GROWTH, FLOWERING, AND SURVIVAL OF FIREWHEEL *GAILLARDIA PULCHELLA* FOUG. BASED ON SEED SOURCE AND GROWING LOCATION

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ABSTRACT

Home region failed to provide any clear short-term improvement in plant growth, vigor, flowering, quality, or survival of *Gaillardia pulchella* Foug. (Asteraceae; firewheel) when plants derived from natural populations in east Texas, northeast Florida, central west Florida, central east Florida, and southeast Florida were grown under low-input landscape conditions in northwestern, northern central, or southeastern Florida. During the 22-wk study, adaptability of east Texas plants was similar to that of northeast Florida and southeast Florida plants within the different sites. At the 2 northern sites, plant growth, vigor, and flowering were greater than for plants grown in southeastern Florida. The patterns of biweekly changes in plant vigor, flowering, and quality ratings were similar among plants of all seed sources within a site. Averaged over the entire study, these ratings were equally high for plants of all seed sources except central east Florida plants. Within a site, survival of northeast Florida, southeast Florida, and east Texas plants was equally high (83 to 100%). Also, 100% of central west Florida plants survived at the 2 northern sites, yet no central west Florida plants survived past week 16 in southeastern Florida. Differences in growth, vigor, flowering, quality, and survival were likely related to the loamier soils at the 2 northern sites and (or) flooding June rains in southeastern Florida.

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KEY WORDS

ecotype, Florida, wildflowers, home region

NOMENCLATURE

USDA NRCS (2005)

Firewheel (*Gaillardia pulchella* Foug. [Asteraceae]), also known as blanketflower and Indian blanket, is native to the US. The original range of *G. pulchella* is believed to be southwestern US grasslands and the Gulf Coast region (Stoutamire 1977; Heywood 1986a; USDA NRCS 2005). However, because *G. pulchella* is a popular species that is able to grow on a variety of soil types and colonize disturbed habitats, it now occurs throughout much of the continental US. The only regions where *G. pulchella* has not been documented are the northwestern US and some mid-Atlantic states from Kentucky to New Jersey.

Gaillardia pulchella and *Gaillardia aestivalis* (Walt.) H. Rock (Asteraceae; lanceleaf blanketflower) are the only 2 *Gaillardia* species native to Florida. In contrast to *G. pulchella*, *G. aestivalis* is rarely cultivated or produced and has a narrower range, with Kansas as its northwestern limit, south to Texas and Florida, and as far north as South Carolina on the east coast (USDA NRCS 2005). Both species prefer dry, sunny sites. In Florida, both species often inhabit sandy soil, with *G. pulchella* frequently found in coastal counties (Wunderlin 1997; Wunderlin and Hansen 2004).

Gaillardia pulchella is an annual or short-lived perennial in Florida, and this species under natural conditions grows to a height of 30 to 61 cm (1 to 2 ft) and is about as wide as tall (Taylor 1992; Wunderlin 2005). Leaves may be basal and linear to lanceolate, grayish green, and very hirsute. Flowers are 3.8 to 7.6 cm (1.5 to 3.0 in) in diameter. The brightly colored corolla is typically bicolored, with an inner band of red surrounded by an outer band of yellow. Relative amounts of red and yellow can vary considerably among plants in natural populations. In addition, the corolla can be entirely red or yellow, have an inner red band surrounded by a white band, or on rare occasions, be pure white (Norcini 2005). Peak flowering in Florida is from May through August, with diminished flowering until frost; in south Florida, *G. pulchella* can bloom at any time of the year (Norcini unpublished observations). *Gaillardia pulchella* is a self-incompatible, obligate outcrosser (Stoutamire 1977) and is pollinated by nonspecialist insects including bees and a soldier beetle (Heywood 1986a).

The concept that plants growing in a particular environment will be better adapted to their home site or region than that same species derived from a different environment—the ecotype concept—has long been known (Turesson 1922). Demand for native wildflower seeds from only local or regional ecotypes by those involved with roadside plantings (Harper-Lore 1999; FDOT 2004) and restoration and revegetation projects (Houseal and Smith 2000; Booth and Jones 2001; Gustafson and others 2005) has substantially risen over the past 10 to 20 y. Through outreach efforts, public awareness of ecotype issues is now becoming more widespread (for example, see CNPS 2001; FWAC 2004; Norcini and Aldrich 2004), resulting in a potential market for local or regional ecotypes in landscape plantings. Landscape use includes residential and commercial sites as well as locations in state and federal parks and forests such as visitor centers and around signage. Because the landscape market for regional ecotypes of wildflowers is relatively new, formal evaluation of native wildflowers from different regional seed sources for their suitability under landscape conditions is very limited. Some horticulturally pertinent information (e.g., flowering traits and survival) about native wildflower ecotypes can be gleaned from common-garden studies, but such studies are typically ecology oriented. Norcini and others (1998) provided preliminary evidence of a home region advantage when plants of *G. pulchella* and *Rudbeckia hirta* L. (Asteraceae; black-eyed susan) derived from Texas and north Florida seed sources were evaluated under low-input landscape conditions in northern Florida. In follow-up studies, additional evidence of regional adaptation in *R. hirta* was reported as plants from Florida sources survived better under Florida conditions than did plants derived from a Texas source (Norcini and others 2001b; Marois and Norcini 2003), although the differences in survival could not be directly attributed to pests or climate (Marois and Norcini 2003). A home region advantage also was observed for *Salvia lyrata* L. (Lamiaceae; lyre-leaved sage). When grown under low-input landscape conditions in northern Florida, plants of *S. lyrata* from a north Florida seed source had higher survival than plants of an Ohio seed source (Norcini and others 2001a). In related work, Stoutamire (1955) observed morphological differences among *G. pulchella* ecotypes evaluated in a common-garden study, and Heywood (1986b) differentiated 2 ecotypes of *G. pulchella* in central Texas by the carbonate content of the soil in which they grew.

Our objective was to evaluate, under low-input landscape conditions, the effect of site and seed source on short-term growth, flowering, vigor, overall quality, and survival of *G. pulchella*, horticultural performance traits that are pertinent to landscape use. Based on the ecotype concept, *G. pulchella* should perform better under regional conditions from which the seeds were derived than for seeds derived from a different environment, especially under low-input conditions. Low-input conditions were utilized: 1) because typical garden conditions, in which moisture and nutrients are nonlimiting, might override potential performance differences among seed sources due to variability in stress tolerance among the seed sources; and 2) to be consistent with environmentally friendly landscape practices, which include the use of mulch to minimize weed growth.

MATERIALS AND METHODS

Plant Material

Gaillardia pulchella seeds were collected from 5 geographic locations in 2004: northeast Florida, central west Florida, central east Florida, southeast Florida, and east Texas (Table 1). All collection sites were sandy, natural areas in full sun where popula-

TABLE 1

Gaillardia puelchella *populations from which seeds were collected.*

Geographic region	Latitude/longitude	Cold hardiness / heat zone[z]	Additional information about sites and populations
Northeast Florida	29.8 N, 81.2 W	9a / 9	Near Crescent Beach (St. Johns County); plants scattered over about 19m^2 in dunes
Central Florida west	28.6 N, 82.3 W	9a / 10	Brooksville vicinity (Hernando County); plants scattered over about 19m^2 in field
Central Florida east	28.8 N, 80.9 W	9b / 9	Scottsmoor vicinity (Brevard County); seeds collected by local native plant expert
Southeast Florida	26.9 N, 80.2 W	10a / 10	Palm Beach Gardens vicinity (Palm Beach County); along old dunes; plants very scattered over about 0.4 ha
East Texas	29.8 N, 95.6 W	9a / 9	Houston vicinity; seeds collected by local native plant expert

[z] USDA Cold Hardiness Zone and American Horticulture Society Heat Zone, respectively.

tions had not been intentionally planted. Seeds were collected from at least 10% of the individuals from throughout each population, with no intentional selection of any particular phenotype within a population. Seeds within a population were pooled. This seed collection protocol was more representative of one that would be undertaken by a grower interested in propagating plants for landscape use than by someone collecting seeds for restoration purposes. For restoration purposes, a collector would have been more attentive to population genetic diversity issues (Rogers and Montalvo 2004).

Seeds were germinated and grown under greenhouse conditions in early January 2005. A subsample of seeds was randomly selected from the pooled seeds from each of the 5 populations. These 5 subsamples were sown on the surface of separate plug trays containing Fafard #2 medium (Fafard, Apopka, Florida), lightly covered (1 to 2 mm [0.04 to 0.08 in]) with Fafard #2, and placed under intermittent mist in a greenhouse. Once plugs were well-rooted, they were potted into 3.8-l (1-gal) pots in Fafard #2. Plants were watered as needed by means of drip irrigation tubes delivering 150 mg/l (ppm) of N delivered as $20N:10P_2O_5:20K_2O$ liquid fertilizer (The Scotts Company, Marysville, Ohio) until a day or two before being transplanted outdoors. While plants used in this study were produced under nonlimiting conditions (moisture, nutrients, temperature, and so on) that might have caused some inadvertent selection of genotypes, such production methods are typically used for growing herbaceous landscape species to be planted in the spring.

To represent the majority of the morphological diversity within populations, 27 plants growing in 3.8-l containers were selected at random from the median 80% of plants (based on size, growth habit, and overall appearance) within a seed source. Of the 27 plants per seed source, 9 plants per seed source were

TABLE 2

Florida site characteristics for Gaillardia pulchella *plantings.*

Location	Latitude/ longitude	Cold hardiness/ heat zone[z]	Organic matter (%)	Estimated N release (kg/ha)	P	K	Mg	Ca	pH
					mg/l				
Northwestern[y]	30.5 N, 84.6 W	8b/9	3.9	137	81	102	131	1040	6.1
Soil type: Ruston series; fine-loamy, siliceous, and semi-active properties (USDA NRCS 1999)									
Northern central[x]	29.6 N, 82.4 W	8b/10	4.0	139	119	60	98	610	5.5
Soil type: Millhopper series; loamy, siliceous, and semi-active (USDA NRCS 1999)									
Southeastern[w]	29.8 N, 81.2 W	9b/10	3.7	132	9	18	42	330	5.4
Soil type: Ankona series; sandy, siliceous, and hyperthermic (USDA NRCS 1999)									

[z] USDA Cold Hardiness Zone and American Horticulture Society Heat Zone, respectively.

[y] North Florida Research and Education Center, Quincy (Gadsden County).

[x] University of Florida campus, Gainesville (Alachua County).

[w] Indian River Research and Education Center, Ft. Pierce (St. Lucie County).

Conversion: (kg/ha) • 0.89 = lb/ac

Figure 1. Gaillardia pulchella planting locations and seed sources in Florida and Texas.

chosen at random and planted at each site on 5 April 2005. To aid establishment, plants were watered as needed for 2 wk by drip (northwestern and northern central Florida) or canal irrigation (southeastern Florida). After plants were established, supplemental irrigation was stopped. No fertilizers or pesticides were applied at any time after transplanting. Plots were hand weeded as needed.

Site Conditions

This study was conducted at 3 sites in Florida (Table 2, Figure 1). Sites were prepared by tilling the soil and covering rows with black landscape fabric (Synthetic Industries, Alto, Georgia). Daily rainfall, minimum and maximum temperatures, and solar radiation were recorded at each site by Florida Automated Weather Network (FAWN) monitoring stations located at or near the sites. Soil samples (one per site) were submitted to A&L Southern Agricultural Laboratories (Pompano Beach, Florida) for elemental analysis; each sample was a composite collected on 5 April 2005 from 3 locations per site.

Plant Growth and Development

Height and width were measured at the time of planting (week 0), week 10, week 17, and at the end of the study (week 22). Height and width were recorded on week 10 because all plants at all sites were at or very near peak flowering based on the authors' visual observations. Plants were at or very near a second peak flowering on week 17, so height and width data were recorded again. Height (H) was measured from the soil level to the highest vegetative point. Mean plant width was determined by measuring widths at the widest vegetative point of the plant passing through the center (W1), and perpendicular to W1 (W2); these widths were added and the sum divided by two. Height and width data were used to determine a growth index (GI), which was calculated as ([W1 + W2]/2 + H)/2; GI is commonly used as an indicator of plant size. At week 10, one plant per seed source from each block was selected at random and harvested to determine shoot dry weight. Stems were severed at soil level and then dried at 70 °C (158 °F) for 1 wk.

Vigor, flowering, and quality of each plant were visually evaluated biweekly for the duration of the study (22 wk). Vigor was rated on a scale from 1 to 3 (increments of 1), with 1 = low vigor, 2 = medium vigor, and 3 = high vigor. Plants with high vigor were those in which the production of new growth outpaced the development of dead or dying foliage. Plants with medium vigor were characterized by maintenance growth, that is, production of new growth about equaled the development of dead or dying foliage. Plants with leaves dying faster than new ones were being produced were rated as low vigor. Flowering was rated on a scale from 0 to 3 (increments of 1), with 0 = no flowers present, 1 = 1 to 3 fully open flowers, 2 = more than 3 flowers, but the fraction of the plant covered in open flowers did not exceed one-third, and 3 = greater than one-third of the plant was covered in open flowers. An open flower was defined as one with fully extended ray florets. Quality was rated on a scale of 1 to 3 (increments of 1), with 1 = low quality, 2 = medium quality, and 3 = high quality. A high rating was assigned to plants that were at or near peak flowering and had a medium or high vigor rating. If a plant had a medium or high vigor rating but had fewer flowers, or had disease or pest problems, the plant was rated as medium. A low rating was assigned to plants that were small or unattractive and had few or no flowers. Plants with a low quality rating would be considered unacceptable for a cultivated landscape.

Experimental Design

The experiment was a 3 (site) x 5 (seed source) factorial with restricted randomization. At each site, seed sources were assigned to plots in a randomized block design. Data were analyzed using mixed model methods. The random effects were blocks-within-sites, and block-by-seed source within sites. The fixed effects were sites and seed source. Means were separated using least squares means (with PDIFF option) as part of the mixed model analyses (SAS 1999); P values were adjusted using the Tukey method when sample sizes were equal, and by the Tukey-Kramer method when sample sizes were unequal (by default in SAS Release 8.01 [SAS 1999]). Survival data were arc-sine transformed prior to analysis. Although home region advantages would be indicated by significant site x seed source interactions, a true measure of a home site advantage would

TABLE 3

Mixed model analysis of plant growth indices for 5 Gaillardia pulchella *seed sources planted in northwestern, northern central, and southeastern Florida.*

Factor		Growth index			
		Week 0[z]	Week 10	Week 17	Week 22
SEED SOURCE					
	Northeast Florida	25 abc[y]	63 a	79 a	80 a
	Central west Florida	26 ab	60 a	63 b	——[x]
	Central east Florida	22 c	53 b	67 ab	68 b[w]
	Southeast Florida	23 bc	58 ab	65 b	68 b[w]
	East Texas	27 a	63 a	79 a	80 a
SITE					
	Northwestern	22 b[v]	68 a[v]	87 a[y]	84 a[y]
	Northern central	24 b	65 a	77 b	81 a
	Southeastern	27 a	46 b	47 c	——[x]
	Effect	*Pr > F*	*Pr > F*	*Pr > F*	*Pr > F*
	Seed source	0.0021	< 0.0001	0.0008	0.0044
	Site	0.0122	0.0008	< 0.0001	< 0.0001
	SS x Site	0.4035	0.0573	0.2500	0.8022

[z] Growth index = ([W1 + W2]/2 + H)/2, with H = height measured from the soil level to the highest vegetative point, W1 = width at the widest vegetative point of the plant passing through the center, and W2 = width perpendicular to W1.

[y] Seed source or site means with different letters within a column are significantly different ($P \leq 0.05$) as determined by least squares means when adjusted by the Tukey-Kramer method.

[x] Non-estimable mean due to plants not surviving.

[w] East Texas plants were significantly different than southeast Florida plants ($P = 0.0407$) but similar to central east Florida plants ($P = 0.0638$); means adjusted by the Tukey-Kramer method.

[v] Site means with different letters within a column are significantly different ($P \leq 0.05$) as determined by least squares means when adjusted by the Tukey method.

have required long-term measures of fitness—seed production, recruitment, and survival (Rogers and Montalvo 2004).

RESULTS AND DISCUSSION

Site Conditions

At planting, soil at the northwestern Florida site had relatively high K, Mg, and Ca as compared with the other 2 sites, especially the southeastern Florida site (Table 2). Soils were acidic at all 3 sites but the least acidic was in northwestern Florida. Nitrogen levels and percentage of organic matter were similar among the 3 sites. Southeastern Florida was subjected to frequent rain from 1 June through 3 July (Figure 2). During that period, measurable rain occurred on 22 of the 33 d, totaling 32 cm (13 in), which was 46 to 66% more than received at that time in northern central and northwestern Florida, respectively. The frequency and quantity of rain resulted in flooding at the southeastern Florida site in late June and early July. Minimum temperatures tended to be higher in southeastern Florida, especially during the first half of the study (Figure 2), resulting in higher average temperatures as compared with the other 2 sites. While the mean monthly maximum temperatures were similar among sites, daily solar radiation tended to be higher in northwestern Florida for several weeks during the first half of the study (Figure 2).

Growth

Growth index (GI) was affected by seed source and site, without a significant interaction (Table 3). The lack of a significant interaction showed that home region failed to cause plants to grow larger. The largest plants were from northeast Florida and east Texas as throughout the study their GIs were equal to or greater than the plants from other seed sources (Table 3). Com-

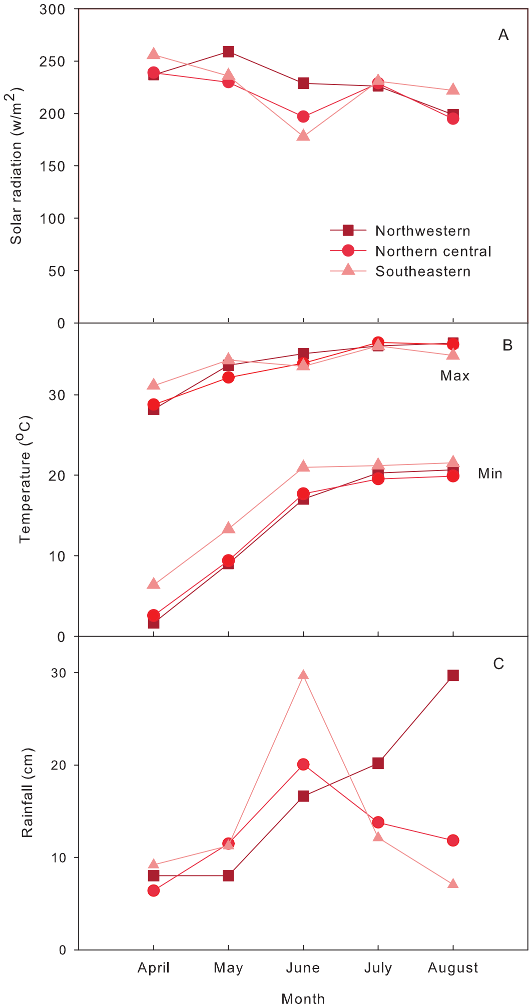

Figure 2. Monthly average total daily solar radiation (A), average maximum and minimum daily temperatures (B), and total of rainfall (1 in = 2.54 cm) (C) from first planting date (5 April 2005) to last evaluation date (9 September 2005) at the northwestern, northern central, and southeastern Florida planting sites.

pared with plants from northeast Florida and east Texas, central east Florida and southeast Florida plants tended to be smaller, whereas central west Florida plants were intermediate in size (Table 3). With regard to site, plants grew more in northwestern Florida and (or) northern central Florida than in southeastern Florida (Table 3). Plants, especially in northwestern and northern central Florida, were much larger than those growing in the wild. Under natural conditions, *G. pulchella* can be up to 61 cm (2 ft) tall (Taylor 1992) and equally wide (Wunderlin 2005), which results in a GI of 32: ([61 + 61]/2 + 61)/2. In our study, plants had GIs that were up to 2.5 times greater than noted for plants in the wild (Table 3). Even in southeastern Florida, where it rained for 11 of the 17 d (total = 24.9 cm [9.8 in]) prior to week 10, the mean GI of plants at week 10 was still 66% higher that of plants in the wild. The larger plant size was probably due to the lack of weed competition and the use of transplants that had been well-fertilized prior to planting. Lack of weed competition

TABLE 4

Mixed model analysis of plant dry weight (g) for 5 Gaillardia pulchella *seed sources planted in northwestern, northern central, and southeastern Florida. Data were collected at week 10 when plants were at peak flowering.*

Seed source	Northwestern	Northern central	Southeastern
Northeast Florida	347[z] A[y]a[x]	190 Aab	121 Ab
Central west Florida	344 Aa	237 Aab	122 Ab
Central east Florida	122 Ba	238 Aa	98 Aa
Southeast Florida	339 Aa	273 Aab	98 Ab
East Texas	306 Aa	234 Aa	134 Aa

Effect	*Pr > F*
Seed source	0.0022
Site	0.0188
SS x Site	0.0006

[z] Means: 1 plant per seed source for each of 3 blocks (replications) per site.

[y] Seed source means within a site with different uppercase letters are significantly different ($P \leq 0.05$) as determined by least squares means when adjusted by the Tukey-Kramer method.

[x] Site means within a seed source with different lowercase letters are significantly different ($P \leq 0.05$) as determined by least squares means when adjusted by the Tukey-Kramer method.

and use of well-fertilized transplants would be a typical scenario for plants used in landscapes. Interestingly, Nelson (2003) noted that under landscape conditions, the expected size of *G. pulchella* would be 30 to 61 cm (1 to 2 ft) tall and 30 to 61 cm (1 to 2 ft) wide. Our results clearly showed that even under low-input landscape conditions *G. pulchella* was larger than that. Because the frequent rains in northwestern Florida occurred after week 17 (Figure 2), the relatively high GIs in northwestern Florida, as well as northern central Florida, were likely due to the loamy soil.

Shoot dry weight at first peak flowering (week 10) was affected by a significant seed source x site interaction, in contrast to growth index (Table 4). The presence of a significant interaction effect, however, failed to provide any clear evidence of a home region advantage. For example, in southeastern Florida (which was near the southeast Florida seed source; Table 1, Figure 1), shoot dry weight for southeast Florida plants was similar to plants of all other seed sources, and at the 2 northern sites, shoot dry weights of southeast Florida plants were the same as that for northeast Florida plants (Table 4). Furthermore, mean shoot dry weights of east Texas plants at all sites were as high as plants from Florida seed sources. Averaged over all seed sources, shoot dry weight of plants installed in northwestern (292 g [10.3 oz]) or northern central Florida (235 g [8.3 oz]) was significantly greater than that for plants grown in southeastern Florida (113 g [4.0 oz]) ($P \leq 0.05$). Shoot dry weight of central east Florida plants (153 g [5.4 oz]), pooled over all sites, was about 1.5 times less than that of plants from other seed sources (219 to 237 g [7.7 to 8.4 oz], respectively), but variability in shoot dry weight data precluded detection of any significant differences ($P < 0.0523$ to $P < 0.1774$).

Vigor, Flowering, and Quality

Averaged over the course of the study, plant vigor was affected by seed source and site but a significant interaction was lacking (Table 5). The absence of an interaction indicated that home region failed to improve plant vigor. Plants of all seed sources, except those of central east Florida, had equally high vigor; central east Florida plants were slightly less vigorous. Plants grown in southeastern Florida were less vigorous than those grown in northwestern or northern central Florida (Table 5). When examining biweekly changes in vigor, ratings within a site were similar among seed sources (Figure 3). Vigor of plants grown in northwestern Florida did not decline much until weeks 20 and 22. In southeastern Florida, however, plant vigor decreased sharply between weeks 12 and 14 and then leveled off. This sharp decline coincided with the flooding that occurred in southeastern Florida in late June and early July. As a result of this decline, vigor ratings pooled over the entire study were lower in southeastern Florida as compared with the two northern sites. In northern central Florida on week 14, vigor of northeast Florida plants was higher than that of central east Florida plants ($P < 0.05$), although vigor of central east Florida plants was similar to that of plants of the other seed sources. By week 20 in northern central Florida, vigor of northeast Florida and central west Florida plants was greater than that of central east Florida plants ($P < 0.05$), but at the end of the study only vigor of central west Florida plants was greater than that of central east Florida plants. Plant vigor ratings among seed sources within a site were similar at any time in northwestern or southeastern Florida.

Flowering was affected by seed source and site but a significant interaction was absent, which again showed the lack of a

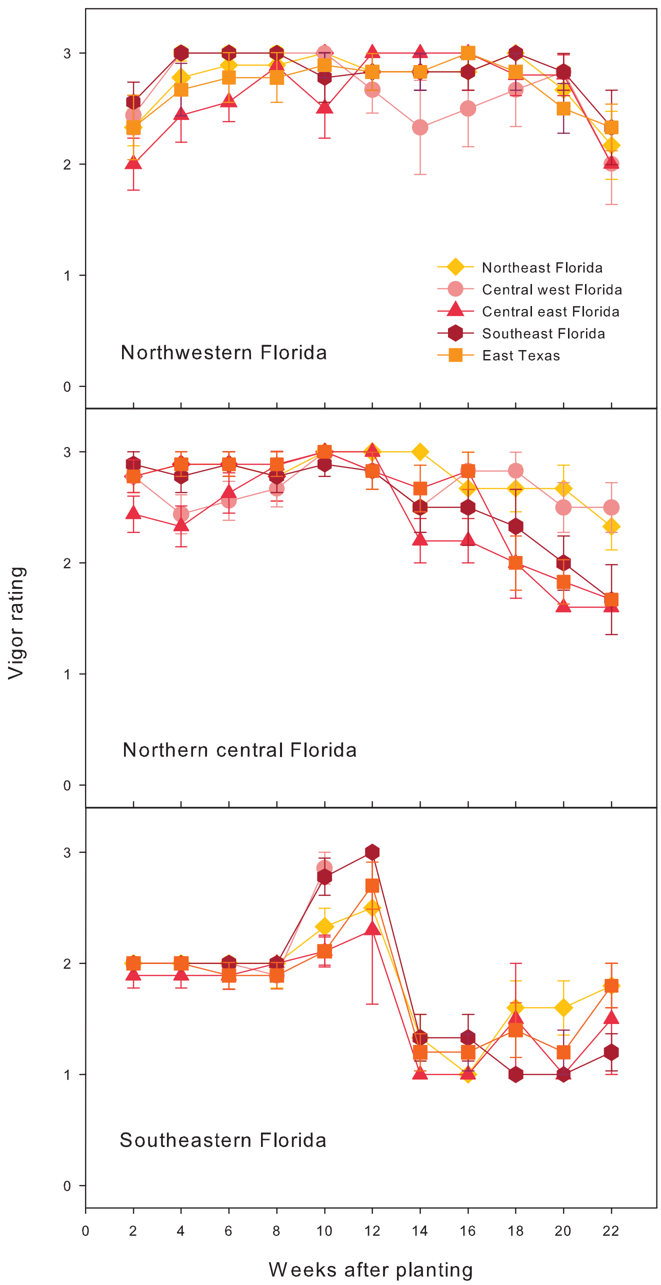

Figure 3. Biweekly plant vigor ratings of 5 *Gaillardia pulchella* seed sources (northeast Florida, central west Florida, central east Florida, southeast Florida, and east Texas) planted in northwestern, northern central, and southeastern Florida. Ratings were based on a scale of 1 to 3, with 1 = low vigor, 2 = medium vigor, and 3 = high vigor. NOTE: For central west Florida plants in southeastern Florida, results for week 12 and later were excluded because only 2 live plants were present on weeks 12 and 14, only one by week 16, and all plants died after that.

TABLE 5

Mixed model analysis of plant vigor, flowering, and quality pooled over the entire study for 5 Gaillardia pulchella *seed sources planted in northwestern, northern central, and southeastern Florida.*

Factor	Vigor[z]	Flowering[y]	Quality[x]
SEED SOURCE			
Northeast Florida[w]	2.5 a[v]	1.8 ab[v]	2.2 a[v]
Central west Florida	2.5 a	1.7 ab	2.1b
Central east Florida	2.2 b	1.6 b	1.9 c
Southeast Florida	2.5 a	1.9 a	2.1 ab
East Texas	2.4 a	1.9 a	2.1 ab
SITE			
Northwestern	2.7 a	1.9 a	2.1 b
Northern central	2.6 a	1.8 a	2.2 a
Southeastern	1.9 b	1.6 b	2.0 b
Effect	*Pr> F*	*Pr> F*	*Pr> F*
Seed source	0.0003	0.0005	< 0.0001
Site	< 0.0001	0.0012	< 0.0001
SS x Site	0.1757	0.4690	0.7232

[z] Vigor was rated on a scale of 1 to 3 (increments of 1), with 1 = low vigor, 2 = medium vigor, and 3 = high vigor; see section on materials and methods for a detailed description of the ratings.
[y] Flowering was rated on a scale from 0 to 3 (increments of 1), with 0 = no flowers present, 1 = 1 to 3 fully open flowers, 2 = more than 3 flowers, but the fraction of the plant covered in open flowers did not exceed one-third, and 3 = greater than one-third of the plant was covered in open flowers.
[x] Quality was rated on a scale of 1 to 3 (increments of 1), with 1 = low quality, 2 = medium quality, and 3 = high quality; see section on materials and methods for a detailed description of the ratings.
[w] Seed source or site means with different letters within a column are significantly different ($P \leq 0.05$) as determined by least squares means when adjusted by the Tukey-Kramer method.
[v] Mean quality rating of northeast Florida plants (2.22) was significantly greater than that for central west Florida plants (2.07) but not that of southeast Florida (2.14) or east Texas (2.09) plants after the Tukey-Kramer adjustment of *P* values.

home region advantage (Table 5). Like vigor, flowering of plants from all seed sources, except central east Florida plants, was rated equally high. However, flowering of central east Florida plants was rated only slightly lower than that of southeast Florida and east Texas plants. The patterns of biweekly trends in flowering over time were generally similar within a site (Figure 4). One notable exception was that flowering of east Texas plants was rated significantly greater than flowering of plants of all other seed sources at all 3 sites on week 4 ($P \leq 0.05$). In addition, flowering of southeast Florida and east Texas plants on week 6 was rated higher than that of plants of the other 3 seed sources ($P \leq 0.05$). As with vigor ratings, decline in flower ratings of plants grown in southeastern Florida coincided with flooding.

Plant quality ratings were affected by ecotype and site, but a significant interaction was lacking. Averaged over the entire study, northeast Florida, southeast Florida, east Texas, and central west Florida plants were rated similarly, but central east Florida plants were rated lower than plants of all other seed sources (Table 5). Quality was rated highest for plants grown in northern central Florida, but quality was only slightly greater than that of plants grown at the other 2 sites. In general, biweekly trends in quality were similar among seed sources within a site over time (Figure 5), but a few exceptions were observed. In northwestern Florida on week 10 (first peak flowering), mean quality of northeast Florida plants was rated higher than all but that of east Texas plants ($P \leq 0.05$); central east Florida plant quality was rated lower than that of northeast Florida and east Texas plants. On week 14 in northern central Florida, mean quality of northeast Florida plants was higher than all but southeast Florida plants ($P \leq 0.05$). In southeastern Florida, mean quality of central east Florida plants was lower than that of plants of all other seed sources (except central west Florida plants, all of which were dead) on weeks 14 and 16 ($P \leq 0.05$). Decline in quality ratings in southeastern Florida coincided with flooding.

Survival

Seed source affected survival rate but a significant seed source x site interaction also influenced survival (Table 5). Sur-

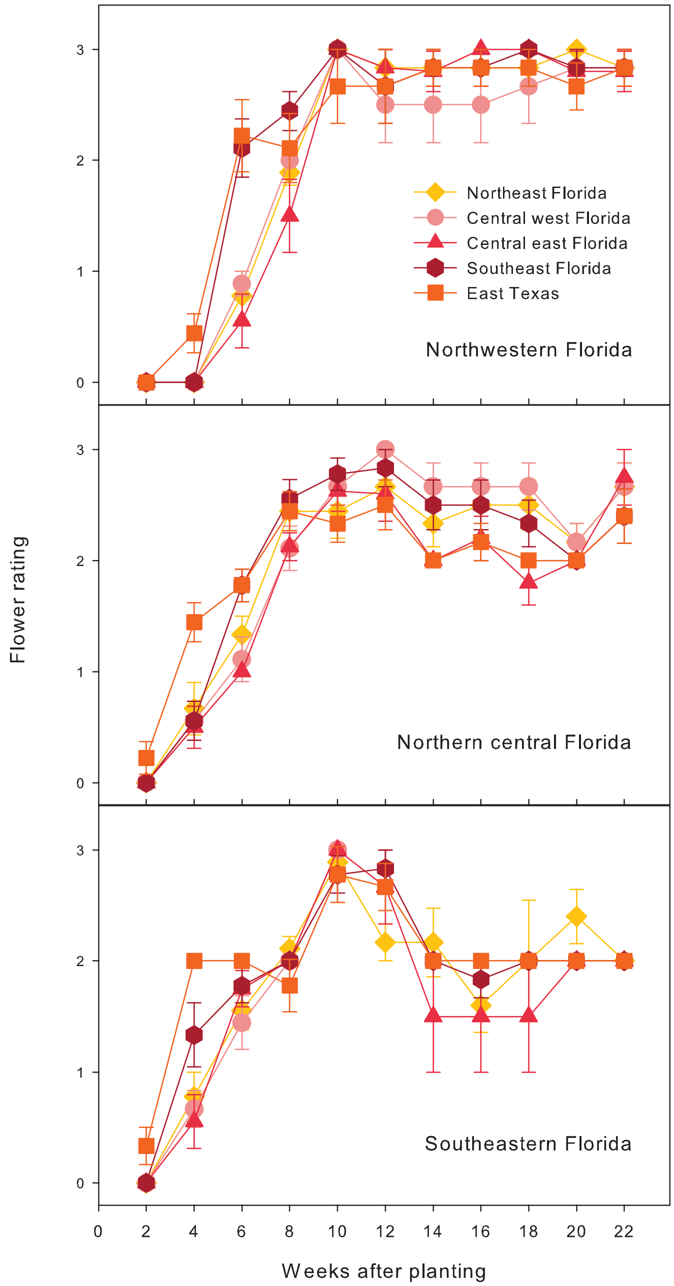

Figure 4. Biweekly flower ratings of plants of 5 *Gaillardia pulchella* seed sources (northeast Florida, central west Florida, central east Florida, southeast Florida, and east Texas) planted in northwestern, northern central, and southeastern Florida. Flowering was rated on a scale from 0 to 3 (increments of 1), with 0 = no flowers present, 1 = 1 to 3 fully open flowers, 2 = more than 3 flowers, but the fraction of the plant covered in open flowers did not exceed one-third, and 3 = greater than one-third of the plant was covered in open flowers. NOTE: For central west Florida plants in southeastern Florida, results for week 12 and later were excluded because only 2 live plants were present on weeks 12 and 14, only one by week 16, and all plants died after that.

TABLE 6

Mixed procedure analysis of plant survival (%) of 5 Gaillardia pulchella *seed sources grown in northwestern, northern central, and southeastern Florida for 22 weeks.*

Seed source	Northwestern	Northern central	Southeastern
Northeast Florida	100[z] A[y]a[x]	100 Aa	83 ABa
Central west Florida	100 Aa	100 Aa	0 Cb
Central east Florida	83 Ba	67 Aa	33 BCa
Southeast Florida	100 Aa	83 Aa	100 Aa
East Texas	100 Aa	83 Aa	83 ABa

Effect	*Pr > F*
Seed source (SS)	0.0027
Site	0.0559
SS x Site	0.0021

[z] Arc-sine transformed data were used for mean separation. Values shown are original percentage of survival.

[y] Seed source means within a site with different uppercase letters are significantly different ($P \leq 0.05$) as determined by least squares means when adjusted by the Tukey-Kramer method.

[x] Site means within a seed source with different lowercase letters are significantly different ($P \leq 0.05$) as determined by least squares means when adjusted by the Tukey-Kramer method.

vival of northeast Florida, southeast Florida, and east Texas plants was about the same at each site (83% or 100%), but all central west Florida plants died when grown in southeastern Florida despite 100% survival of central west Florida plants at the other 2 sites (Table 6). Survival of central east Florida plants appeared to differ among sites, but high variability in survival rates was too high for detection of significant differences. Variability in survival also precluded detection of a significant site effect ($P < 0.0559$). Despite the significant interaction, consistent evidence of home region improving survival was absent. For example, survival of southeast Florida plants grown in southeastern Florida was similar to that of northeast Florida or east Texas plants, and in northwestern and northern central Florida, plant survival of all seed sources was equally high. Interestingly, survival of east Texas plants in southeastern Florida was greater than that of plants from central west Florida.

CONCLUSIONS

Under the low-input landscape conditions of this study, a short-term home region advantage likely was absent for *G. pulchella*, especially given that plants from Texas performed as well as plants derived from Florida seed sources. Adaptability of east Texas plants was comparable with central east Florida, northeast Florida, and southeast Florida plants within the different growing sites. Growth, vigor, flowering, and quality of central west Florida plants usually were similar to that of plants of other sources within a site; however, central west Florida plants were intolerant of southeastern Florida conditions. As previously mentioned, Norcini and others (1998) observed a home region advantage for plants of *G. pulchella* derived from a north Florida seed source—north Florida plants had 100% survival under low-input landscape conditions but plants from a commercial seed producer in Texas did not survive past mid-August. While information about the original seed origin of Texas seed was unavailable, *G. pulchella* being grown for seed at the commercial operation likely had been subjected to some selection process for desirable traits. At the very least, the diversity of that commercial seed was probably less than the east Texas seed used in the current study, and hence plants grown from the commercial seed in the 1998 study might have been less adaptable than plants of east Texas.

The poor survival of central west Florida plants and lower overall vigor and quality ratings of central east Florida plants might have resulted from biparental inbreeding depression (Heywood 1993). *Gaillardia pulchella* is a self-incompatible, obligate outcrosser (Stoutamire 1977) that is pollinated by nearest-neighbor nonspecialist insects (Heywood 1986a). The central west Florida and central east Florida populations possibly had limited genetic diversity and possibly were isolated enough from other *G. pulchella* populations to preclude gene flow into these populations, resulting in a gradual decline of offspring due to inbreeding depression. Heywood and Levin (1984) concluded that geographic distance among *G. pulchella* populations was correlated with genetic distance, therefore gene flow among populations would decrease the farther apart they were. Hence, at

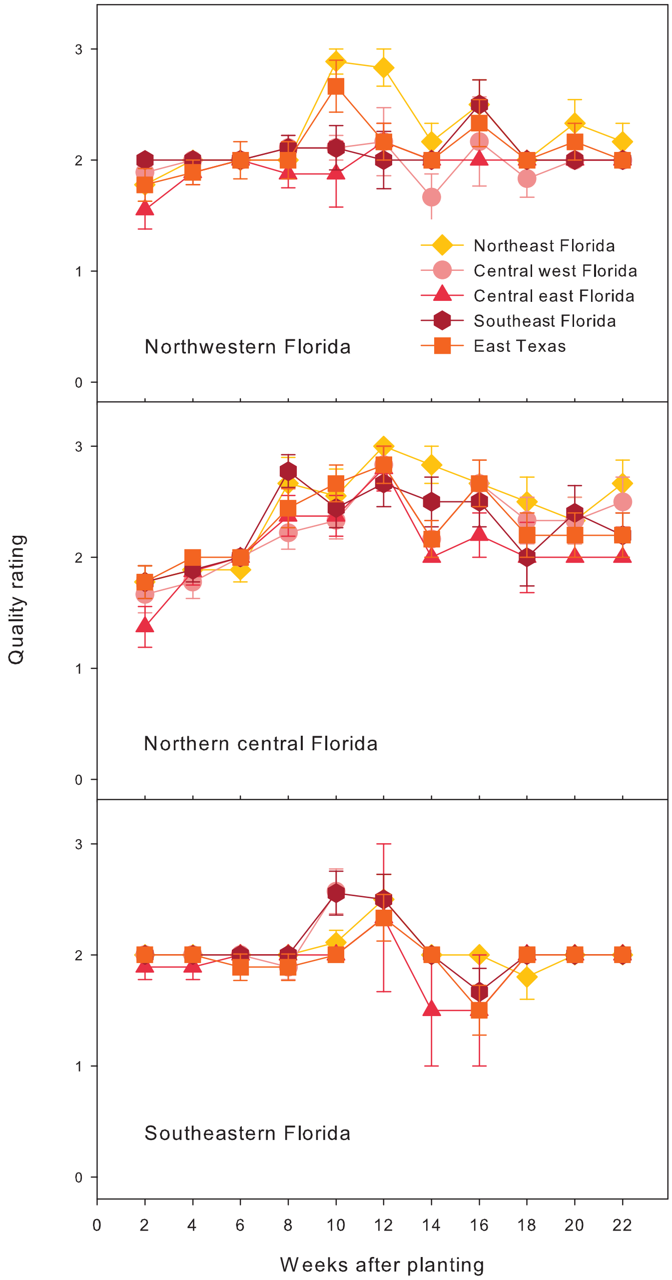

Figure 5. Biweekly plant quality ratings of 5 *Gaillardia pulchella* seed sources (northeast Florida, central west Florida, central east Florida, southeast Florida, and east Texas) planted in northwestern, northern central, and southeastern Florida. Ratings were based on a scale of 1 to 3, with 1 = low quality, 2 = medium quality, and 3 = high quality. NOTE: For central west Florida plants in southeastern Florida, results for week 12 and later were excluded because only 2 live plants were present on weeks 12 and 14, only one by week 16, and all plants died after that.

least some central west Florida and central east Florida plants used in this study might have been relatively unfit. Rogers and Montalvo (2004) noted that seeds sown under nursery conditions "might . . . allow germination of . . . less fit individuals."

Care should be taken when collecting seeds from natural populations of *G. pulchella*, given that biparental inbreeding depression is a concern. While determining the fitness of a population is difficult, those collecting seeds for producing landscape plants or for seed increasing, or to apply directly on a restoration site, should consider population size, variability within the population, and proximity to other populations of *G. pulchella*. A good choice for seed collection would be from a population that exhibited a high degree of variation in flower color and that was in view of another population. Collectors should avoid gathering seeds of *G. pulchella* from small, isolated populations that have very uniform individuals as offspring might be relatively unfit. Geographic distance between seed source and outplanting site would seem to be less of an issue for residential or commercial landscape plantings based on the results of our study—northeast Florida, southeast Florida, and east Texas plants grew equally well at all sites. However, if preserving the genetic integrity of local populations was a concern, as might be the case in landscape plantings at visitor centers in state and national parks and forests, or a restoration planting, geographic distance between seed source and outplanting site would be a very important consideration.

Finally, only short-term performance and home region effects were evaluated in this study, and long-term growth is unknown. While plants of 3 of the *G. pulchella* seed sources, east Texas, northeast Florida, and southeast Florida, seemed to be highly adaptable, the true measure of their adaptability would be their ability for "reproduction and recruitment" (Kalmbacher and others 2004) in a more competitive situation. Reproduction and recruitment must be considered when assessing long-term site adaptation of *G. pulchella* since it is an annual to short-lived perennial (Taylor 1992; Wunderlin 2005) that must rely on reproduction and recruitment for the population to be sustainable.

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