied genotypes. Heatherly [23] and Bajaj et al. [24] also reported that May plantings generally produced greater yields than April and June plantings.

Comparison of maturity between three planting dates indicates that the April planting exhibited the shortest maturity among all the large-seeded and most of the small-seeded lines (Table 4). Significant difference in maturity between May and June were detected in all genotypes but not between April and May. Soybeans planted in May were significantly or numerically taller than the other planting dates for all genotypes in this study. All genotypes showed significant difference in height when compared to the April and May planting dates (Table 4).

Planting date did not affect seed size among all three size groups in the current study. Hurburgh [25] reported that late planting often suffers from less than ideal rainfall during pod fill and causes fewer seeds to be produced; however, precipitation later in the season may cause larger seed size. Since June planting in the mid-south gives rise to a fairly competitive yield, double cropping large-seeded food-grade soybean may be a viable option for some wheat farmers.

Effect of irrigation on agronomic traits of food-grade soybean

Greater yields were associated with irrigation in all three genotypic groups in this study. In the irrigated plots, yields in the large-seeded, small-seeded, and conventional lines were increased by 24.7, 26.8, and 24.7%, respectively, compared to the non-irrigated treatment (Table 5). Furthermore, irrigation improved overall yield by an average of 26.1% (Table 5). The conventional line and three out of five small-seeded lines had significantly bigger seed size under irrigation. However, irrigation did not significantly affect seed size of large-seeded lines (Table 5). In agreement with the findings from Korte et al. [26], irrigation significantly delayed maturity from two to five days for all genotypes by lengthening the seed-fill period. Vasilas et al. [27] also reported that the duration of seed-fill period and yield are positively associated, as was observed in this study. Plant height was numerically increased under irrigation in all varieties and significantly increased in all large-seeded and two small-seeded lines (Table 5).

In this study, the irrigation effect on agronomic traits corresponded with the Arkansas Soybean Handbook [2]. Similar to what was observed in this study, the Arkansas Soybean Handbook reported that irrigation could prevent fluctuations in soil moisture that attribute to smaller seed and shorter plants [2]. These results were also consistent with other similar studies [9,23]. Bajaj et al. [9] observed an 83% increase in yield and a 17% increase in plant height when irrigated, averaged among eight genotypes planted in Arkansas. Heatherly [23] also reported increased yields under irrigation.

Effect of row spacing on agronomic traits of food-grade soybean

Row spacing did not significantly affect yield, seed size, maturity, and height in this study (Table 6). The wide-row (WR) spacing had a slight numerical yield advantage (10.2%) over narrow-row (NR) spacing on large-seeded soybeans (Table 6). This was expected since the larger-seeded genotypes were also the shortest plants included in this study (Table 3) and the NR planting could have increased plant height and

Genotype	Yield	Seed Size	Maturity	Height	Quality Score	Lodge Score	Shatter Score	Green Seed	Purple Seed	Mottling
	kg ha^{-1}	g 100 $seeds^{-1}$	days†	cm	1 to 5‡	1 to 5§	1 to 5¶		(%)	
Large-seeded:										
V99-5089	1830.3	17.1	140	46.5	2.5	1.2	1.1	5.0	2.0	7.5
MFL-552	1998.9	19.3	143	47.9	2.3	1.2	1.1	5.1	2.6	8.0
Mean	$1914.6^{a\#}$	18.2^{c}	141.7^{b}	47.2^{a}	2.4^{b}	1.2^{b}	1.1^{a}	5.1^{a}	2.3^{b}	7.8^{b}
Small-seeded:										
B-3	2336.2	8.1	138	66.5	1.8	1.9	1.6	6.3	0.4	3.9
V97-3000	2358.4	9.0	137	48.4	2.3	1.0	1.2	7.2	1.3	8.0
Camp	2116.5	6.7	134	41.0	2.0	1.0	1.2	4.9	0.6	5.0
MFS-591	2237.4	7.2	146	55.3	2.3	1.4	1.1	16.1	0.8	6.2
SS-516	2805.9	11.4	138	55.3	2.2	1.0	1.1	5.6	1.8	8.4
Mean	2370.9^{b}	8.5^{a}	138.6^{a}	53.3^{b}	2.1^{a}	1.3^{c}	1.2^{b}	8.0^{b}	1.0^{a}	6.3^{a}
Conventional Check:										
Hutcheson	2936.2^{c}	13.7^{b}	141.8^{b}	57.7^{b}	2.2^{a}	1.1^{a}	1.1^{a}	7.0^{b}	1.6^{a}	6.1^{a}
Overall mean	2327.5	11.6	140	52.3	2.2	1.2	1.2	7.1	1.4	6.7
LSD (0.05)	81.35	0.49	0.76	1.30	0.15	0.09	0.07	1.46	0.47	0.94

† Number of days from emergence to full maturity.
‡ Quality score, 1 = best, 5 = worst.
§ Lodging score, 1 = upright, 5 = prostrate.
¶ Shatter score, 1 = no shatter, 5 = 100% shattered.
# Means with the same lower case letter within a column were not significantly different at P=0.05.

Table 3: Agronomic performance of food-grade soybeans in comparison with a conventional check across two locations and over three years.

	Yield				Size				Maturity				Height			
Genotype	April	May	June	LSD	April	May	June	LSD	April	May	June	LSD	April	May	June	LSD
	kg ha^{-1}				g 100 $seed^{-1}$				days†				cm			
Large-seeded:																
V99-5089	$1438^{a\ddagger}$	2217^{c}	1832^{b}	340	16.8^{a}	17.6^{a}	17.1^{a}	1.0	135^{a}	139^{b}	146^{c}	3	39.8^{a}	53.0^{c}	46.7^{b}	4.0
MFL-552	1608^{a}	2311^{b}	2078^{b}	346	18.7^{a}	19.9^{b}	19.4^{ab}	1.2	138^{a}	143^{b}	149^{c}	3	39.6^{a}	54.3^{c}	49.8^{b}	4.0
Mean	$1523^{A\S}$	2264^{A}	1955^{A}	----	17.8^{C}	18.8^{C}	18.2^{C}	----	137^{B}	141^{B}	147^{C}	----	39.7^{A}	53.6^{A}	48.2^{A}	----
Small-seeded:																
B-3	1998^{a}	2607^{b}	2404^{b}	344	8.0^{ab}	7.9^{a}	8.4^{b}	0.5	136^{a}	136^{a}	143^{b}	3	57.9^{a}	73.5^{b}	68.2^{b}	5.7
V97-3000	1804^{a}	2805^{b}	2469^{b}	401	9.0^{a}	8.1^{a}	10.0^{a}	2.1	132^{a}	135^{b}	144^{c}	2	40.2^{a}	54.8^{c}	50.2^{b}	4.2
Camp	1440^{a}	2555^{b}	2362^{b}	368	6.8^{a}	6.5^{a}	6.8^{a}	0.4	129^{a}	133^{b}	141^{c}	2	33.3^{a}	46.3^{b}	43.5^{b}	3.5
MFS-591	1847^{a}	2466^{b}	2392^{b}	380	7.2^{a}	7.1^{a}	7.2^{a}	0.5	145^{a}	145^{a}	148^{b}	3	46.1^{a}	62.9^{c}	57.0^{b}	4.9
SS-516	2365^{a}	3290^{b}	2759^{a}	443	11.5^{a}	11.3^{a}	11.5^{a}	0.6	133^{a}	137^{b}	144^{c}	3	48.2^{a}	62.5^{c}	55.1^{b}	4.6
Mean	1891^{B}	2744^{B}	2477^{B}	----	8.5^{A}	8.2^{A}	8.8^{A}	----	135^{A}	137^{A}	144^{A}	----	45.1^{B}	60.0^{B}	54.8^{B}	
Conventional Check																
Hutcheson	2508^{aC}	3368^{bC}	2934.2^{abC}	466	13.7^{aB}	13.5^{aB}	13.8^{aB}	0.8	137^{aB}	142^{bC}	146^{cB}	2	50.0^{aC}	64.9^{cC}	58.3^{bC}	4.8
Overall Mean	1876	2702	2404	----	11.5	11.5	11.8	----	136	139	145	----	44.4	59.0	53.6	----
LSD	135	149	141	----	0.6	0.5	1.3	----	2	1	1	----	2.0	2.5	2.3	----

† Number of days from emergence to full maturity.
‡ Means with the same lower case letter within a row were not significantly different at P = 0.05.
§ Means with the same capital letter within a column were not significantly different at P = 0.05.

Table 4: Effect of planting date on major agronomic traits of food-grade soybeans.

caused the plants to reach full canopy coverage sooner. However, both V99-5089 and MFL-552 have a bushy plant architecture, which enables them to reach full canopy quickly despite their height; hence, the NR spacing did not increase yield for the large-seeded lines as was expected (Table 6). The smaller-seeded genotypes had a small numerical (< 1.0%) yield advantage when planted with NR spacing, when compared to WR (Table 6). The taller, less bushy varieties such as B-3, SS-516, and Hutcheson can take advantage of the NR spacing by reaching canopy sooner, thus maximizing light interception and limiting weed competition. These results were in agreement with Parker et al. [28] and Beatty et al. [12], who reported that variety, environment, and cultural practices affect yield response of NR spacing.

Heritability of agronomic traits of food-grade soybean

Knowledge of the heritability of desirable traits is valuable for predicting inheritance in offspring. However, yield heritability is very complex because it is largely affected by environment and controlled by multiple genes. In the current study, yield exhibited the lowest heritability (r = 0.45) among the four major agronomic traits examined (Table 7). Konovsky et al. [29] also reported low heritability of yield (r = 0.04) among conventional and food-grade genotypes; however, greater heritability of yield (r = 0.64) among more divergent genotypes was reported by Cicek et al. [30]. In the current study, the 2004 Weiner environment produced the two highest yield heritabilities (r = 0.66) for April and May plantings ; conversely, the 2002 Weiner environment produced the lowest heritability of r = 0.24 for the April planting (Table 7). The results from this study support the complexity and

	Yield			Size			Maturity			Height		
Genotype	Irrigated	Non-irr	LSD	Irrigated	Non-irr	LSD	Irrigated	Non-irr	LSD	Irrigated	Non-irr	LSD
	——— kg ha^{-1} ———			——— g 100 seed^{-1} ———			——— days† ———			——— cm ———		
Large-seeded:												
V99-5089	2051^{b‡}	1674^{a}	283	17.4^{a}	16.9^{a}	0.8	142^{b}	138^{a}	3	66.8^{b}	45.9^{a}	3.5
MFL-552	2263^{b}	1784^{a}	284	19.8^{a}	19.0^{a}	1.0	145^{b}	141^{a}	3	49.7^{b}	46.8^{a}	3.6
Mean	2157^{A§}	1729^{A}	----	18.6^{C}	17.9^{C}	----	144^{B}	140^{B}	----	58.2^{B}	46.4^{A}	----
Small-seeded:												
B-3	2586^{b}	2088^{a}	281	8.3^{b}	7.9^{a}	0.4	139^{b}	137^{a}	2	66.8^{a}	66.4^{a}	5.0
V97-3000	2631^{b}	2087^{a}	337	9.6^{a}	8.5^{a}	1.7	139^{b}	135^{a}	2	50.2^{b}	46.5^{a}	3.6
Camp	2316^{b}	1921^{a}	323	6.8^{a}	6.6^{a}	0.3	137^{b}	132^{a}	2	42.0^{a}	40.0^{a}	3.2
MFS-591	2679^{b}	1895^{a}	296	7.4^{b}	7.0^{a}	0.4	148^{b}	144^{a}	3	58.6^{b}	53.4^{a}	4.2
SS-516	3104^{b}	2509^{a}	367	11.7^{b}	11.1^{a}	0.5	140^{b}	136^{a}	2	56.5^{a}	54.0^{a}	4.1
Mean	2663^{B}	2100^{B}	----	8.8^{A}	8.2^{A}	----	141^{A}	137^{A}	----	54.8^{A}	52.1^{B}	
Conventional Check:												
Hutcheson	3259^{bC}	2614^{aC}	381	14.1^{bB}	13.3^{aB}	0.6	144^{bB}	140^{aB}	2	58.6^{aB}	56.9^{aC}	4.2
Overall Mean	2611	2071	----	11.9	11.3	----	142	138	----	56.1	51.2	----
LSD (0.05)	141	114	----	0.9	0.4	----	1	1	----	1.8	2.0	----

† Number of days from emergence to full maturity.
‡ Means with the same lower case letter within a row were not significantly different at *P* = 0.05.
§ Means with the same capital letter within a column were not significantly different at *P* = 0.05.

Table 5: Effect of irrigation [irrigated and non-irrigated (non-irr)] on major agronomic traits of food-grade soybeans.

	Yield			Size			Maturity			Height		
Genotype	Narrow†	Wide	LSD	Narrow	Wide	LSD	Narrow	Wide	LSD	Narrow	Wide	LSD
	——— kg ha^{-1} ———			——— g 100 seed^{-1} ———			——— days‡ ———			——— cm ———		
Large-seeded:												
V99-5089	1695.2^{a§}	1965.1^{a}	285.6	16.9^{a}	17.3^{a}	0.8	139^{a}	141^{a}	3	46.0^{a}	47.0^{a}	3.53
MFL-552	1947.2^{a}	2051.5^{a}	290.9	19.1^{a}	19.6^{a}	1.0	143^{a}	143^{a}	3	47.4^{a}	48.3^{a}	3.66
Mean	1821.2^{A¶}	2008.3^{A}	----	18.0^{C}	18.4^{C}	----	141^{B}	142^{B}	----	46.7^{A}	47.6^{A}	----
Small-seeded:												
B-3	2383.2^{a}	2289.8^{a}	288.2	8.0^{a}	8.2^{a}	0.4	137^{a}	139^{b}	2	66.3^{a}	66.8^{a}	4.93
V97-3000	2355.5^{a}	2363.1^{a}	345.4	9.3^{a}	8.8^{a}	1.7	137^{a}	137^{a}	2	48.1^{a}	48.6^{a}	4.19
Camp	2088.9^{a}	2148.2^{a}	327.6	6.6^{a}	6.0^{a}	0.3	133^{a}	135^{b}	2	40.9^{a}	41.1^{a}	3.78
MFS-591	2192.4^{a}	2277.1^{a}	315.1	7.1^{a}	7.2^{a}	0.4	145^{a}	147^{a}	3	55.3^{a}	55.4^{a}	3.25
SS-516	2850.8^{a}	2762.0^{a}	374.9	11.3^{a}	11.6^{a}	0.5	137^{a}	139^{a}	3	56.0^{a}	54.6^{a}	5.35
Mean	2374.2^{B}	2368.0^{B}	----	8.5^{A}	8.5^{A}	----	138^{A}	139^{A}	----	53.3^{B}	53.3^{B}	
Conventional Check:												
Hutcheson	2998.7^{aC}	2875.1^{aC}	390.4	13.4^{aB}	13.9^{aB}	0.6	141^{aB}	143^{bC}	2	58.1^{aC}	57.3^{aC}	4.25
Overall Mean	2314.0	2341.5	----	11.5	11.7	----	139	140	----	52.3	52.4	----
LSD	107.6	121.0	----	0.9	0.4	----	1	1	----	1.8	1.8	----

† Narrow = 38.1 cm row spacing. Wide = 78.2 cm row spacing.
‡ Number of days from emergence to full maturity.
§ Means with the same lower case letter within a row were not significantly different at *P* = 0.05.
¶ Means with the same capital letter within a column were not significantly different at *P* = 0.05.

Table 6: Effect of row spacing on major agronomic traits of food-grade soybeans.

inconsistency of the yield heritability, which is also highly dependent on environmental conditions [31,32].

In the current study, seed size was highly heritable (r = 0.89) and ranged from r = 0.73 to 0.95, indicating that seed size is mainly controlled by genotype; therefore, cultural management may not be effective in altering seed size (Table 7). Similarly, Gupta et al. [32] reported seed size heritabilities between r = 0.42 to 0.81. Heritability for maturity ranged from r = 0.22 to 0.81, with an average of r = 0.49 across all environments (Table 7). Cicek et al. [30] reported greater heritability for maturity than found in this study, which was likely due to the limited population generated from the single cross used in their study. Height heritability ranged from r = 0.38 to 0.91, with an average r = 0.62, similar to the results from Cicek et al. [30] of r = 0.74 broad sense heritability. Finding desirable traits with high heritability is useful in breeding in order to select lines based on phenotypic observation without the use of molecular markers.

Correlations of Agronomic Traits of Food-Grade soybean

Yield was negatively correlated with maturity (r = -0.18; P = 0.05), but positively correlated to plant height (r = 0.60; P = 0.001). The correlation between yield and plant height was very strong, indicating that selecting tall varieties may help improve yield of specialty soybeans. Cicek et al. [30] also observed a positive correlation between yield and maturity (r = 0.38) and a similar correlation between yield and plant height (r = 0.58). This study indicated that there was no significant correlation between yield and seed size. However, Mansur et al. [33] reported a strong positive correlation between yield and seed size (r = 0.92). Maturity and seed size were positively correlated (r = 0.197; P = 0.05), which is similar to the correlation reported by Cicek et al. [30] (r = 0.14).The discrepancy between the three studies was likely caused by the differences in genotypes used in each study. Genotypes in our study were all MG V varieties, with seed sizes ranging from very small (7 g 100 seed^{-1}) to very large (19 g 100 seed^{-1}), while the other two studies used recombinant inbred lines. Practical breeding requires close attention to the correlation between traits especially when two desirable traits exhibit a negative correlation. Information from correlations of the traits can be complimented with the information of molecular markers to efficiently breed food-grade soybean lines with desired attributes.

Conclusion

Planting date, irrigation, and row spacing affects specialty soybean similarly to conventional soybean in major agronomic traits such as yield, seed size, maturity, and plant height. Using both irrigation and the Conventional Soybean Production System is expected to improve yield of specialty soybean. However, row spacing did not affect yield of food-grade soybean as much as it affected grain-type soybeans. This study can contribute valuable breeding and production information to mid-south specialty soybean breeders and growers.

	Yield			Seed Size			Maturity			Height		
Environment	Apr	May	June	April	May	June	April	May	June	April	May	June
2002 Fayetteville	0.48	0.46	0.52	0.93	0.91	0.93	0.61	0.55	0.53	0.71	0.63	0.42
2002 Weiner	0.24	0.49	0.47	0.76	0.94	0.95	0.69	0.59	0.46	0.72	0.91	0.86
2003 Fayetteville	0.50	0.50	0.49	0.75	0.94	0.84	0.42	0.81	0.22	0.48	0.69	0.56
2003 Weiner	0.29	0.52	0.38	0.73	0.97	0.87	0.24	0.64	0.41	0.42	0.84	0.38
2004 Fayetteville	0.58	0.26	0.31	0.92	0.83	0.94	0.60	0.31	0.50	0.76	0.54	0.58
2004 Weiner	0.66	0.66	0.30	0.97	0.93	0.88	0.50	0.44	0.41	0.71	0.54	0.41
Overall Mean	0.46	0.48	0.41	0.84	0.92	0.90	0.51	0.56	0.42	0.63	0.69	0.54

† Number of days from emergence to full maturity.

Table 7: Heritability of major agronomic traits of food-grade soybeans.

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