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1 **Response to selection in the initial stages of a perennial sorghum breeding program**

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26 **Abstract**

27 When developed, perennial grain sorghum could provide an opportunity for more ecologically
28 sound food production. In 2002, we initiated a perennial sorghum breeding program, using
29 *Sorghum bicolor* (L.) Moench X *S. halepense* (L.) Pers. populations. In 2011-13, we evaluated
30 27 breeding lines from three stages of the program in field experiments to estimate response to
31 selection during the program's first seven years for perenniality and more domesticated
32 phenotype. Regression analysis of mean grain yield and single-grain weight on breeding cycle
33 (0, 1, 2) indicated a significant increase in each of the seeded experiments and for means over all
34 years. For winter survival index, the regression coefficient was small but significant and negative
35 in 2011, while non-significant in 2012. Grain yield was not significantly correlated with survival
36 index, while single grain weight was significant and negatively correlated with survival index,
37 with $r = -0.4923$. We conclude that combined selection for perenniality, a more domesticated
38 phenotype, adaptation, greater grain size, and higher grain yield can result in progress in
39 breeding perennial sorghum.

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47 **Key words:** grain yield; rhizomes; single grain weight; *Sorghum bicolor*; *Sorghum halepense*;
48 survival index

49 **Introduction**

50 Higher crop yields observed since the start of the Green Revolution resulted from development
51 of new grain cultivars with annual growth habit, along with widespread use of irrigation and
52 extensive application of fertilizers, herbicides, and pesticides. Yields from these conventional
53 farming systems may have already reached their peak ([Gressel 2008](#); [Foley et al. 2011](#); [de Ribou
54 et al. 2013](#)), and may decline further as agricultural regions experience continued soil
55 degradation associated with annual cropping systems ([Glover et al., 2010](#)).

56 Replacing annual cereal, grain legume, and oilseed crops with improved long-lived
57 perennial crops that produce similar products holds potential not only for increasing food
58 security, but also for enhancing environmental stability and ecosystem resilience ([Cox et al.
59 2006](#); [Crews 2005](#); [DeHaan et al. 2005](#); [Glover et al. 2010](#); [Piper and Kulakow 1994](#); [Ridley et
60 al. 2001](#); [Sacks et al. 2006](#)). Among the potential benefits of using perennial crops over annual
61 versions is their ability to improve water quality, reduce soil erosion, conserve soil organic
62 matter, and reduce reliance on fertilizers and tillage operations ([Glover et al. 2010](#)). However,
63 perennial, grain-producing crop species currently exist only in the development stage, and much
64 genetic research and breeding remains to be done before perennial grain crops can be deployed
65 in agriculture ([Batello et al. 2014](#)).

66 Inasmuch as agricultural crops are grown for unique characteristics, two major traits are
67 of primary importance in determining user acceptability and utilization: grain yield and
68 individual grain size ([Cox et al. 2006](#); [Gepts 2004](#)). It has been proposed that during evolution,
69 maximizing fitness required that different hierarchies of phenotypic plasticity be developed,
70 leading to a tradeoff between seed production and vegetative propagation ([Bradshaw 1965](#);
71 [Sadras 2007](#); [Westoby et al. 1992](#)). Were it to exist, such a tradeoff would lead to predictions that

72 plants are more likely to die after reproducing as observed in annuals ([Law 1979](#)) and that in
73 perennials, large reproductive output in one year would be negatively correlated with growth and
74 survival that year or in the following year ([Sohn and Policansky 1977](#)). Although grain yields
75 and sizes of wild perennial crop species are smaller than those of annual crops ([Piper and](#)
76 [Kulakow 1994](#); [Cox et al. 2006](#); [Moffat 1996](#)), this contrast is not evidence for a physiological
77 tradeoff. Rather, it is a trend observed among species produced by natural selection pressures on
78 the one hand and artificial selection carried out in a properly managed agricultural environment
79 on the other hand. It has been shown that the latter type of selection can increase seed yield in
80 perennial crop populations without negative effects on perenniality or other characters; given
81 that, it is argued, artificial selection has the potential to generate perennial crops with acceptable
82 yields, if applied to seed yield and perennial growth habit simultaneously ([DeHaan et al. 2005](#);
83 [Moffat 1996](#)).

84 In an effort to develop perennial sorghum, The Land Institute has generated tetraploid
85 sorghum populations derived from crosses involving a range of *Sorghum bicolor* (L.) Moench
86 and *S. halepense* (L.) Pers. parents, the aim being to combine high seed yield with overwintering
87 ability via rhizome production. Grain sorghum, which belongs to *S. bicolor*, is a diploid ($2n = 2x$
88 $= 20$) annual species ([Ellstrand and Foster 1983](#); [Doggett 1988](#)). It is one of the world's most
89 important crops based on area sown and production ([FAO 1993](#)). *S. halepense* is a tetraploid ($2n$
90 $= 4x = 40$) perennial that reproduces by both sexual and vegetative means ([Warwick and Black](#)
91 [1983](#)). It is reported to be one of the world's ten most important weeds ([Holm et al. 1977](#)) and
92 has disseminated naturally worldwide. Grain sorghum hybridizes with *S. halepense*, often called
93 johnsongrass, under field conditions ([Baker 1972](#); [Arriola and Ellstrand 1996](#)). Making *Sorghum*

94 *bicolor* X *S. halepense* crosses by hand is facilitated by using a diploid male-sterile or induced
95 tetraploid grain sorghum plant as the female parent ([Hadley 1958](#); [Piper and Kulakow 1994](#)).

96 Rhizomes and perenniality are considered ancestral and fundamentally related traits in
97 monocots and grasses ([Dahlgren et al. 1985](#)). Production of rhizomes is the sole means by which
98 *S. halepense* and *S. bicolor* X *S. halepense* plants can survive year to year in temperate climates
99 with cold winters ([Piper and Kulakow 1994](#)). Rhizomes are absent in *S. bicolor*. Numerous
100 chromosomal regions affecting rhizome development and perennial growth habit have been
101 mapped in *Sorghum* interspecific crosses ([Paterson et al. 1995](#); [Hu et al. 2003](#)); clearly,
102 perenniality in this genus is a quantitative trait.

103 By crossing the two species, backcrossing to *S. bicolor*, and selecting for winter survival,
104 we have developed perennial progenies with phenotypes intermediate between those of the
105 parental species. We have not previously evaluated trends in perenniality and grain production
106 under selection during the initial years of this perennial sorghum development program, nor have
107 relationships between perenniality and grain production previously been examined in *S. bicolor*
108 X *S. halepense* populations. Understanding of these mechanisms is crucial when defining new
109 criteria for selection in perennial grains. In this paper we examine (1) the response of grain yield,
110 single grain weight, and survival in *Sorghum bicolor* X *S. halepense* populations to selection for
111 a more domesticated perennial phenotype, and (2) the relationship between survival index and
112 the traits grain yield and single grain weight. The overall goal was to determine whether progress
113 was made in the first seven years of the perennial sorghum breeding program and whether
114 associations exist between degree of perenniality and productivity traits.

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116

117 **Materials and Methods**

118 **Germplasm**

119 The perennial parents of the breeding line used in this study were derived from populations
120 developed at The Land Institute, Salina Kansas, USA, during the period 1984–94 by self-
121 pollinating hybrids between *S. bicolor* and *S. halepense* (Piper and Kulakow, 1994). The
122 institute’s current perennial sorghum selection program commenced in 2002 when crosses were
123 made between *S. bicolor* inbred lines and perennial plants selected from two bulk seed lots taken
124 from storage, each of which was made up of an unknown number of the 1984–94 populations.
125 Although the parents of those populations belonged to *S. bicolor* and *S. halepense*, the identities
126 of the specific parental accessions are unknown.

127

128 **Population development**

129 In 2002-04, a large number of crosses were made between diploid, annual, male-sterile inbred
130 lines of *S. bicolor* and perennial tetraploid plants drawn from the populations described in the
131 preceding paragraph. Both nuclear and nuclear-cytoplasmic male-sterile *S. bicolor* lines were
132 used in making crosses. A yield trial comprising a total of 400 F₂-derived lines in the F₃ from 17
133 of those annual X perennial parental combinations was conducted in the summer of 2005, and
134 approximately 300 plants that survived through the following winter were preserved and self-
135 pollinated in the summer of 2006. In subsequent years, many of these plants were selfed,
136 intercrossed, crossed with perennial plants from the original population, and/or crossed with a
137 range of *S. bicolor* inbred lines. Progenies of these crosses were evaluated in 2008, and surviving
138 plants were selected in the spring of 2009. We refer to the perennial plants used as parents in the
139 2002-04 crosses as cycle 0, and we refer to the winter-hardy plants selected in the field in the

140 spring of 2006 and 2009 as cycles 1 and 2, respectively. After field evaluation of selfed
141 progenies of plants from cycles 0 through 2 in 2010, six lines from cycle 0, six from cycle 1, and
142 fifteen from cycle 2 (Table S1) were selected for this study. Lines were selected that had the
143 most crop-like, least “wild” overall phenotype among the lines in their cycle. That is, we selected
144 those having less profuse tillering and nodal branching, less shattering, denser panicles, and
145 larger individual grains than other lines from their selection cycle. We had less information
146 available—only one year of observation— on which to base selections from cycle 2 than on
147 which to base selections from the other cycles; therefore, we included a larger number of lines
148 from cycle 2 to ensure that we were including superior lines from that cycle.

149

150 **Experimental design**

151 Experiments were sown in late May in 2011, 2012, and 2013. They included the above 27 lines
152 from the three selection cycles along with a local accession of *S. halepense* designated Gypsum 9
153 and a local commercial grain sorghum hybrid, ‘Phillips 664’. Each experiment was sown on The
154 Land Institute’s research farm on the south edge of Salina, Kansas (lat. 38.84° N, long. 97.61°
155 W, elev: 373 m) in montmorillonitic, mesic pactic Argiustoll soils (Soil Survey of Saline County,
156 Kansas, 1992). In 2011 and 2012, seeds were sown in plot areas that had been under fallow for at
157 least eighteen months. The experiments were conducted using a randomized complete-block
158 design (RCBD) with four replicates. Experimental units were single 3 m rows. Because the
159 genotypes used in the study varied greatly in height and growth pattern, we provided a common
160 border by sowing experimental rows alternately with rows of the grain sorghum hybrid ‘Phillips
161 664’. Rows were spaced 0.91m apart, with 1.5 m alleys between the ends of rows. Initial
162 densities were approximately 30 plants per row. To permit easier access to the perennial

163 genotypes with their tall, highly branched growth habit, the rows of ‘Phillips 664’ were mowed
164 at approximately flowering stage, and mowed again after they regrew and before they flowered
165 again. For both 2011 and 2012 experiments, no fertilizer and/or herbicide were used. The 2013
166 experiment was in a split-plot design with two main-plot treatments: (1) randomized plots newly
167 sown into the spaces formerly occupied by two randomly chosen replicates of the 2012
168 experiment, after removing regrowing and volunteer plants through tillage, and (2) two
169 regrowing replicates of the 2012 experiment. The subplot treatments were breeding lines,
170 referred to hereinafter as genotypes. In the 2013 experiment, we applied nitrogen fertilizer
171 primarily as urea at a rate of 34 kg/ha.

172

173 **Data collection**

174 At physiological maturity, grain was hand-harvested from all rows in each experiment. In 2013,
175 plants in the regrowing treatment began emerging in mid-May, three weeks before the newly-
176 seeded treatment was sown. The regrowing plants grew and developed rapidly, initiating
177 flowering in early July and continuing to produce new inflorescences through the summer;
178 therefore, three harvests of ripe grain, in mid-August, mid-September, and mid-October, were
179 required. Total threshed grain from each plot in each year and experiment was dried and
180 weighed. Then from each, approximately 5g sample was removed and mechanically dehulled,
181 and the hullless grain weighed. Pre-dehulling grain yield per linear meter of row (g m^{-1}) was
182 multiplied by the ratio of the corresponding small sample’s hullless grain weight to its pre-
183 dehulling grain weight to estimate grain yield. The number of seed in each hullless grain sample
184 was determined with an electronic seed counter, and mean weight of individual grains was
185 estimated as weight divided by number.

186 All genotypes under evaluation had experienced inter-row competition from the same
187 border genotype, 'Phillips 664', but that competition had varied in time; it was stronger early in
188 the season and then was reduced by mowing as the season progressed. Therefore, yield data
189 could not reasonably be extrapolated to a land-area basis; instead, we have expressed yield
190 herein as grams per linear meter (g m^{-1}) of row.

191

192 **Mulching**

193 After harvest in 2011 and 2012, two randomly chosen replicates were covered with a mulch of
194 chopped wheat straw to a depth of approximately 8 cm. The mulch was intended to insulate the
195 soil and increase overall rhizome survival and spring emergence. Winter survival in 2011-12 was
196 evaluated as number of ramets emerged per linear meter of row by April 9, 2012; in 2012-13, it
197 was estimated as the proportion of plants that produced emerging ramets by May 21, 2013 (the
198 spring of 2013 being colder, and average emergence later than in 2012). The two estimates were
199 converted to a common survival index by dividing each observed value by the mean value of the
200 entry with highest survival and then multiplying by 100.

201

202 **Data Analysis**

203 Analyses of variance for all traits were performed using JMP version 11 (SAS Institute, Inc.) in a
204 combined analysis for all years. Genotypes and cycles were specified as fixed; year and
205 replicates were considered as random effects. Changes in mean grain yield, single grain weight,
206 and survival per cycle were estimated by linear regression of cycle mean grain yields, mean
207 single grain weight and survival indices on cycle number (0, 1, 2). Regression coefficients were

208 used to estimate change per cycle in grain yield, single grain weight, and survival per cycle of
209 selection.

210 In 2013, we compared newly-sown plots with plots in their second year of growth, having
211 been sown in 2012. We performed the analysis of variance as a split-plot design with year of
212 growth as the main-plot treatment and genotypes as the subplot factor. There were two replicates,
213 with main plots and subplots randomized.

214 To determine the effect of mulch on winter survival, we compared survival indices of
215 mulched and non-mulched plots. Survival index data were analyzed as a split-plot design, with
216 mulch/no mulch as the main-plot treatment and genotypes as subplot treatment.

217 Simple correlation analyses were carried out using SAS statistical program (SAS Institute
218 version 9.1.3) to examine relationship between the survival index and the traits grain yield and
219 single grain weight.

220

221 **Results**

222 **Grain yield and single-grain weight**

223 Because high-yielding, large-seeded plants as well as winter-hardy plants occur very rarely in
224 annual x perennial sorghum populations evaluated in Kansas, very large populations must be
225 evaluated in order to identify perennial plants with even slight improved productivity.

226 Analysis of variance showed highly significant ($P < 0.01$) differences among years,
227 breeding cycles, and genotypes-within-cycles for grain yield (Table 1). Mean squares from cycle
228 x year and genotypes-within-cycles x year for grain yield were not significant, indicating that
229 relative mean yields of cycles were consistent across years. Variation among the three selection
230 cycles was further partitioned into a linear component and a residual. In each of the four

231 experiments (not shown) and in the combined analysis over years (Table 2), mean squares for the
232 linear effect of selection cycle were positive and highly significant ($P < 0.01$), indicating that
233 selection had the effect of increasing grain yield.

234 The regression coefficients in Table 2 are estimates of the mean response to selection per
235 cycle for grain yield, single grain weight, and survival index. Regression coefficients for grain
236 yield and single grain weight were significant and positive in all three years' experiments grown
237 from seed and over all years. The mean rate of gain across the three seeded experiments was 52.8
238 g m⁻¹ cycle⁻¹, indicating improvement per cycle equivalent to 56% of the cycle 0 mean. For
239 single grain weight, the highest gain, observed in 2012, was 0.97 mg cycle⁻¹ and the mean gain
240 across seeded experiments was 0.60 mg cycle⁻¹ (Table 2). For survival, the regression coefficient
241 was small and negative in 2011 and non-significant in 2012.

242 We compared cycle and check yields with those of the *S. halepense* and *S. bicolor* checks
243 in 2011, 2012, and 2013 (Table 3) and for mean grain yield over all years (Table 4). (The low
244 yields in 2012 were largely the result of an unusual early freeze the night of October 4.)
245 Consistent with the positive regression coefficients, rankings were highly consistent year to year,
246 with cycle 0 the lowest and cycle 2 the highest in every case. The significant regression
247 coefficients imply significant differences among all cycles within each year. Furthermore, mean
248 grain yields for cycle 0 were significantly ($P < 0.01$) higher than those of the *S. halepense* check,
249 Gypsum 9, and the means for cycle 2 were significantly lower ($P < 0.01$) than those of the
250 commercial *S. bicolor* hybrid 'Phillips 664' in each year. Therefore, mean grain yields and
251 single-grain weights shown (Tables 3 and 4) of the checks and all three breeding cycles differed
252 significantly within each year. The mean yield of the highest yielding line in each year averaged
253 54% of the mean yield of Phillips 664 over those years (Table 3).

254 Mean survival indices of the three selection cycles (0, 1, 2) were lower than those of
255 Gypsum 9, but the experimental line with highest survival had a higher survival index than
256 Gypsum 9 (Table 4).

257 In 2013, comparing newly-sown plots with plots in the second year of growth (i.e.,
258 having been sown in 2012 and regrowing from rhizomes in 2013), the analysis of variance
259 showed a highly significant ($P < 0.01$) linear effect of selection cycle, and a significant ($P <$
260 0.05) cycle by year interaction (Table S2). Mean grain yields of genotypes in selection cycles 1
261 and 2 in regrowth plots were not significantly lower than those of their corresponding first year
262 counterparts (Table 3). Because of the early emergence, rapid growth rate, and early flowering
263 observed in the second year of growth, plants were harvested three times, in mid-August, mid-
264 September, and mid-October, with 16 %, 37 % and 47 % of the mean total grain weight
265 harvested on the first, second and third date of harvesting, respectively.

266

267 **Survival index**

268 When we compared survival index of entries under mulch and those with no mulch, there was a
269 highly significant ($P < 0.01$) difference in winter survival for genotypes, mulch, cycles,
270 genotypes within cycle, and mulch x genotypes within cycle interaction in 2011-12 evaluations;
271 however, in 2012-13 only genotypes, mulch and genotypes within cycle were significant (Table
272 S3). Mean survival index in mulched blocks was 32 on a 1-to-100 scale, while that of non-
273 mulched was 7, and the mean survival index in nonmulched plots was zero for several individual
274 lines. Because of that, and because of the nonsignificant genotype x mulch interaction, we
275 analyzed relationships between survival index and other traits using data from mulched plots
276 only, and used the 2012 mulched plots as the “regrowing” treatment in 2013.

277 Pearson's correlation analysis showed that grain yield was not significantly correlated (r
278 = -0.2637, $P > 0.15$) with survival index, and a scatter plot shows a wide range of survival and
279 yield in all three selection cycles (Fig. 1). Single grain weight was significant and negatively
280 correlated with survival index ($r = -0.4923$, $P < 0.01$).

281

282 **Discussion**

283 Like grain yield and single-grain weight, rhizomatousness and winter survival in the genus
284 *Sorghum* are highly complex traits, affected by genetic factors on almost every chromosome pair
285 ([Paterson et al. 1995](#)). In a region with cold winters and often little snow cover, such as the U.S.
286 Central Great Plains, we find that winter-hardy perennial plants occur at very low frequencies in
287 populations derived from crosses between annual and perennial plants—even from *S. bicolor* x
288 *S. halepense* crosses. In the southern United States with its mild winters, frequency of winter
289 survival is much higher. Paterson et al., (1995), studying a population of 370 F₂ progeny derived
290 from a cross between *S. bicolor* and *S. propinquum* (a non-winter-hardy diploid perennial) and
291 grown in a field near College Station, Texas, USA (lat. 30.58° N, long. 96.36° W, elev: 97 m)
292 found 92.2% of progeny surviving the region's mild winter. In a trial of F₂-derived lines in F₃
293 derived from the same population, when grown in 2006 in Salina, Kansas, we observed no
294 ramets emerging from rhizomes before the onset of winter and observed no emergence at all the
295 following spring.

296 Selection in both cycles was based chiefly on gross morphological differences among
297 plants and their progenies in perenniality, grain size, and domestication traits, and in the second
298 cycle this was based only on individual plant phenotypes. Although grain yield had not been a
299 selection criterion in any cycle, we found improvements in grain yield and and single-grain

300 weight that were consistent across years of growth and years of evaluation. However, even the
301 highest-yielding lines from cycle 2 did not approach the commercial hybrid check in grain yield
302 or single grain weight, and all lines had phenotypes intermediate between those of *S. halepense*
303 and *S. bicolor*; that is, none would be acceptable as a crop cultivar at this stage of development
304 even if they had demonstrated higher yields. Since 2009, we have practiced additional cycles of
305 hybridizing perennial lines with a broader range of *S. bicolor* parents and have been selecting
306 among segregating progenies for perenniality, traits of domestication, grain yield, and single-
307 grain weight. We will continue doing so.

308 In 2013, mean grain yields of cycle 1 and 2 genotypes were not significantly different
309 from those in regrowing plots. That was despite our experience that, thanks to its longer growing
310 season, with other things being equal, a perennial plant produces a higher grain yield in its
311 second year of growth than in the first year. However, the second-year yield of a plot depends in
312 part on the survival rate. In a plot with less than 100% winter survival, a single plant regrowing
313 from rhizomes has the opportunity to occupy a larger area both within and beside the previous
314 year's row than does a plant growing from seed in a dense stand the first year. Nevertheless, in
315 the second year of growth, there were blank spots in rows that were not completely filled in, and
316 that reduced their total yield.

317 A previous study evaluating overwintering in *S. bicolor* x *S. halepense* population
318 indicated that after two backcrosses seed yield was similar or even exceeded the yield of the
319 cultivated parent ([Kraus 1990](#)). However, after the first backcross, rhizome production dropped
320 markedly ([Kraus 1990](#); [Anderson 1989](#); [Jones 1991](#)), to the point of not being sufficient for
321 overwintering. To overcome this challenge, [Jones \(1991\)](#) suggested for stronger selection for
322 rhizome traits before backcrossing, and use of higher-yielding BC₂F₄ parents instead of

323 tetraploid cultivated sorghum in order to increase the chance of recapturing important agronomic
324 traits while retaining sufficient rhizome production. Results from our backcrossing and selection
325 program support the conclusions of Jones (1991), and we backcross only winter-hardy perennial
326 plants to *S. bicolor*.

327 There was no large change in mean survival index across cycles of selection.
328 Furthermore, degree of perenniality as signified by survival index was not associated with grain
329 yield in this collection of 27 genotypes. There was a moderately negative correlation with single-
330 grain weight, which would not preclude development of larger-seeded perennial sorghum
331 cultivars but could add to the time required.

332 Our findings demonstrate that continuous improvement in perennial sorghum can be
333 accomplished with traditional plant breeding techniques, provided selection for more
334 domesticated phenotype, adaptation, and higher grain yield and grain weight are practiced
335 simultaneously.

336

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1 Table 1. Analysis of variance for grain yields (g m^{-1}) of 27 lines from cycles 0, 1, and 2 of a
 2 perennial sorghum selection program evaluated in 2011, 2012, and 2013.
 3

Source of variation	Degrees of freedom	Mean square ^a
Year Evaluated	2	91397**
Cycle	2	11678**
Linear	1	150580**
Residual	1	4827*
Genotype(Cycle)	24	6176**
Cycle*Year	4	2001
Genotype(Cycle)*Year	48	1107
Pooled Error	131	1077

4 ^a * indicates $p < 0.05$; ** indicates $p < 0.01$; all other mean squares were not significant.

Table 2. Coefficients of regression of mean grain yield and mean single-grain weight on cycle number (0, 1, 2) for 27 lines from a perennial sorghum selection program.

	Year	Grain yield (g m ⁻¹ cycle ⁻¹)	Single grain weight (mg ⁻¹ cycle ⁻¹)	Survival Index
Seeded plots	2011	65*** ^a	0.51**	-5.4*
	2012	38.4**	0.97**	1.6 ns
	2013	52.5**	0.52 ns	
	Mean	52.8**	0.60**	-2.48 ns
Plots regrowing from rhizomes	2013	13.2 ns	0.29 ns	

^a * indicates $p < 0.05$; ** indicates $p < 0.01$; ns indicates values are non-significant.

Table 3. Mean grain yield of selection cycles 0, 1, and 2 in newly seeded plots (2011-2013), and in second-year plots sown in 2012 and evaluated when regrowing from rhizomes in 2013 (“2013-regrowth”).

Genotype or Group	Number of genotypes	2011	2012	2013	2013-regrowth
<i>S. halepense</i>	1	43	49	38	119
Cycle 0	6	109	45	125	188
Cycle 1	6	205	107	191	165
Cycle 2	15	250	126	233	206
Highest Line	1	357	200	316	312
Commercial hybrid	1	547	432	640	---

Table 4. Three-year mean grain yield, single-grain weight, and survival index of lines in cycles 0, 1, and 2 of a perennial sorghum selection program, along with a *S. halepense* check, a commercial hybrid check, and the experimental line with the highest mean for the respective trait (which in each case belonged to cycle 2).

Genotype or Group	Number of genotypes	Grain Yield (gm ⁻¹)	Single Grain Weight (mg)	Survival Index
<i>S. halepense</i>	1	43	4.2	72
Cycle 0	6	93	7.1	35
Cycle 1	6	168	8.3	32
Cycle 2	15	203	8.9	31
Highest line	1	272	10.5	79
Commercial hybrid	1	540	10.6	---

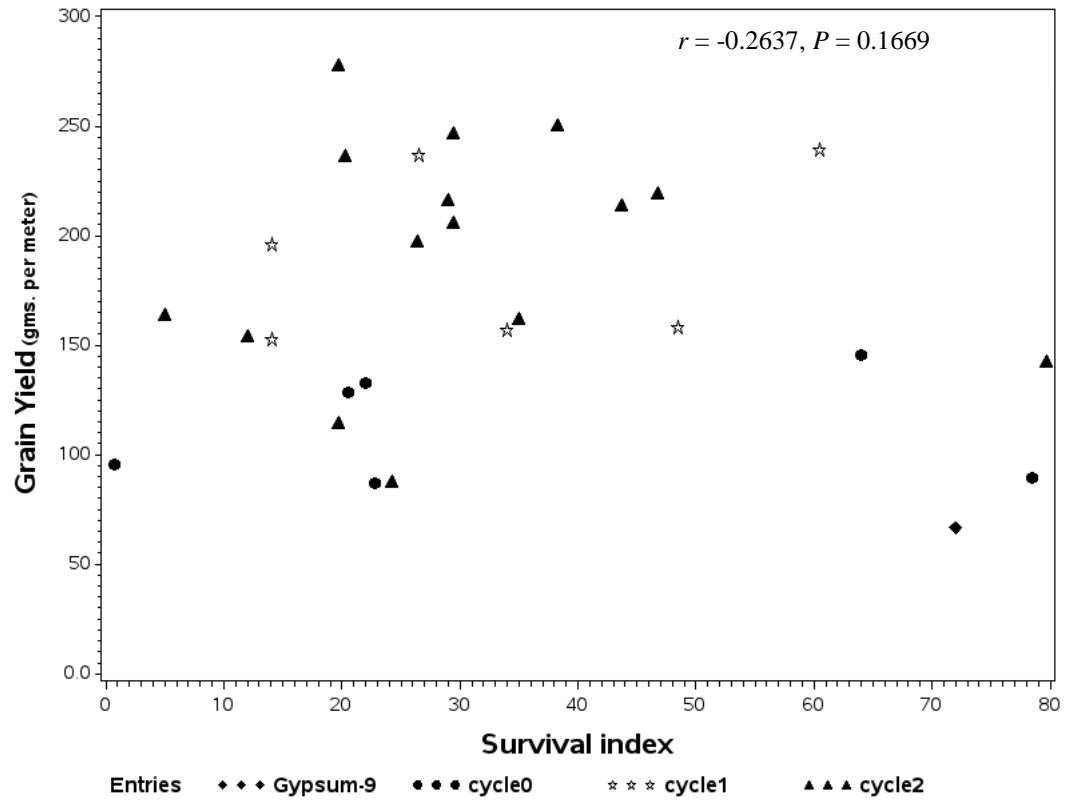


Fig. 1. Scatter diagram showing relationship between mean grain yield and mean survival index for selection cycles 0, 1, and 2.

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