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Broadening the Genetic Base of Bermudagrass

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Summary

Broadening the genetic base of cultivated plant species is crucial for breeding. A large genetic variation exists for common bermudagrass [*Cynodon dactylon* (L.) Pers.] in the Mediterranean region, shown to be within the center of diversity for the species. Thus, the objective of this study was to develop turf type tetraploid bermudagrass lines. Five local hexaploid *C. dactylon* var. *dactylon* genotypes were crossed with diploid *C. transvaalensis* Burtt-Davy (African bermudagrass) during June–October 2011. The seeds were germinated and seedlings grown in pots. Hybrid individuals were determined via sequence related amplified polymorphic (SRAP) molecular markers. Thirty four percent of the 910 seedlings were found to be true hybrids, and 60 % (182) of these were selected for their turfgrass characteristics and transplanted into the field along with commercial bermudagrass cultivars ('Riviera', 'Tifway', 'Princess 77') and parental lines at a density of four plugs per m^2. The experimental design was a randomized complete block design with three replications, established at Akdeniz University, Antalya on 28 July, and Alata Horticultural Research Station, Erdemli, Mersin, Turkey on 5 August 2012. Establishment rate (plot coverage), fall colour retention, spring green up, turfgrass colour and quality, seed head density, leaf texture, and growth habit were assessed from August 2012 to September 2013. One year after establishment, the turfs were subjected to drought stress for 45 days, which was followed by resumption of irrigation for recovery of the turf. Percentage of leaf firing under drought stress, and post-drought stress turf recovery were recorded. Significant variations existed for establishment rate, growth habit (prostrate *vs.* upright), seed head density (0–756 seed heads per m^2, leaf texture (very fine to coarse), drought resistance, colour and turf quality among hybrids. Morphological and adaptive traits were significantly correlated with each other at varying magnitudes. Turfgrass quality was significantly and positively associated with spring green up (r = 0.74), leaf texture (r = 0.45), establishment rate (r = 0.53) and turf recovery after drought stress (r = 0.35), indicating possibility for indirect selection. The hybrid genotypes with superior turf characteristics and drought resistance can be used to develop new, better adapted tetraploid bermudagrass cultivars for landscaping and sports turf.

Key words. *C. dactylon* – *C. transvaalensis* – diploid – hexaploid – interspecific hybrids

Introduction

The genus *Cynodon* (L.) Rich. belongs to the family *Gramineae* (*Poaceae*) (Renvoize and Clayton 1992) and includes nine species and ten varieties (Harlan et al. 1970c). They are used for pasture, forage, turfgrass, soil stabilization, and remediation (Burton 1947; Taliaferro 2003). *Cynodon* L. is comprised of cross-pollinated species with self-fertility of up to 3 % (Burton and Hart 1967). The genus includes ploidy series of diploids, triploids, tetraploids, pentaploids, and hexaploids with a base chromosome number of x = 9 (Wu et al. 2006). *Cynodon* is considered an autoploid (Zeven 1979). Intra- and inter-ploidy level crosses can produce viable seeds (Taliaferro 2003). *Cynodon dactylon* is frequently referred to as "common" bermudagrass due to its widespread distribution and prevalence (Kenworthy et al. 2007). Harlan and De Wet (1969) suggested that an area from West Pakistan to Turkey was the center of evolutionary activity. *C. dactylon* var. *dactylon* is the most widely distributed and genetically variable species in the genus. Wu et al. (2006) reported triploid, tetraploid, pentaploid, and hexaploid *Cynodon* genotypes from China. However, Gulsen et al. (2009) showed the presence of *Cynodon* accessions with all known ploidy levels in Turkey. The ratio of diploids was 3.3 %, triploid 1.6 %, tetraploids 67.5 %, pentaploids 19.8 %, and hexaploid 7.7 %. The tetraploid germplasm have been the sole genetic resource for seeded-type bermudagrass breeding. However, hexaploid *C. dactylon* genotypes possessed a high genetic diversity (Gulsen et al. 2009), darker colour and higher drought tolerance than most tetraploids under Mediterranean conditions (Sever Mutlu unpublished data).

C. transvaalensis, often referred to as African bermudagrass, is a diploid (2n = 2x = 18) and indigenous to the Transvaal region of South Africa (De Wet and Harlan 1971). The species has hairy, erect leaves and is characterized as small, short in stature, fine-textured, and yellow-green in colour (Juska and Hanson 1964; Harlan et al. 1966, 1970a, b; Hanna 1986). Kenworthy et al. (2006) reported a significant variation in African bermudagrass for morphological characteristics. The species also possesses a high intra genetic variation as well as inter genetic variation as compared to hexaploid *C. dactylon* var. *dactylon* genotypes (Wu et al. 2005). It is valued as turf and for use in interspecific hybridization with *C. dactylon* var. *dactylon* to produce turf cultivars. *C. transvaalensis* has been utilized as parents in developing triploid- and tetraploid-vegatative type bermudagrass cultivars (ex. 'Tifway' and 'Patriot').

To the best of our knowledge, there has been only one report where a tetraploid (2n = 4x = 36 chromosomes) interspecific F_1 hybrid bermudagrass cultivar from a cross of hexaploid *C. dactylon* by diploid *C. transvaalensis* was developed (Taliaferro et al. 2006). 'Patriot' is a vegetative-type turf bermudagrass cultivar characterized by its dark blue-green colour and good turf quality. The maternal parent of 'Patriot' was a *C. dactylon* var. *dactylon*, 'Tifton 10', and the paternal parent was a *C. transvaalensis*. 'Tifton 10' is a commercial hexaploid (2n = 6x = 54) cultivar. The *C. transvaalensis* has 18 chromosomes (diploid; 2n = 2x = 18). 'Patriot' is a tetraploid with 2n = 4x = 36 chromosomes, presumably having inherited 27 chromosomes (3 genomes) from 'Tifton 10' and 9 chromosomes (1 genome) from the *C. transvaalensis* parent.

C. transvaalensis (2x) was also crossed with *C. dactylon* (6x) to produce tetraploid hybrid plants in this study. The hybrid status of a plant derived from interspecific cross may be understood either by molecular markers, or ploidy analysis via C-banding or ploidy analyzer equipments. SRAP is a PCR-based molecular marker technique (Li and Quiros 2001), and are used for mapping, tagging and identifications of hybrids (Hao et al. 2008; Mutlu et al. 2008; Ye et al. 2013).

The tetraploid genotypes have been the sole genetic pool for development of seeded-type bermudagrass cultivars. Thus, the aim of the study was to broaden the genetic base of bermudagrass by introducing genomes of hexaploid *C. dactylon* and of diploid *C. transvaalensis* into the tetraploid background. The fertile hybrid individuals are expected to be used in seeded-type (4x) bermudagrass breeding while sterile hybrids with superior turfgrass characteristics can be used as vegetative-type bermudagrass cultivars (ex. 'Patriot').

Materials and Methods

Plant Material

The hexaploid *C. dactylon* accessions were collected in the Mediterranean coastal region of Turkey (Gulsen et al. 2009), and well characterized for their drought tolerance and turfgrass colour and quality (Sever Mutlu unpublished data). The parental *C. dactylon* genotypes were selected among 14 hexaploids for their superior turfgrass colour and drought resistance (Sever Mutlu unpublished data). The diploid *C. transvaalensis* Burtt-Davy was an experimental line. The five different hexaploid genotypes were used as maternal parent and the diploid *C. transvaalensis* as paternal parent. The clonally propagated parental genotypes were grown in pots and crossed within isolated chambers at Akdeniz University greenhouses, Antalya, Turkey in 2011. Seeds were harvested and kept at 5 °C for 3 months until they were germinated in a controlled greenhouse (15 °C/27 °C, night/day). The seedlings were transplanted into the pots in January 2012.

Determination of hybrids using molecular markers

The leaf samples were taken from seedlings. DNA of parental genotypes and seedlings was extracted using CTAB (cetyltrimethylammonium bromide) method (Doyle and Doyle 1990). Sequence related amplified polymorphic (SRAP) primers were used to screen for polymporphism between *C. dactylon* and *C. transvaalensis* parental genotypes (Fig. 1). The primer sequences, PCR and agarose gel conditions for SRAP analyses were as described by Li and Quiros (2001). The dominant markers representing male parent (*C. transvaalensis*) alleles then were used to identify true-hybrids among seedlings (Fig. 1). The hybrids identified with molecular markers were grown in pots and selection was made based on general turfgrass characteristics (colour, leaf texture, growth habit, and internode length). Then, the selected hybrids, parental lines, and bermudagrass cultivars 'Princess 77', 'Riviera' and 'Tifway' were clonally propagated for field evaluation in April 2012.

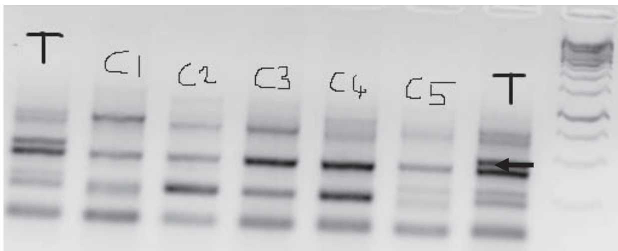

Fig. 1. Parental polymorphism screen with SRAP molecular markers. Polymorphic marker between paternal parent *C. transvaalensis* and maternal parents *C. dactylon* is shown with an arrow. T: *C. transvaalensis*, C1: *C. dayctylon* 190; C2: *C. dayctylon* 183; C3: *C. dayctylon* 129; C4: *C. dayctylon* 135; C5: *C. dayctylon* 121.

Field evalution

Field evaluation of bermudagrass hybrids was carried out in Antalya and Mersin, located in the Mediterranean region of Turkey. The locations differed strongly for their soil type, sandy *vs.* clay loam. However, the climate at both locations is Mediterranean with a strong marine influence (warm, dry summers and cooler, but mild winters). In the spring and summer of 2012, existing vegetation on the sites were killed with glyphosate [N-(phosphonomethyl) glycine] and tilled into the soil. The topsoil was graded and rolled. The soil at the Antalya location was a clay loam (37 % sand, 29 % silt, and 34 % clay) with 1.6 % organic matter, and an electrical conductivity (i.e. measure of the soluble salts) of 0.23 dS m^{-1}. Soil on the site had a pH = 8.7, Olsen extractable Phosphorus (P) of 31 mg kg^{-1}, potassium (K) of 407 mg kg^{-1} (Carson 1980), calcium (Ca) 5150 mg kg^{-1}, and magnesium (Mg) 337 mg kg^{-1}. The soil at the Mersin location was a sandy (Typic Xerofluvent) soil with a 1.1 % OM, EC of 0.18 dS m^{-1}, pH 8.3, P level of 12 mg kg^{-1}, K level of 114 mg kg^{-1}, Ca of 2100 mg kg^{-1}, and Mg of 180 mg kg^{-1}.

The hybrids obtained from the crosses between hexaploid *C. dactylon* and diploid *C. transvaalensis* were evaluated in the field along with the seeded type tetraploid bermudagrass cultivars 'Princess 77' and 'Riviera', the triploid vegetative type 'Tifway', and parental genotypes. Greenhouse-grown plugs of hybrids, parental lines and bermudagrass cultivars were transplanted into the field according to a randomized complete block design with three replications. Plot size was 1 by 1 m separated by 0.5 m alleys where 4 plugs m^{-2} were planted in July (Antalya) and August (Mersin) 2012. During establishment, the plots were fertilized with 5 g N m^{-2} of 15N-6.6P-12.5K, a complex fertilizer, at planting, and were irrigated to prevent visual wilt symptoms. In 2013 turfs received 17.5 g N m^{-2} per season with applications made as 5 g N m^{-2} in May, June, and July, and 2.5 g N m^{-2} in August using a slow release 33N-3P-6K granular fertilizer (Anderson's, Maumee, OH, USA). Plots were mowed weekly at 50 mm with clippings removed. Glyphosate was applied regularly to the borders between plots to control cross contamination.

Measurements and observations

After transplanting into the field, turfgrass establishment, quality and colour were rated biweekly throughout growing season. Turfgrass establishment and spring greenup were based on a visual estimate scale of 0 to 100 %, where 0 % = no green vegetation cover and 100 % = 100 % green vegetation cover. Spring green-up was assessed until all plots reached 100 % green cover in the spring from March through May 2013. Fall dormancy and fall colour retention was rated biweekly until all plots reached complete dormancy from November through December 2012. Fall dormancy was based on a visual estimate scale of 0 to 100 %, where 0 % = no dormancy and 100 % = complete dormancy with straw brown vegetation cover. Turfgrass colour was based on a 1–9 visual rating scale, where 1 = straw brown, 6 = light green, and 9 = dark green. Fall colour retention assesses overall plot colour and is especially useful in quantifying the response of warm-season grasses to temperature changes or frost occurring in fall. Turfgrass quality ratings were based on National Turfgrass Evaluation Program (NTEP) guidelines using a 1–9 visual rating scale, where 1 = poorest, 6 = acceptable, and 9 = best (Ntep 2014). Quality ratings were based on combination of colour, density, uniformity, texture, weed, and disease infestation or sensitivity to environmental stress. Visual assessment of seedheads (Antalya only) were based on a 1 to 10 rating scale with 1 equaling no seedheads, and rated when turfgrass was in active growth in October 2012 and May 2013. In Antalya, seedhead density was also determined quantitatively by counting seedheads in a 0.3 by 0.3 m area using a frame randomly tossed over the plots in October 2012, and growth habit was rated in June 2013 using a 1 to 5 scale with 1 being prostrate, 3 intermediate and 5 completely upright. Visual assessment of leaf texture was made at both locations when the turfgrass was actively growing in June 2013. Turfgrass texture was an estimate of leaf width. The visual rating of texture was based on a 1 to 9 rating scale with 1 equaling coarse and 9 equaling fine.

Assessment of drought resistance

One year after establishment in June 2013 a study was conducted at both locations to evaluate drought stress resistance and recovery from drought stress. Plots were watered to prevent water stress and promote healty turf growth until the begining of the drought stress period, which lasted 45 d from 15 June to 30 July 2013 at each location. At the beginning of the drought stress treatment, grasses showed 100 % green cover and plots were watered to saturation. Percentage of leaf firing was recorded weekly during the 45 d drought stress period. Subsequently, to assess post-drought response of the progenies, the plots were saturated with water and normal watering frequency was maintained thereafter during the turf recovery phase. Leaf firing was assessed using a scale of 0 to 100 % with 0 = no symptoms and 100 % = complete leaf firing, as was previously reported by Beard and Sifers (1997). Turf recovery was assessed weekly as the percentage of green shoot development for 45 d post drought stress period, and rated using a visual scale of 0 to 100 % with 0 % = no green vegetation and 100 % = green vegetation over the entire plot.

Statistical analyses

The experimental design was a randomized complete block with three replications. Treatment differences were tested using analysis of variance procedures with PROC

GLM (SAS release 8.0; SAS Institute, Cary, NC). Means were separated using Fisher's protected least significant difference ($P < 0.05$) procedure. Least significant difference values are reported for combining abilities of parental genotypes at the 0.05 level. The PROC CORR procedure was used to perform correlation analyses among morphological, adaptive and drought resistance trait descriptors.

Results and Discussions

The interspecific crosses yielded many seeds (Table 1). The average germination of the unhulled (caryopses with intact lemma and palea) 3 to 4 months old hybrid seeds was relatively low (44 %), ranging from 11 to 55 % (Table 1). This might be due to genetic factors such as hybrid lethality that has often been observed in interspecific crosses in plants and is considered a reproductive barrier between plant species (Yamagata et al. 2010). The mean germination of hulled and unhulled seeds of five *C. dactylon* genotypes was reported as 67 % and 56 %, respectively (Ahring and Todd 1978).

SRAP analysis

The true hybrids of progenies of *C. dactylon* × *C. transvaalensis* cross-combinations were identified by SRAP markers. First, parental genotypes were screened with SRAP primers, and markers were selected yielding male parent specific band that were absent from the female parents (Fig. 1), then seedlings were screened to identify the hybrids. The hybridity of the individual seedlings was identified by the presence of male parent specific bands, produced by SRAP primers Em2/Me6, Em2/Me8, Em2/Me11, Em3/Me1, Em3/Me3, Em3/Me8, and Em3/Me12 (Fig. 2). There were 305 seedlings with these specific bands, which were therefore identified as true hybrids (Table 1). Hybridity of the progeny ranged from 4 to 48 % among crosses, with a mean hybridity of 34 %. The amplified bands of SRAP were easy to score and stable (Fig. 2). The results suggest that SRAP markers could be used as effective molecular markers for the identification of the hybrid progenies of bermudagrass. The source of variation among hybrid seed was the hexaploid genotypes of *C. dactylon* because the male parent *C. transvaalensis* was common in all crosses. Although, Burton and Hart (1967) reported that bermudagrass is highly outcrossed as a result of cross-pollination and self-incompatibility, and *Cynodon* L. is comprised of cross-pollinated species with self-fertility of up to 3 % (Richardson et al. 1978; Kenna et al. 1983), the results of this study indicates a self fertility of up to 96 %. The rate of cross-pollination/self fertility among *C. dactylon* genotypes requires further study.

Field evaluation

Means, standard deviations, and ranges for establishment, growth habit, leaf texture, flower and shoot density, dormancy, fall colour retention, spring green-up, turfgrass quality and colour, and leaf firing, and post-drought stress recovery are summarized in Table 2a and 2b for Antalya and Mersin locations, respectively. General combining

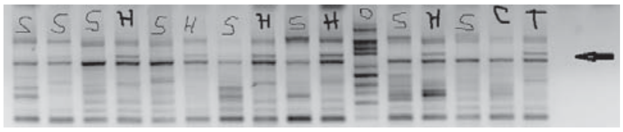

Fig. 2. Determination of hybrid progenies obtained from the crosses *C. dactylon* (6X) × *C. transvaalensis* (2x). A specific dominant SRAP marker from *C. transvaalensis* was used to identify true hybrid individuals. The polymorphic marker is shown with an arrow (T: *C. transvaalensis*; C: *C. dactylon*; H: hybrid; S: selfed; and O: outcrossed individuals).

Table 1. Genotypes of hexaploid *Cynadon dacytlyon* (*C. d.*; ♀) × diploid *Cynadon transvaalensis* (*C. t.*; ♂) used in crosses. Number of seeds sown, numbers of seedlings germinated, number of hybrids tested with molecular markers, numbers and percent identified as hybrids, numbers transplanted into the field, and percent sterile hybrids observed in the field.

Cross		No. of sown seeds	No. of seedlings	No. of seedlings screened with molecular marker	No. and percent of hybrid seedlings	No. of seedlings transplanted into field	Percent sterile hybrids (%)
♀	♂						
C. d. 190	*C. t.*	663	345	200	73 (37 %)	33	3
C. d. 183	*C. t.*	663	294	231	76 (33 %)	53	23
C. d. 129	*C. t.*	663	367	258	59 (23 %)	39	5
C. d. 135	*C. t.*	663	230	197	94 (48 %)	54	46
C. d. 121	*C. t.*	221	24	24	3 (4 %)	3	33
Total		2873	1260	910	305	182	22

Table 2a. Means, standard deviations and ranges for 12 trait descriptors of adaptation, morphology, and drought resistance in 2012–2013 on 182 tetraploid (4x) progenies derived from crosses of five *C. dactylon* (*C. d.*; 6x) with one *C. transvaalensis* (*C. t.*; 2x) line along with parental lines and three standard cultivars in Antalya, Turkey.

(a) Location: Antalya	♀ *C. d.* (6x) x ♂ *C. t.* (2x) progenies		Parental lines ♀ *C. d.* (6x)		♂ *C. t.* (2x)	Bermudagrass cultivars 'Princess 77'	'Riviera'	'Tifway'
Trait	Mean ± SD	Min.–Max.	Mean ± SD	Min.–Max.	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Establishment (%)[1]								
4 WAP[2]	52 ± 21	5–95	50 ± 16	25–75	42 ± 8	67 ± 28	75 ± 5	68 ± 8
6 WAP	76 ± 22	5–100	80 ± 15	40–98	78 ± 6	88 ± 12	96 ± 2	94 ± 8
Turfgrass quality[3]	5.1 ± 0.9	2.0–7.2	5.5 ± 0.4	4.5–6.0	6.9 ± 0.8	6.7 ± 0.3	7.1 ± 0.7	7.2 ± 0.5
Turfgrass colour[4]	7.0 ± 0.8	5.3–9.0	7.4 ± 0.5	6.8–8.3	5.9 ± 0.1	6.8 ± 0.4	7.0 ± 0.9	6.8 ± 0.3
Growth habit[5]	3.0 ± 0.9	1.0–5.0	2.0 ± 0.4	2.0–3.3	3.0 ± 0.5	3.0 ± 0.4	3.0 ± 0.2	3.0 ± 0.2
Seed head density[6] (no m^{-2})	73 ± 82	0–756	102 ± 67	28–244	62 ± 46	272 ± 56	88 ± 41	46 ± 4
Visual seed head density[7]								
12 Oct. 2012	4.0 ± 2.8	1–10	6.0 ± 2.7	1–10	6.0 ± 1.5	9.0 ± 1.2	7.0 ± 1.2	6.0 ± 1.0
13 May 2013	5.0 ± 3.0	1–10	7.0 ± 1.8	4–10	8.0 ± 1.2	9.0 ± 0.6	6.0 ± 1.2	7.0 ± 0.6
Leaf texture[8]	6.1 ± 1.0	3.0–8.5	5.7 ± 0.5	5.0–6.5	8.0 ± 0.5	7.3 ± 0.3	7.7 ± 0.3	8.0 ± 0.5
Spring green-up (%)[9]								
01 Apr.	44 ± 19	0–90	51 ± 14	35–75	60 ± 22	67 ± 3	53 ± 20	68 ± 16
15 Apr.	60 ± 20	5–95	65 ± 13	45–80	68 ± 25	82 ± 3	72 ± 12	80 ± 10
30 Apr.	78 ± 18	5–100	85 ± 7	70–95	83 ± 13	93 ± 3	87 ± 8	87 ± 8
Fall dormancy (%)[10]								
15 Nov.	37 ± 15	5–75	24 ± 9	5–40	20 ± 10	20 ± 9	17 ± 15	10 ± 5
15 Dec.	52 ± 17	10–100	42 ± 17	25–75	30 ± 10	30 ± 9	27 ± 15	23 ± 3
01 Jan.	83 ± 13	30–100	84 ± 13	55–100	70 ± 5	60 ± 26	53 ± 18	78 ± 8
Fall colour retention[11]								
30 Nov.	4.5 ± 1.1	1.0–8.5	5.4 ± 0.6	4.0–6.0	4.7 ± 0.8	4.8 ± 0.3	5.8 ± 1.0	6.5 ± 1.0
15 Dec.	3.2 ± 1.1	1.0–6.0	3.9 ± 0.9	2.0–5.5	3.7 ± 0.6	3.8 ± 0.8	4.8 ± 1.5	5.3 ± 0.3
Leaf firing (%)[12]								
2 WOD[13]	26 ± 21	0–95	19 ± 10	0–35	23 ± 10	15 ± 5	23 ± 8	20 ± 10
3 WOD	69 ± 23	5–100	65 ± 21	15–90	55 ± 15	45 ± 10	57 ± 10	57 ± 13
Turf recovery (%)[14]								
1 WOR[15]	28 ± 15	1–85	22 ± 5	15–30	15 ± 5	22 ± 3	23 ± 3	12 ± 8
2 WOR	53 ± 14	5–90	43 ± 5	20–50	43 ± 3	55 ± 13	58 ± 8	53 ± 3
3 WOR	73 ± 16	20–100	70 ± 7	60–80	65 ± 5	70 ± 13	77 ± 10	85 ± 5
4 WOR	81 ± 15	25–100	83 ± 8	65–90	75 ± 5	78 ± 12	88 ± 8	95 ± 5

1) Establishment ratings were based on a 0–100 % visual rating scale, with 0 = no coverage, 100 = full coverage over the whole plot area. 2) WAP indicates weeks after transplanting into the field. 3) Turfgrass quality ratings were based on a 1–9 visual rating scale, with 1 = poorest, 6 = acceptable, 9 = best. 4) Turfgrass colour was based on a 1–9 visual rating scale, where 1 = straw brown, 6 = light green, and 9 = dark green. 5) Growth habit was rated using a 1 to 5 scale with 1 being prostrate, 3 intermediate and 5 completely upright. 6) Seedhead density was determined quantitatively by counting seedheads in a 0.3 by 0.3 m area using a frame randomly tossed over the plots. 7) Visual assessment of seedheads were based on a 1 to 10 rating scale with 1 equaling no seedheads. 8) The visual rating of leaf texture was based on a 1 to 9 rating scale with 1 equaling coarse and 9 equaling fine. 9) Turfgrass spring green-up was rated using a visual scale of 0 to 100, with 100 = green vegetation over the entire plot, and 0 = no green vegetation. 10) Fall dormancy was based on a visual estimate scale of 0 to 100 %, where 0 % = no dormancy and 100 % = complete dormancy with strawn brown vegetation cover. 11) Fall colour retention was based on a 1–9 visual rating scale, where 1 = straw brown, 6 = light green, and 9 = dark green. 12) Turfgrass leaf firing ratings were based on a 0–100 % visual rating scale, with 0 = no symptoms, 100 = complete leaf firing. 13) WOD indicates weeks of drought stress. 14) Turf recovery ratings were based on a 0–100 % visual rating scale, with 0 = no green shoot development, 100 = full green shoot development. 15) WOR indicates weeks of recovery after drought.

Table 2b. Means, standard deviations and ranges for 12 trait descriptors of adaptation, morphology, and drought resistance in 2012–2013 on 182 tetraploid (4x) progenies derived from crosses of five *C. dactylon* (*C. d.*; 6x) with one *C. transvaalensis* (*C. t.*; 2x) line along with parental lines and three standard cultivars in Mersin, Turkey.

(b) Location: Mersin	♀ *C. d.* (6x) x ♂ *C. t.* (2x) progenies		Parental lines ♀ *C. d.* (6x)		♂ *C. t.* (2x)	Bermudagrass cultivars 'Princess 77'	'Riviera'	'Tifway'
Trait	Mean ± SD	Min.–Max.	Mean ± SD	Min.–Max.	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Establishment (%)[1,*]								
4 WAP[2]	39 ± 17	5–85	35 ± 9	25–50	37 ± 16	48 ± 10	35 ± 13	42 ± 8
6 WAP	66 ± 21	5–100	74 ± 8	65–90	53 ± 15	80 ± 13	78 ± 8	82 ± 3
Turfgrass quality[3]	5.3 ± 0.8	2.0–7.3	5.5 ± 0.3	5.0–6.0	7.0 ± 0.5	6.4 ± 0.5	6.8 ± 0.9	7.7 ± 0.1
Turfgrass colour[4]	6.8 ± 1.0	4.0–9.0	7.5 ± 0.7	6.5–8.8	6.0 ± 0.3	6.9 ± 0.4	7.1 ± 0.4	7.3 ± 0.3
Leaf texture[8]	5.9 ± 1.1	3.0–8.0	5.2 ± 0.7	4.0–6.0	8.0 ± 0.0	7.5 ± 0.5	8.0 ± 0.0	8.5 ± 0.5
Spring green-up (%)[9]								
15 Mar.	47 ± 8	0–65	49 ± 7	50–60	57 ± 8	45 ± 5	45 ± 5	52 ± 6
21 Mar.	55 ± 6	25–70	56 ± 6	55–65	63 ± 3	52 ± 3	50 ± 5	67 ± 8
01 Apr.	77 ± 11	45–95	82 ± 7	70–90	87 ± 3	78 ± 12	83 ± 13	90 ± 5
Fall dormancy (%)[10]								
15 Nov	31 ± 12	0–75	29 ± 7	20–40	17 ± 3	20 ± 9	23 ± 8	17 ± 3
15 Dec	53 ± 15	10–95	50 ± 10	35–70	25 ± 0	35 ± 9	37 ± 8	32 ± 8
27 Dec	74 ± 15	20–100	69 ± 11	55–90	38 ± 8	53 ± 8	48 ± 10	53 ± 10
Fall colour retention[11]								
8 Nov	6.1 ± 0.8	4.0–8.5	6.3 ± 0.9	5.0–8.0	5.2 ± 0.3	6.3 ± 0.8	6.0 ± 0.5	6.0 ± 0.9
8 Dec	5.1 ± 0.9	2.5–7.5	5.4 ± 1.0	4.0–7.0	4.7 ± 1.0	5.5 ± 1.3	4.8 ± 0.6	4.7 ± 1.2
25 Dec	2.6 ± 1.1	1.0–6.0	2.5 ± 0.7	2.0–4.0	3.7 ± 1.5	3.8 ± 1.0	3.3 ± 1.5	3.3 ± 1.5
Leaf firing (%)[12]								
2 WOD[13]	48 ± 24	5–100	31 ± 25	10–85	17 ± 8	20 ± 5	40 ± 9	20 ± 3
3 WOD	68 ± 25	10–100	56 ± 27	15–95	38 ± 21	33 ± 9	53 ± 10	30 ± 5
Turf recovery (%)[14]								
1 WOR[15]	24 ± 14	1–70	35 ± 18	10–70	23 ± 8	27 ± 3	23 ± 8	27 ± 3
3 WOR	46 ± 21	1–95	68 ± 21	25–95	40 ± 10	50 ± 5	47 ± 8	48 ± 3
4 WOR	59 ± 25	1–100	79 ± 18	45–100	62 ± 13	82 ± 6	78 ± 8	82 ± 3
6 WOR	67 ± 28	1–100	86 ± 17	55–100	72 ± 13	92 ± 6	88 ± 8	93 ± 3

1) Establishment ratings were based on a 0–100 % visual rating scale, with 0 = no coverage, 100 = full coverage over the whole plot area. 2) WAP indicates weeks after transplanting into the field. 3) Turfgrass quality ratings were based on a 1–9 visual rating scale, with 1 = poorest, 6 = acceptable, 9 = best. 4) Turfgrass colour was based on a 1–9 visual rating scale, where 1 = straw brown, 6 = light green, and 9 = dark green. 8) The visual rating of leaf texture was based on a 1 to 9 rating scale with 1 equaling coarse and 9 equaling fine. 9) Turfgrass spring green-up was rated using a visual scale of 0 to 100, with 100 = green vegetation over the entire plot, and 0 = no green vegetation. 10) Fall dormancy was based on a visual estimate scale of 0 to 100 %, where 0 % = no dormancy and 100 % = complete dormancy with strawn brown vegetation cover. 11) Fall colour retention was based on a 1–9 visual rating scale, where 1 = straw brown, 6 = light green, and 9 = dark green. 12) Turfgrass leaf firing ratings were based on a 0–100 % visual rating scale, with 0 = no symptoms, 100 = complete leaf firing. 13) WOD indicates weeks of drought stress. 14) Turf recovery ratings were based on a 0–100 % visual rating scale, with 0 = no green shoot development, 100 = full green shoot development. 15) WOR indicates weeks of recovery after drought.

abilities (GCA) (Sprague and Tatum 1942; Griffing 1956) of *C. dactylon* parental lines for the same data set are provided in Table 3.

Four weeks after transplanting, the establishment of interspecific hybrids (n = 182) in Antalya ranged from 5 to 95 % (avr. 51 %). The mean establishment of *C. dactylon* parents was 50 %, with a range from 25 to 75 %, and of *C. transvaalensis* 42 %. The commercial checks 'Riviera', 'Tifway' and 'Princess 77' established 75, 68 and 67 %, respectively, at the same time in Antalya (Table 2a). Similar trends were observed in Mersin (Table 2b). Transgressive segregation was evident for establishment rate among interspecific progeny and can be used to improve establishment rate of bermudagrass cultivars.

Table 3a. General combining abilities of five *C. dactylon* (*C. d.*) and one *C. transvaalensis* (*C. t.*) line for 10 trait descriptors of adaptation, morphology, and drought resistance in 2012–2013 calculated from 182 tetraploid (4x) hybrid progenies derived from *C. dactylon* (6x) × *C. transvaalensis* (2x) cross in Antalya and Mersin, Turkey.

		C. transvaalensis(2x) ♂											
		Establishment[1] (%)				Turfgrass Quality[2]		Turfgrass Colour[3]		Leaf Texture[4]		Sping green-up[5] (%)	
C. d. (6x) ♀	Hybrids (n)	4 weeks after planting		6 weeks after planting								1 Apr	
		Loc M[6]	Loc A	Loc M	Loc A	Loc M	Loc A	Loc M	Loc A	Loc M	Loc A	Loc M	Loc A
190	33	34 (05–80)[7]	45 (05–85)	58 (05–95)	70 (15–100)	5.0 (3.0–6.5)	4.8 (1.5–6.7)	7.1 (4.5–8.8)	7.3 (5.5–9.0)	6.2 (4–8)	6.5 (4.5–8.0)	73 (35–95)	36 (00–80)
183	53	41 (20–85)	55 (20–95)	69 (20–95)	79 (30–100)	5.6 (3.0–7.3)	5.4 (2.7–7.2)	7.0 (4.0–9.0)	7.2 (5.5–9.0)	5.8 (3–8)	6.1 (4.0–8.5)	83 (60–95)	49 (05–85)
129	39	36 (05–75)	47 (05–95)	65 (05–100)	73 (05–100)	5.3 (3.0–6.5)	5.3 (1.5–6.8)	6.7 (5.0–8.8)	7.0 (5.5–8.8)	5.4 (3–8)	5.8 (3.5–8.0)	79 (55–95)	46 (00–90)
135	54	42 (05–85)	53 (05–95)	69 (10–95)	77 (20–100)	5.4 (2.5–7.3)	5.1 (2.0–6.8)	6.7 (4.5–8.5)	6.9 (5.3–8.5)	5.7 (3–8)	6.0 (3.5–7.0)	76 (45–95)	44 (05–85)
121	3	42 (15–80)	56 (15–80)	62 (15–100)	71 (25–95)	5.0 (4.8–5.3)	4.5 (3.5–5.0)	6.5 (5.3–7.8)	6.7 (5.0–8.8)	6.3 (5–7)	6.4 (6.0–7.0)	71 (65–80)	29 (10–35)
Mean		39	52	65	74	5.3	5.0	6.8	7.0	5.9	6.1	77	41
LSD[8]		7.5	8.0	9.0	Ns[9]	0.3	0.4	0.4	0.3	0.4	0.3	4.0	8.0

[1)] Establishment ratings were based on a 0–100 % visual rating scale, with 0 = no coverage, 100 = full coverage over the whole plot area. [2)] Turfgrass quality ratings were based on a 1–9 visual rating scale, with 1 = poorest, 6 = acceptable, 9 = best. [3)] Turfgrass colour was based on a 1–9 visual rating scale, where 1 = straw brown, 6 = light green, and 9 = dark green. [4)] The visual rating of leaf texture was based on a 1 to 9 rating scale with 1 equaling coarse and 9 equaling fine. [5)] Turfgrass spring green-up was rated using a visual scale of 0 to 100, with 100 = green vegetation over the entire plot, and 0 = no green vegetation. [6)] Loc M and Loc A indicates Mersin and Antalya locations respectively. [7)] Ranges of the respective means are given within parenthesis. [8)] LSD values indicate significant means separation at $\alpha = 0.05$. [9)] NS = not significant at P = 0.05 probability level.

The mean summer turfgrass quality of the hybrid progenies ranged from 2.0 to 7.2 (avr. 5.1) where commercial checks were around 7.0, and the mean quality of parental lines was 5.5 and 6.9 for *C. dactylon* and *C. transvaalensis*, respectively, in Antalya (Table 2a). Results indicate that new bermudagrass cultivars with qualities comparable to commercial checks can be produced using the interspecific progenies. Turfgrass colour of progenies ranged from 5.3 to 9.0 (avr. 7.0). The checks had 6.9 and parental lines ranged from 6.8 to 8.3 for *C. dactylon* and 5.9 for *C. transvaalensis* in Antalya (Table 2a). Transgressive segregation for darker green colour proved that bermudagrass cultivars with enhanced colour can be developed. The fertile progenies with the dark green colour can be used in breeding tetraploid seeded-type bermudagrass lines/cultivars for enhanced colour. A similar trend was observed in Mersin (Table 2b).

In general, the leaf texture of *C. dactylon* is coarser than of *C. transvaalensis*, which contains plants of smaller size and more refined texture (Taliaferro 2003). The mean leaf textures in Antalya were 6.1 (range 3.0–8.5) for progenies, 5.7 (range 5.0–6.5) for *C. dactylon*, and 8.0 for the *C. transvaalensis* parents, and 7.7 (range 7.3–8.0) for the checks (Table 2a). Identification of progenies with finer leaf texture than, or comparable to, *C. transvaalensis* shows that tetraploid bermudagrass cultivars with fine leaf texture can be developed.

The growth habit of progenies ranged from prostrate (1.0) to upright (5.0) with an intermediate (3.0) mean at the Antalya location. Both checks and *C. transvaalensis* showed intermediate (3.0), and *C. dactylon* parental lines prostrate-intermediate (2.0) growth habit (Table 2a). We identified 14 interspecific hybrid progenies with a prostrate growth habit that can be used to develop improved bermudagrass cultivars tolerant of lower mowing heights.

Sterility is a common outcome of interspecific hybrids as reported for the cultivar ‘Patriot’ obtained by similar interspecific crosses. Forty-one of the 182 hybrids did not produce seed heads in this study. Hexaploid genotypes differed significantly in ability to produce fertile *vs.* sterile progeny when crossed with *C. transvaalensis*. The percent sterile hybrids ranged from 3 to 46 %, with a mean sterility of 22 %, depending on the hexaploid genotypes (Table 1). In Antalya, the average number of seed heads per m^2 in October was 73 ranging from 0 to 756. *C. dactylon* parents had a mean of 102 (range 28–244), *C. trans-*

Table 3b. General combining abilities of five *C. dactylon* (*C. d.*) and one *C. transvaalensis* (*C. t.*) line for 10 trait descriptors of adaptation, morphology, and drought resistance in 2012–2013 calculated from 182 tetraploid (4x) hybrid progenies derived from *C. dactylon* (6x) × *C. transvaalensis* (2x) cross in Antalya and Mersin, Turkey.

		C. transvaalensis(2x) ♂													
		Fall Dormancy[10] (%)				Leaf Firing[11] (%)				Turf Recovery[12]				Growth	Seed heads
		15 Nov		15 Dec		Weeks of Drought Stress				Weeks of Recovery				Habit[13]	density[14]
C. d.	Hybrids					2		3		3		4			(m^2)
(6x) ♀	(n)	Loc M	Loc A	Loc M	Loc A	Loc M	Loc A	Loc M	Loc A	Loc M	Loc A	Loc M	Loc A	Loc A	Loc A
190	33	33 (05–60)	36 (05–70)	53 (20–80)	52 (10–85)	51 (05–100)	26 (00–90)	69 (10–100)	68 (05–100)	44 (01–95)	69 (20–100)	56 (01–100)	78 (25–100)	2 (01–04)	70 (03–284)
183	53	35 (10–75)	38 (05–75)	58 (25–100)	57 (15–100)	46 (05–95)	29 (00–95)	67 (10–100)	70 (05–100)	55 (05–90)	75 (20–100)	70 (05–100)	84 (30–100)	2 (01–04)	62 (00–756)
129	39	27 (05–60)	33 (05–70)	49 (20–85)	47 (15–80)	53 (05–95)	23 (00–70)	73 (15–100)	68 (05–100)	40 (01–95)	77 (25–100)	51 (01–100)	84 (35–100)	3 (01–05)	85 (01–723)
135	54	30 (00–75)	35 (05–65)	52 (10–95)	49 (25–80)	43 (05–95)	22 (00–70)	64 (15–100)	65 (05–100)	43 (05–75)	73 (30–95)	58 (05–95)	81 (40–100)	3 (01–05)	32 (00–563)
121	3	28 (10–40)	44 (25–65)	47 (35–70)	56 (40–75)	58 (30–95)	40 (10–75)	76 (45–100)	87 (50–100)	34 (10–60)	59 (20–90)	46 (15–70)	72 (35–100)	3 (01–04)	114 (00–313)
Mean		31	37	52	53	50	28	70	72	43	71	57	80	3	73
LSD		5.0	6.0	6.0	7.0	12	9.5	Ns	10	9.5	6.9	11	6.0	0.4	37

[10] Fall dormancy was based on a visual estimate scale of 0 to 100 %, where 0 % = no dormancy and 100 % = complete dormancy with strawn brown vegetation cover. [11] Turfgrass leaf firing ratings were based on a 0–100 % visual rating scale, with 0 = no symptoms, 100 = complete leaf firing. [12] Turf recovery ratings were based on a 0–100 % visual rating scale, with 0 = no green shoot development, 100 = full green shoot development. [13] Growth habit was rated using a 1 to 5 scale with 1 being prostrate, 3 intermediate and 5 completely upright. [14] Seedhead density was determined quantitatively by counting seedheads in a 0.3 by 0.3 m area using a frame randomly tossed over the plots.

vaalensis of 62, and checks of 135 (range 46–272). Assessment of visual seed head density in October and May also yielded similar results (Table 2a). Interspecific hybridization resulted in some progenies without any identifiable seed head that are candidates for vegetative type cultivar, and some progenies with highly prolific seed heads, which can be used to enhance seed yield.

Intra- and interspecific variation exists in base spring green-up temperatures for growth in warm-season turfgrass species (Unruh et al. 1996; Madakadze et al. 2003). A great variation for spring green-up was also reported among bermudagrass cultivars (Croce et al. 2001; Ntep 2006; Sever Mutlu et al. 2011). In this study, spring greenup reached 90 % among progenies as early as first week of April, while checks ('Tifway', 'Riviera', 'Princess 77') averaged 63 %, and parents *C. dactylon* 51 % and *C. transvaalensis* 60 % in Antalya (Table 2a). Fall dormancy averaged 27 % for checks, 52 % (range 10–100 %) for progenies, 42 % for *C. dactylon* parents (range 25–75 %), and 30 % for *C. transvaalensis* in mid-December in Antalya (Table 2a), with similar trend in Mersin location (Table 2b). Transgressive segregants (ex. 10 % dormancy) can be utilized to extend period for green cover in areas with subtropical climate. In parallel to fall dormancy, fall colour retention ranged from 1.0 (straw brown) to 6.0, with a mean of 3.2 for progenies, 4.6 for checks (range 3.8–5.3), 3.9 (range 2.0–5.5) for *C. dactylon* parents, 3.7 for *C. transvaalensis* on 15 December in Antalya. Taliaferro (2003) indicated that the ability of cultivars grown in subtropical environments to respond to chilling temperatures with minimal loss of colour and growth is a desired quality. Results indicate that variations exist for fall colour retention, dormancy and spring green up that can be utilized to develop cultivars with shorter winter dormancy and/or better fall colour retention.

The use of drought resistant turfgrass species and cultivars is one of the most important strategies to reduce irrigation requirement where water availability for landscape irrigation is increasingly limited (Carrow et al. 1990). Zhou et al. (2012) indicated that variation in drought resistance within the genus *Cynodon* has largely been neglected. Several studies of bermudagrass proved that wild ecotypes/genotypes selected from breeding programs performed better in drought conditions than popular commercial cultivars and might be an excellent source of drought resistance (Hays et al. 1991; Zhou et al. 2009, 2012). Leaf firing refers to leaf chlorosis and necrosis starting at leaf tips and margins, and progressing down the leaf in response to progressive drought stress. This character is a good indication of overall turfgrass drought resistance under field conditions provided that the drought stress treatment begins with the soil at field capacity throughout the root zone (Carrow 1996; Beard and Sifers 1997). Leaf firing after three weeks of drought stress ranged from 5 to 100 % with a mean of 69 % among progenies, 53 % for checks (range 45–57 %), 65 % for *C. dactylon* parents (range 15–90 %), and 55 % for *C. transvaalensis*. All genotypes, including parents and checks, reached complete dormancy at the end of drought stress period.

Turf recovery after drought stress is another indication of drought resistance (Beard and Sifers 1997). There was great variation for turf recovery among progenies after rewatering of plots. Percent turf recovery of the progenies after three weeks in Antalya and Mersin ranged from 20 to 100 % (avr. 73 %) and from 1 to 95 % (avg. 46 %) respectively. Corresponding figures were 70–85 % (avr. 77 %) and 47–50 % (avr. 48 %) for checks, 60–80 % (avr. 70 %) and 25–95 % (avr. 68 %) for *C. dactylon* and 65 % and 40 % for *C. transvaalensis* in Antalya and Mersin, respectively, three weeks after rewatering of plots (Table 2a and 2b). Although both locations had similar climatic conditions, they differed greatly for soil type, i.e. clay *vs.* sandy soil. Because the degree of drought injury depends upon the growing medium (soil), plant and atmospheric factors (Schmidt 1973) and sandy soils dry out quickly during dry periods, they are often incapable of supplying plants with enough water to meet the transpirational requirements (Emmons 2000). Therefore, the Mersin location, with a sandy soil type, represented a much harsher environment for plants during drought stress period, and this was observed as lower turf recovery rates than at Antalya. Transgressive segregation was observed for lower leaf firing under prolonged drought stress and fast recovery after drought stress in both locations, indicating the possibility to enhance drought resistance of bermudagrass cultivars. Beard and Sifers (1997) reported that *C. dactylon* genotypes selected under subtropical conditions (e.g. Mediterranean) were generally ranked higher for drought resistance compared to those selected under temperate conditions. The progenies superior for turfgrass characteristics and drought resistance, as demonstrated by lower leaf firing and better turf recovery values, can be utilized to broaden the genetic base for seeded type bermudagrass improvement.

Estimates of combining ability are useful in determining the breeding value of bermudagrass lines by suggesting the appropriate use in a breeding program. The general combining ability (GCA) is a measure of the additive genetic action, while the specific combining ability (SCA) is assumed to be a deviation from additivity (Sprague and Tatum 1942). Crossing a line (i.e. *C. transvaalensis*) to five *C. dactylon* provided the mean performance of the *C. transvaalensis* in all its crosses. This mean performance is called the general combining ability of the line. Any particular cross, then, has an expected value, which is the sum of the general combining abilities of its two parental lines. The cross may, however, deviate from this expected value to a greater or lesser extent. This deviation is called the specific combining ability of the two lines in combination. Griffing (1956) defined diallel crosses in terms of genotypic values where the sum of general combining abilities for the two gametes is the breeding value of the cross. We can assume the mean performance of hybrid progenies as GCA of the *C. dactylon* parental genotypes, as it involves the means of the SCA of a number of progenies, because of the fact that both parental lines are highly heterozygous in nature. Mean performance of hybrid progenies were used to calculate general combining abilities for *C. dactylon* (6x) and *C. transvaalensis* (2x) parental genotypes for establishment, turfgrass colour and quality, leaf texture, spring green-up, fall dormancy, drought resistance as assessed by leaf firing and turf recovery, growth habit, and seed head density (Table 3). GCA for establishment was significantly different among *C. dactylon* genotypyes where progenies obtained from crosses involving 190 were the slowest to establish. The *C. dactylon* 183 produced the best turfgrass quality in both locations. The *C. dactylon* 190 and 183 yielded the darkest green colour. The *C. dactylon* 121 and 190 produced progenies with the finest leaf texture. The *C. dactylon* 183 showed the earliest spring green-up. The 129 had the best fall colour retention as assessed by the lowest fall dormancy on 15 November and December. The *C. dactylon* 135 developed the lowest leaf firing two and three weeks under drought stress in both locations. And the *C. dactylon* 183 achieved a faster turf recovery than rest of the genotypes. The *C. dactylon* 190 and 183 yielded a more prostrate growth habit. The *C. dactylon* 121 yielded the highest and 135 the lowest seed head density. Significant variation for breeding values existed among parental genotypes for turfgrass characteristics and drought resistance attributes. The ranges indicate a high variation for SCA where a number of hybrid progenies were identified with commercialy competitive turfgrass colour and quality (Table 3).

Correlation coefficients among establishment rate (EST), turfgrass quality (TQ) and colour (TC), leaf firing (LF) under drought stress, turf recovery (REC) after drought stress, growth habit (GH), seed head density (VSD = visual seed head density; SD = seed head count), leaf texture (LT), fall dormancy (FD) and colour retention (FCR), and spring green up (GU) are presented in Table 4. The relatively high positive relationship were respectively found for all pairings of EST and TQ and GU, TQ and GU and LT, REC and GU, VSD and SD. The negative correlation were observed between TQ and FD, TC and GH, LF and REC, FD and FCR, FD and GU. The relatively high correlations between EST and TQ (r = 0.53) and EST and GU (r = 0.47) simply reflected the opportunity for spontaneous selection for the traits. TQ was also positively correlated with GU (r = 0.74), LT (r = 0.45) and REC (r = 0.35), but negatively correlated with FD (r = 0.35). Therefore, selection for plants with finer leaf texture, faster establishment, earlier spring green up, and better recovery after drought stress should improve the turfgrass quality. The negative correlations respectively between LF and REC (r = −0.38), and TC and GH (r = −0.45) indicate that plants with lower leaf firing under drought stress recovers better, and with prostrate growth habit exhibits darker green colour.

In conclusion, hybrid progenies exhibited transgressive segregation for establishment, turfgrass colour and quality, spring green-up, fall dormancy, fall colour retention, leaf firing under drought stress, and post-drought stress turf recovery. Bermudagrass, the hexaploid genotypes more so, is heterogenous; therefore, the progeny produced from mating the two species could have a phenotypic appearance that ranges from resembling *C. transvaalensis* to resembling *C. dactylon*. In a hexaploid *C. dactylon* (2n = 6x = 54) × diploid (2n = 2x = 18) *C. transvaalensis* cross, gamete contribution of hexaploid parent would be 3x = 27 and of diploid parent x = 9, creating a tetraploid (4x = 36) genotype. Once combined in a tetraploid background, alleles of both hexaploid and diploid parents can be used in development of seeded-type tetraploid cultivars. Allelic contribution of hexaploid and diploid genotypes into the tetraploid gene pool is expected to enhance turfgrass characteristics and drought tolerance of seeded-type bermudagrass cultivars. Reasons for the success of the interspecific hybrid cultivars in comparison with intraspecific cultivars undoubtedly are the result of the combining of desirable traits from the two respective species. Elite interspecific hybrid progenies combine the generally superior traits of common bermudagrass (darker green colour, greater turf performance, higher drought resistance) with the generally superior turfgrass characteristics of *C. transvaalensis* (fine texture and greater sod density). Parental genotypes exhibited a high variation in GCA for turfgrass characteristics and drought resistance. Thus, additive genetic variation exists among *C. dactylon* genotypes that can be utilized to broaden the genetic base of bermudagrass cultivars. Morphological and adaptive traits were significantly correlated with each other at varying magnitudes. Turfgrass quality was significantly associated with spring green up, leaf texture, establishment rate and turf recovery, indicating possibility for indirect selection.

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Table 4. Significant correlations between the adaptive, morphological, and drought resistance traits in 182 tetraploid (4x) progenies derived from crosses of five *C. dactylon* (6x) with one *C. transvaalensis* (2x) lines in Antalya, Turkey.

Traits	TQ	TC	LF	REC	GH	VSD	SD	LT	FD	FCR	GU
EST[1]	0.53**[2]	−0.26**	−0.09*	0.19**	0.09	0.35**	0.30**	0.25**	−0.23**	0.16**	0.47**
TQ	–	−0.15**	−0.18**	0.35**	−0.06	0.20**	0.16**	0.45**	−0.35**	0.22**	0.74**
TC		–	−0.16**	0.15**	−0.45**	−0.17**	−0.06	−0.21**	0.27**	−0.12*	−0.15**
LF			–	−0.38**	−0.007	0.11*	0.04	−0.03	0.17**	−0.19**	−0.17**
REC				–	−0.02	0.20**	0.14**	0.05	−0.25**	0.23**	0.35**
GH					–	0.16**	0.04	−0.18**	−0.20**	−0.22**	0.06
VSD						–	0.60**	0.18**	−0.23**	0.19**	0.29**
SD							–	0.16**	−0.07	0.02	0.15**
LT								–	−0.16**	0.12**	0.25**
FD									–	−0.77**	−0.38**
FCR										–	0.24**

[1] EST = Establishment rate at 4 weeks after transplanting into field; TQ = Turfgrass quality; TC = Turfgrass colour; LF = Turfgrass leaf firing at 3 weeks of drought stress; REC = Turfgrass recovery at 3 weeks of recovery after drought; GH = Growth habit; VSD = Visual assessment of seedhead density; SD = Seed head density; LT = Leaf texture; FD = Fall dormancy in December; FCR = Fall colour retention in December; GU = Spring green-up in April.

[2]*, ** Indicating significance at probability of 0.05 and 0.01, respectively.

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