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Hybrid zoysia grass potential for turf use in transitional climate zones of Türkiye

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Abstract: This study aimed to determine the winter survival of Turkish hybrid zoysia grasses under the transitional climate conditions of Isparta. The plant materials were the 214 hybrids developed from crosses involving *Zoysia japonica* and *Zoysia matrella* parents, and five commercial cultivars (Emerald, Empire, JaMur, Zenith, and Zeon) as controls. Spring green-up rates were assessed from May to July to evaluate post-winter recovery and adaptation. The findings suggest that a total of 37 hybrids (17%) did not survive winter cold stress. Significant variation in spring green-up rates was observed among the hybrids, with some outperforming both parents, demonstrating transgressive segregation. A total of 63 hybrids (29%) achieved 100% spring green-up, indicating their suitability for use in urban green spaces in regions with a transitional climate. Given the increasing importance of water conservation, these selected hybrids are highly recommended for use in larger-scale green area projects. Additionally, some hybrids outperformed commercial cultivars, suggesting that utilizing these locally developed hybrid lines could reduce dependence on foreign turfgrass varieties while offering sustainable solutions for landscape use without compromising turf quality.

Keywords: Hybrid lines, transitional climates, spring green-up, winter dormancy, zoysia grass.

Türkiye’nin geçiş iklim bölgelerinde hibrit zoysia çiminin kullanım potansiyeli

Öz: Bu çalışma, Isparta'nın geçiş iklim koşullarında Türk hibrit zoysia çimlerinin kışın hayatta kalma oranlarını belirlemeyi amaçlamıştır. Bitki materyali olarak *Zoysia japonica* ve *Zoysia matrella* ebeveynlerinin çaprazlamalarından elde edilen 214 melez ve kontrol olarak beş ticari çeşit (Emerald, Empire, JaMur, Zenith ve Zeon) kullanılmıştır. Kış sonrası geri gelme ve adaptasyonu değerlendirmek amacıyla, Mayıs'tan Temmuz'a kadar yeniden yeşillenme oranları belirlenmiştir. Bulgular, tüm hibritlerin %17’sini oluşturan toplam 37 hibrit hattın kış soğuk stresine dayanamadığını göstermiştir. Hibritler arasında ilkbaharda yeniden yeşillenme oranlarında önemli farklılıklar gözlemlenmiş olup bazı hatlar her iki ebeveynden de daha iyi performans göstererek transgresif açılım sergilemiştir. Toplamda 63 hibrit hat (%29) %100 yeşillenme oranına ulaşmış ve geçiş iklimine sahip bölgelerdeki kentsel yeşil alanlarda kullanım için uygun olduklarını göstermiştir. Su tasarrufunun giderek daha fazla önem kazandığı göz önünde bulundurulduğunda, bu hibritlerin geniş çaplı yeşil alan projelerinde kullanımı önerilmektedir. Ayrıca, bazı hibritler ticari çeşitlerden üstün performans sergilemiş olup bu yerel hibrit hatların kullanılması, çim sektöründeki dışa bağımlılığı azaltabilir ve yüksek çim kalitesini korurken peyzaj kullanımına sürdürülebilir çözümler sunabilir.

Anahtar kelimeler: Hibrit hatlar, geçiş iklimleri, ilkbaharda yeniden yeşillenme, kış dormansisi, zoysia çimi.

1. Introduction

Landscape design and management are essential for the efficient use of water resources, crucial for sustaining landscapes, enhancing aesthetic value, and maintaining ecological balance. However, the global water crisis has intensified due to rising demand from population growth, industrial activities, and agricultural irrigation, leading to widespread water scarcity that affects millions of people and ecosystems. Approximately 71% of the Earth's surface consists of water; however, just 2.5% is freshwater, the majority of which is sequestered in glaciers and aquifers (Kim & Lee, 2002), with less than 1% available for human use (Mishra, 2023). The depletion of water resources and

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rising demand underscore the need for sustainable water use strategies, especially in water-intensive sectors like agriculture and landscape management. Irrigated areas make up 20% of the world's arable land, consuming over 70% of global freshwater (Droogers et al., 2010). Thus, implementing water-saving techniques in landscape design is essential. Xeriscaping employs low water-requiring plants (Özyavuz & Özyavuz, 2012), and drip irrigation to minimize evaporation and runoff (Shareef et al., 2019), both of which are effective for water conservation. Additionally, rainwater harvesting systems capture and store rainwater for irrigation (Kinkade-Levario, 2007), while mulching helps preserve soil moisture and reduce evaporation (Patil Shirish, 2013). These techniques enhance water efficiency in landscapes, promoting ecological sustainability and economic savings. Selecting appropriate plants not only improves environmental sustainability but also enhances aesthetic appeal, conserves water, and protects biodiversity. Sustainable resource management requires the use of low-water plants in landscape designs due to the growing water scarcity.

Durability reflects a plant's ability to withstand harsh environments. It is necessary to choose winter-hardy species for colder climates and drought-resistant varieties for hot, dry regions. For example, turfgrass species like *Cynodon dactylon* L. (bermudagrass) and *Zoysia japonica* Steud. (zoysia grass) are resilient to drought and heavy foot traffic, making them ideal for parks and sports areas in tropical and subtropical regions. In transitional climates, where both cool-season (C_3) and warm-season (C_4) turfgrasses can thrive, choices should consider intended use, aesthetic goals, maintenance capabilities, and sustainability objectives. C_4 turfgrasses are generally more suitable due to their lower water requirements, which is increasingly important in times of water scarcity. They also demand less frequent irrigation, mowing, fertilization, and pesticide application, resulting in lower energy and material use, and a smaller carbon footprint. However, Çakır & Tuğluer (2021) revealed that predominantly C_3 turfgrass mixtures were used in three urban parks in Isparta, indicating an underutilization of more sustainable turfgrass options.

Improving water use efficiency in landscape management and agricultural irrigation is essential under increasing water scarcity. One effective strategy is using drought-resistant species and varieties, with C_4 plants being significant alternatives due to their water-saving potential. In transitional climate zones, prioritizing C_4 species over C_3 can enhance sustainable landscape practices by optimizing water use, making C_4 turfgrasses a better option for sustainable landscaping.

Zoysia grass is a perennial C_4 turfgrass, valued for its dense texture and resilience against drought, foot traffic, weeds, diseases, and pests, and has recently been adopted in Türkiye. However, its widespread use is limited because of slow growth rate, prolonged establishment and dormancy periods, insufficient adaptability studies for Türkiye's climates, and high costs of seeded and hybrid varieties. Despite these challenges, zoysia grass excels in shaded environments compared to bermudagrass, which tends to thin out. It also requires less maintenance, offers superior drought tolerance, and provides dense coverage that suppresses weeds.

The *Zoysia* genus includes eleven species, but only a few are commonly used as turfgrass, including *Z. japonica* (Steud.), *Z. matrella,* (L.) Merr., *Z. pacifica* (Goudsw.) M. Hotta & Kuroki, and hybrids like *Z. japonica* × Z. *matrella* and *Z. japonica* × *Z. pacifica* (Magni et al., 2017). These species differ in both morphological characteristics and resilience to stress conditions (Riffell et al., 1995; Dunn et al., 1999; Reinert & Engelke, 2001; White et al., 2001; Patton & Reicher, 2007; Trappe et al., 2011; Wherley et al., 2011; Patton et al., 2017; Irkörücü, 2018). Each *Zoysia* species offers distinct advantages, suggesting potential for increased use in Türkiye as research and applications expand.

Hybridization in plants enhances genetic diversity and improves specific traits, often resulting in new species or varieties. Plant breeders commonly use this method to develop high-performance varieties, with hybrid zoysia grasses exemplifying this approach. These hybrids, created by crossbreeding species like *Z. japonica, Z. pacifica,* and *Z. matrella*, are particularly well-suited for warm climates, making them ideal for landscaping and sports fields due to their resilience. Hybrids involving *Z. japonica* are especially promising for transitional climates, offering cold resistance, improved water use efficiency, disease resistance, and lower maintenance requirements (Reinert & Engelke, 2001; White et al., 2001). The combination of *Z. japonica* and *Z. matrella* is advantageous, as *Z. japonica* provides cold tolerance and rapid growth, while *Z. matrella* offers finer texture, superior turf quality, and better shade resistance (Patton et al., 2017). By selecting these species as primary and secondary parents, breeders can create optimal traits for various environments. It was hypothesized that hybrid zoysia grasses with strong survival rates can establish high-quality, sustainable green spaces in Türkiye's transitional climate, serving as a viable alternative to traditional C_3 grass species. This study aimed to determine the winter survival potential of the Turkish hybrid zoysia grass lines under the transitional climate conditions of Isparta. The results of this study are expected to contribute to the creation of high-quality and sustainable green areas in transitional climates.

2. Materials and Methods

The field evaluation was conducted in Isparta province (37.808333 °N, 30.527500 °E), Türkiye, during 2020 and 2021. A total of 214 hybrid lines developed through reciprocal interspecific hybridizations between *Z. japonica* and *Z. matrella* at Akdeniz University (Antalya, Türkiye), as part of the "TAGEM/17/ARGE/15" project were evaluated in the study. These hybrid lines, with potential for use as turfgrass, were selected through a preliminary evaluation of hybrid genotypes developed based on general turfgrass characteristics such as growth rate, leaf texture (coarse or fine), color (dark or light green), and growth habit (dwarf or upright). Alongside the hybrids, two zoysia grass lines (*Z. japonica* and *Z. matrella*) used as parents in the crosses, and five commercially available zoysia grass cultivars (Emerald, Empire, JaMur, Zenith, and Zeon) as controls were included in the study. Commercially available zoysia grass cultivars preferred in green spaces in the Mediterranean region of Türkiye were selected for the study. Their adaptation to Mediterranean growing conditions of Türkiye has been reported (Avcıoğlu & Geren; 2012; Severmutlu et al., 2011a; 2011b; Kır et al., 2018). The adaptation of the commercial varieties used as controls has not been determined in Isparta. Among the 214 hybrid lines, 80 were produced from the crossbreeding of *Z. japonica* (♀) with *Z. matrella* (♂), while 134 lines resulted from the crossbreeding of *Z. matrella* (♀) with *Z. japonica* (♂).

The research area is located in the transitional climate zone, which includes both Mediterranean and continental climates. Based on 33 years of temperature observations for Isparta, the annual average temperature for the province is 12.5 °C. Furthermore, the annual average maximum temperature is 19.0 °C, whereas the annual average minimum temperature is 6.4 °C. The warmest months in Isparta are July and August, and the coldest months are January and February. The annual precipitation is 568 mm, accompanied by average of 99 rainy days per year (General Directorate of Meteorology, 2024). Table 1 presents the climate data for Isparta during the trial period, showing seasonal temperature and precipitation variations.

Table 1. Monthly climate data for Isparta: temperature and precipitation averages.

Months	Avg. Temp. (°C)	Avg. High Temp. (°C)	Avg. Low Temp. (°C)	Avg. Monthly Precip. (mm)
September2020	19.8	28.1	11.8	14.7
October 2020	14.5	23.2	7.6	35.6
November 2020	9.2	15.6	2.5	41.6
December 2020	4.5	9.2	1.3	58.9
January 2021	2.2	7.2	-1.2	60.7
February 2021	3.8	8.7	0.5	50.1
March 2021	7.1	13.0	1.6	52.3
April 2021	11.8	18.4	5.2	48.9
May 2021	17.0	19.0	9.3	49.8
June 2021	21.2	23.5	13.4	28.9
July 2021	25.1	32.4	17.1	17.8
August 2021	24.6	33.1	16.8	15.4

Table 2. Soil properties of the trial area.

Analysis Name		Analysis Method	Unit	Results
Texture	Sand	Bouyoucos Hydrometer	%	32
	Silt	Bouyoucos Hydrometer	%	25
	Clay	Bouyoucos Hydrometer	%	43
EC		(1:2.5)	dS/m	0.22
pH		(1:2.5)	-	7.81
Lime		(Calcimetric)	%	14.41
Organic Matter		(Walkley Black)	%	1.10
Nitrogen		(Kjeldahl)	ppm	650
Phosphorus		(Olsen-Spectrophotometer)	ppm	11.50
Potassium		(A. Acetate-AAS)	ppm	210.77
Calcium		(A. Acetate-AAS)	ppm	8,798.20
Magnesium		(A. Acetate-AAS)	ppm	611.22
Iron		(DTPA-AAS)	ppm	2.74
Copper		(DTPA-AAS)	ppm	1.29
Manganese		(DTPA-AAS)	ppm	8.65
Zinc		(DTPA-AAS)	ppm	0.98

The field treatment plots, measuring 1 m × 1 m, were organized in a trial designed as a randomized complete block with three replications. The soil sample taken from a depth of 0-30 cm from the experimental field was analyzed in accordance with the principles reported by Jackson (1962). The pH, salinity, organic matter content, texture classes, and nutrient contents of the soil in the experimental field are presented in Table 2. The experimental field has a clay loam texture, non-saline (low EC), slightly alkaline pH, high lime, and low organic matter content.

Prior to planting, the trial area was cultivated between August and September and mechanically cleared of weeds. The topsoil was graded and rolled to ensure an even surface. Throughout the trial period, no fertilizers or pesticides were applied. On September 21, 2020, three grass plugs were harvested from each genotype cultivated in the Akdeniz University Research Field using a grass profile sampling tool with a diameter of 10.8 cm (A = 91.61 cm^2). The harvested grass profiles were promptly transported to Isparta, where they were individually planted in the designated plots on the same day. Following planting, irrigation was applied using a sprinkler system at a rate of 7 mm three times daily for two weeks to support establishment and subsequently reduce visual turfgrass stress symptoms. Weeds were mechanically controlled at regular intervals, and no incidents requiring pest control were recorded.

The assessment of spring green-up, indicative of both the transition from winter dormancy to active spring growth and winter survival, was conducted between May and July. Spring green-up was quantified using a visual estimate scale ranging from 0% to 100%, where 0% indicates the absence of green vegetation cover and 100% signifies complete coverage of the plot with green vegetation (Severmutlu et al., 2011b). The data were analyzed using the PROC GLM procedure in SAS (version 9.1; SAS Institute, Cary, NC, USA). Mean comparisons were performed using Fisher's protected least significant difference (LSD) test at a 0.05 significance level.

3. Results and Discussion

The optimal growth temperature for *Zoysia* species ranges from 25 to 35 °C (Xie, 2015). Like other C_4 turfgrass species, *Zoysia* species enter a dormant state during the fall and winter months as temperatures decrease. *Zoysia* species and cultivars vary in their genetic ability concerning the onset of dormancy, tolerance to low temperatures in winter months, and coming back from dormancy in the spring (Pompeiano et al. 2014; Engelke & Anderson 2003). During the dormant period, turfgrasses lose their green color and turn straw yellow, and they typically return to their green color as temperatures rise in the spring. Consequently, it is advantageous for warm-season turfgrasses to enter dormancy late in the fall and to green up early in the spring, maintaining their green color for an extended period. As air temperatures dropped in late November, hybrid zoysia grasses began to enter dormancy. From mid to late May, as temperatures began to rise, the plants began their green-up phase. Table 3 presents data on the spring green-up of the hybrids observed between May and July. Spring green-up refers to the transition of dormant turfgrass from a winter-damaged state to active growth (Morris & Shearman, 2006). The data on the spring green-up of the genotypes are critical for assessing their post-winter adaptation success. Understanding these characteristics can help to identify and develop more resilient cultivars that can withstand winter stresses and recover effectively in the spring. While most hybrids exhibited a relatively low spring green-up rate on May 19, a significant increase was observed from June 10 onwards. This trend suggests that the spring green-up process accelerated in response to the increased temperatures observed in the second half of May. Similarly, Rimi et al. (2011), Severmutlu et al. (2011b), Pompeiano et al. (2014) and Oh et al. (2015) reported that rising temperatures accelerate spring green-up. This phenomenon is attributed to enhanced photosynthetic activity and metabolic processes stimulated by temperature fluctuations. Significant differences were found among hybrids in the spring green-up rate (Table 3). For example, the MJ46 genotype showed a 60% spring green-up on the 19th of May, while many of the other genotypes did not begin the spring green-up process on that date.

These results highlight the existence of considerable variation in the genetic ability of hybrids to adapt to the prevailing climatic and soil conditions in the region. Previous studies have also reported both intra- and interspecific variation in spring green-up temperatures among C_4 turfgrasses (Croce et al., 2001; Severmutlu et al., 2011b). The 63 different hybrids (29%) namely, JM-14, JM-19, JM-25, JM-30, JM-38, JM-4, JM-7, JM-9, JM-e46, JM-e47, JM-e51, JM-e55, JM-G75, JM-h77, JM-h79, JM-z57, JM-z61, JM-z62, JM-z69, JM-z74, JM-zm1, JM-zm3, MJ-103, MJ-104, MJ-11, MJ-111, MJ-112, MJ-12, MJ-17, MJ-18, MJ-22, MJ-24, MJ-25, MJ-26, MJ-42, MJ-44, MJ-46, MJ-49, MJ-5, MJ-50, MJ-53, MJ-54, MJ-56, MJ-59, MJ-6, MJ-62, MJ-65, MJ-69, MJ-74, MJ-8, MJ-87, MJ-88, MJ-92, MJ-95, MJ-e115, MJ-e116, MJ-mz1, MJ-mz10, MJ-mz2, MJ-mz4, MJ-mz9, MJ-T2, and MJ-T5 exhibited a rapid spring green-up process beginning on May 19, achieving a 100% spring green-up rate within a short period. These hybrid lines represent promising candidates for successful adaptation in transitional climate, such as Isparta.

Table 3. Spring green-up rates (%) of the genotypes.

No.	Genotypes	May 19	June 10	June 22	July 1	No.	Genotypes	May 19	June 10	June 22	July 1
	Commercial Cultivars					65	JM-z62	10	0	70	100
1	Emerald	1	5	10	25	66	JM-z63	5	15	40	75
2	Empire	5	15	85	100	67	JM-z64	0	0	0	0
3	JaMur	25	75	100	100	68	JM-z65	5	10	40	80
4	Zenith	20	30	60	90	69	JM-z66	5	10	35	70
5	Zeon	5	25	50	85	70	JM-z67	5	15	25	50
	Parental Lines					71	JM-z68	5	35	60	90
1	*Z. matrella*	1	8	15	30	72	JM-z69	10	40	85	100
2	*Z. japonica*	0	10	35	72	73	JM-z70	5	25	55	85
	Hybrids (*Z. japonica*♀ x *Z. matrella*♂)					74	JM-z71	0	0	5	10
1	JM-10	5	10	45	70	75	JM-z72	5	5	10	20
2	JM-11	5	10	35	60	76	JM-z73	1	0	0	0
3	JM-12	5	10	20	40	77	JM-z74	10	30	70	100
4	JM-13	5	25	60	90	78	JM-zm1	35	90	100	100
5	JM-14	10	35	70	100	79	JM-zm2	10	30	70	95
6	JM-15	1	5	20	40	80	JM-zm3	5	35	70	100
7	JM-16	5	20	50	70		Hybrids (*Z. matrella*♀ x *Z. japonica*♂)				
8	JM-17	0	0	0	0	1	MJ-1	0	0	0	0
9	JM-19	35	90	95	100	2	MJ-10	5	35	75	95
10	JM-2	5	35	55	85	3	MJ-100	0	0	0	0
11	JM-20	0	10	0	0	4	MJ-101	5	35	55	90
12	JM-21	5	5	30	50	5	MJ-102	1	10	35	55
13	JM-22	0	0	0	0	6	MJ-103	15	50	90	100
14	JM-23	5	25	45	75	7	MJ-104	5	25	70	100
15	JM-24	10	15	40	70	8	MJ-105	0	0	0	0
16	JM-25	10	40	70	100	9	MJ-106	0	0	0	0
17	JM-26	5	1	30	75	10	MJ-107	1	20	45	75
18	JM-27	0	0	0	0	11	MJ-108	0	0	0	0
19	JM-28	0	0	0	0	12	MJ-109	5	20	70	85
20	JM-29	5	25	50	85	13	MJ-11	10	45	95	100
21	JM-3	5	35	60	90	14	MJ-110	1	0	5	20
22	JM-30	10	30	65	100	15	MJ-111	5	40	85	100
23	JM-31	10	35	60	95	16	MJ-112	10	35	70	100
24	JM-32	0	25	45	70	17	MJ-113	10	20	50	75
25	JM-33	1	10	40	75	18	MJ-114	5	15	40	75
26	JM-34	5	10	30	65	19	MJ-12	15	90	100	100
27	JM-35	0	0	0	0	20	MJ-13	10	35	50	80
28	JM-36	0	0	0	0	21	MJ-14	0	1	5	10
29	JM-37	0	0	10	25	22	MJ-15	5	15	50	85
30	JM-38	35	45	100	100	23	MJ-16	5	25	65	95
31	JM-39	0	0	0	0	24	MJ-17	15	25	90	100
32	JM-4	10	35	75	100	25	MJ-18	10	25	75	100
33	JM-40	15	25	60	85	26	MJ-19	0	0	0	0
34	JM-41	1	5	10	25	27	MJ-2	0	5	10	25
35	JM-42	0	0	0	0	28	MJ-20	5	15	40	65
36	JM-43	0	0	0	0	29	MJ-21	0	5	10	15
37	JM-44	1	10	40	65	30	MJ-22	20	30	80	100
38	JM-5	10	30	70	95	31	MJ-23	5	30	50	80
39	JM-6	0	0	0	0	32	MJ-24	10	40	32	100
40	JM-7	20	50	80	100	33	MJ-25	20	50	90	100
41	JM-8	5	30	50	85	34	MJ-26	5	45	80	100
42	JM-9	10	45	75	100	35	MJ-27	5	25	50	85
43	JM-e44	0	0	0	0	36	MJ-28	5	20	50	85
44	JM-e46	10	40	95	100	37	MJ-29	5	25	55	70
45	JM-e47	10	35	75	100	38	MJ-3	0	0	0	0
46	JM-e48	5	10	55	80	39	MJ-30	5	15	39	85
47	JM-e49	10	35	55	85	40	MJ-31	0	0	0	0
48	JM-e50	10	10	35	70	41	MJ-32	5	15	35	70
49	JM-e51	25	90	100	100	42	MJ-33	0	0	0	0
50	JM-e52	1	1	5	20	43	MJ-34	1	10	20	35
51	JM-e53	0	0	0	0	44	MJ-35	5	35	60	95
52	JM-e54	5	5	15	25	45	MJ-36	5	30	50	80
53	JM-e55	10	40	95	100	46	MJ-37	10	30	75	95
54	JM-g75	15	50	90	100	47	MJ-38	15	45	60	85
55	JM-h76	5	15	50	85	48	MJ-39	0	10	30	60
56	JM-h77	40	50	85	100	49	MJ-4	0	5	15	30
57	JM-h78	0	1	10	25	50	MJ-40	5	15	50	80
58	JM-h79	30	95	100	100	51	MJ-42	20	90	100	100
59	JM-z	5	10	10	25	52	MJ-43	1	5	10	25
60	JM-z56	10	45	45	75	53	MJ-44	5	30	70	100
61	JM-z57	10	45	80	100	54	MJ-45	0	10	30	70
62	JM-z59	1	1	10	25	55	MJ-46	60	90	100	100
63	JM-z60	5	5	10	20	56	MJ-47	5	20	55	85
64	JM-z61	15	40	70	100	57	MJ-48	0	5	5	20

Table 3. Spring green-up rates (%) of the genotypes (continued).

No.	Genotypes	May 19	June 10	June 22	July 1	No.	Genotypes	May 19	June 10	June 22	July 1
58	MJ-49	5	30	80	100	97	MJ-84	0	0	0	0
59	MJ-5	5	30	70	100	98	MJ-85	5	15	40	80
60	MJ-50	5	15	70	100	99	MJ-86	5	30	55	85
61	MJ-51	5	20	45	75	100	MJ-87	15	40	85	100
62	MJ-52	1	15	20	40	101	MJ-88	10	70	85	100
63	MJ-53	10	45	70	100	102	MJ-89	5	25	60	85
64	MJ-54	10	45	85	100	103	MJ-9	5	25	60	90
65	MJ-55	5	1	10	25	104	MJ-90	5	5	45	85
66	MJ-56	10	75	80	100	105	MJ-91	1	0	5	10
67	MJ-57	5	30	65	95	106	MJ-92	15	45	100	100
68	MJ-58	0	0	0	0	107	MJ-93	5	20	60	85
69	MJ-59	20	35	75	100	108	MJ-94	5	25	55	85
70	MJ-6	5	30	70	100	109	MJ-95	15	40	90	100
71	MJ-60	5	10	15	30	110	MJ-96	5	10	40	80
72	MJ-61	0	0	0	0	111	MJ-97	5	10	40	65
73	MJ-62	10	40	100	100	112	MJ-98	1	5	10	25
74	MJ-63	0	0	0	0	113	MJ-99	0	0	0	0
75	MJ-64	0	0	0	0	114	MJ-e115	10	40	70	100
76	MJ-65	15	60	90	100	115	MJ-e116	10	40	85	100
77	MJ-66	0	5	15	30	116	MJ-mz1	10	40	75	100
78	MJ-67	1	5	5	15	117	MJ-mz10	10	40	95	100
79	MJ-68	0	0	0	0	118	MJ-mz11	5	40	40	75
80	MJ-69	5	20	50	100	119	MJ-mz12	1	10	10	25
81	MJ-7	0	0	0	0	120	MJ-mz2	35	80	95	100
82	MJ-70	5	15	35	70	121	MJ-mz3	0	0	10	20
83	MJ-71	1	0	10	30	122	MJ-mz4	10	30	70	100
84	MJ-72	0	0	0	0	123	MJ-mz5	1	5	35	70
85	MJ-73	1	15	65	90	124	MJ-mz6	0	0	0	0
86	MJ-74	5	25	70	100	125	MJ-mz7	0	0	0	0
87	MJ-75	1	15	35	75	126	MJ-mz8	5	10	50	80
88	MJ-76	0	0	0	0	127	MJ-mz9	10	35	70	100
89	MJ-77	5	5	30	65	128	MJ-T1	5	20	60	95
90	MJ-78	10	25	45	70	129	MJ-T2	15	40	80	100
91	MJ7-9	1	5	40	75	130	MJ-T3	1	5	10	20
92	MJ-8	30	75	100	100	131	MJ-T4	1	15	40	70
93	MJ-80	10	20	20	40	132	MJ-T5	10	45	85	100
94	MJ-81	1	1	10	20	133	MJ-T6	5	20	35	55
95	MJ-82	0	0	0	0	134	MJ-T7	5	5	10	15
96	MJ-83	5	5	20	50		$LSD_{0.05}$	4.9	9.6	13.2	16.8

On the other hand, 37 hybrids (17%) including JM-17, JM-20, JM-22, JM-27, JM-28, JM-35, JM-36, JM-39, JM-42, JM-43, JM-6, JMe-44, JMe-53, JMz-64, JMz-73, MJ-1, MJ-100, MJ-105, MJ-106, MJ-108, MJ-19, MJ-3, MJ-31, MJ-33, MJ-58, MJ-61, MJ-63, MJ-64, MJ-68, MJ-7, MJ-72, MJ-76, MJ-82, MJ-84, MJ-99, MJ-mz6, and MJ-mz7 had a 0% spring green-up rate, indicating they suffered from winterkill and fully died out. These hybrids probably did not initiate dormancy until it got too cold for them to survive under cold winter conditions in Isparta. These underperforming hybrid lines may have slower growth rates or be less tolerant of environmental stresses. These hybrids may require very short dormancy and it may be conceivable to test these hybrids in regions having mild winter climatic conditions to evaluate their adaptability and survival.

To effectively illustrate the overall spring green-up performance trends, the analysis conducted using quartiles (25%) is presented in Table 4. A significant proportion of the hybrids (49%) exhibited relatively high performance, achieving a spring green-up rate of 76% or above by July 1. These elevated adaptation rates suggest that certain hybrid zoysia grasses may represent a promising option for transition climatic zones. This performance is particularly important considering that hybrid zoysia grasses have been highlighted in literature for their superior tolerance to environmental stressors, including drought and cold. Beard (1973) reported that zoysia grass had a greater tolerance to freezing than other warm-season turf grasses, and Dunn et al. (1999) demonstrated a wide range of cold tolerance among zoysia grass cultivars. The high spring green-up rates of some genotypes, which reached 100% green-up, echo the results of the study by Pompeiano et al. (2014), who reported strong adaptability and rapid green-up in certain *Zoysia* genotypes in the transitional climate zone of Italy. Figure 1 visualizes the frequencies and distribution of spring green-up rates across the genotypes on the specified observation dates.

0% spring green-up: This group includes 37 distinct hybrids, which faced difficulty adapting to Isparta's climate. This suggests that these hybrids probably suffered from winter kill Surprisingly, in 15 of these hybrids (41%), the maternal parent was *Z. japonica* which is well known for its best tolerance to low temperatures among all zoysia grass species (Emmons, 2000). This result suggests that resistance to cold temperatures may not be associated with maternal inheritance. It also further indicating large intra and inter-specific variation exist among zoysia grasses. Overall the hybrids in this group apparently have low dormancy requirements and, hence do not become dormant before the onset of cold winter onset. Hence, they could not survive winter cold in a non-dormant state, making these genotypes unsuitable for Isparta.

1-25% spring green-up: The range encompasses 25 distinct hybrids. The genotypes that demonstrated markedly suboptimal spring green-up performance were also unable to thrive in the environmental conditions of Isparta. The inability of these genotypes to demonstrate complete spring green-up can be attributed to their higher temperature requirements and their relatively slow growth/regeneration habit.

26-50% spring green-up: A total of 12 hybrids are present within this group. The genotypes exhibited low-to-medium spring green-up rates. These genotypes exhibited some degree of success, although the results were far from optimal. Since their regional adaptations have only been partially achieved, further improvement studies are necessary to enhance success in other settings. These genotypes may exhibit greater efficacy under certain ecological niches where springs are earlier or warmer than Isparta region.

51-75% spring green-up: A total of 34 genotypes within this group have shown relative success in adapting to the climatic conditions of Isparta. These genotypes were characterized by their relatively high spring green-up rates and moderate resistance to stress factors. Further testing is necessary to ascertain the optimal conditions for these genotypes. There is potential for these genotypes to be cultivated on a larger scale, provided they continue to adapt well to the prevailing environmental conditions. The likelihood of these genotypes serving as a sustainable option in the transitional climate zone is considerable.

76-99% spring green-up: The presence of 43 distinct genotypes within this group indicates significant performance under Isparta conditions. These genotypes are promising regarding both spring green-up, winter survival, and overall adaptation to the region. Utilizing these genotypes in green spaces in Isparta will potentially contribute to water conservation efforts. Additionally, testing these genotypes in different transition zones could help determine their success in other regions. Future studies should focus on a more detailed examination of these genotypes, particularly evaluating characteristics such as drought tolerance and water use efficiency.

100% spring green-up: This group includes 63 distinct genotypes, demonstrating a notable degree of success. These genotypes are well-suited to both the climatic and environmental conditions of Isparta, indicating that they can effectively complete their growth cycles. It is recommended that these genotypes be widely disseminated and serve as references for future similar projects. They may represent optimal choices for water conservation, durability, and longevity. Future studies should conduct a more detailed examination of these genotypes, focusing on their drought tolerance and water use efficiency. The genotypes in this group show potential for commercial application since their performance is likely to be comparable to, if not superior to, that of currently available commercial genotypes. However, their success should be validated through testing in larger areas. Moreover, assessments of their stress resistance and other turf performance characteristics are crucial before implementing them widely.

To provide a comprehensive assessment, Table 5 presents the means, standard deviations, and ranges for the spring green-up data of the hybrids, parental lines, and commercial cultivars used in the study. The findings show that, up until the second half of June, some of the hybrids outperformed commercial checks in terms of spring green-up performance and then showed comparable results. For example, on June 10, the spring green-up ratio of some hybrids was as high as 95%, whereas it was only between 5 and 75% in the commercial cultivars. Commercial zoysia grass varieties used in this study are widely used in the turfgrass market in Türkiye. These lines serve as benchmarks, showcasing stable performance under specific environmental conditions. To evaluate the commercialization potential of hybrid lines, it is crucial to conduct direct comparisons with existing commercial varieties. Such comparisons highlight the relative advantages or disadvantages of the hybrid lines, providing insight into their competitive position against current market alternatives.

Several individual hybrid lines, including MJ-46 and JM-19, have surpassed the performance of all the commercial checks, which in turn indicates their potential for commercialization. The commercial cultivars also demonstrated significant differences in their spring green-up rate among them. JaMur and Empire consistently excelled throughout the measurement periods, reaching 100% green-up in June 22 and July 1, respectively. Emerald ranked the lowest, achieving a maximum spring green-up rate of only 25% in Isparta. Zeon followed with a maximum rate of 85%, showing gradual improvement over time. Zenith attained a maximum spring green-up rate of 90%. Empire also performed well, reaching a maximum of 100%. The performance of commercial varieties, especially JaMur and Empire also supports the hypothesis that zoysia grass can be an alternative to C_3 turfgrass species in Isparta.

In hybridization studies, the performance and genetic characteristics of parental genotypes determine the quality and adaptability of the resulting hybrids. The parents play a crucial role in determining the hybrids' resistance to various stress factors, including diseases, drought, and adverse climatic conditions. Comparative analyses are essential for assessing the degree of genetic divergence between the hybrids and their parent varieties. By evaluating the hybrids in relation to the parental lines, researchers can ascertain whether the desired traits have been effectively expressed in the hybrid lines. The parental lines exhibited lower spring green-up rates compared to the hybrids. On June 10, when the mean spring green-up rates of *Z. japonica* and *Z. matrella* parents were 10% and 8%, respectively, the average spring green-up rate of hybrids (n = 214) varied from 0 to 95% (Table 5). Thus, transgressive segregation was evident for earlier spring green-up and better winter survival among hybrid progenies. In general, the parental line *Z. japonica* demonstrated better spring green-up performance than *Z. matrella*.

Table 4. Distribution of genotypes according to spring green-up rates as of July 1.

Spring green-up percentage range	Number of the genotypes	% of all genotypes
0%	(15)◊+(22)▫=37	17
1% - 25%	(10)+(15)=25	12
26% - 50%	(8)+(4)=12	6
51% - 75%	(14)+(20)=34	16
76 % - 99%	(15)+(28)=43	20
100%	(22)+(41)=63	29

◊, ▫: Numbers in the first parentheses represent *Z. japonica* ♀ x *Z. matrella* ♂ hybrids, and numbers in the second parentheses represent *Z. matrella* ♀ x *Z. japonica* ♂ hybrids.

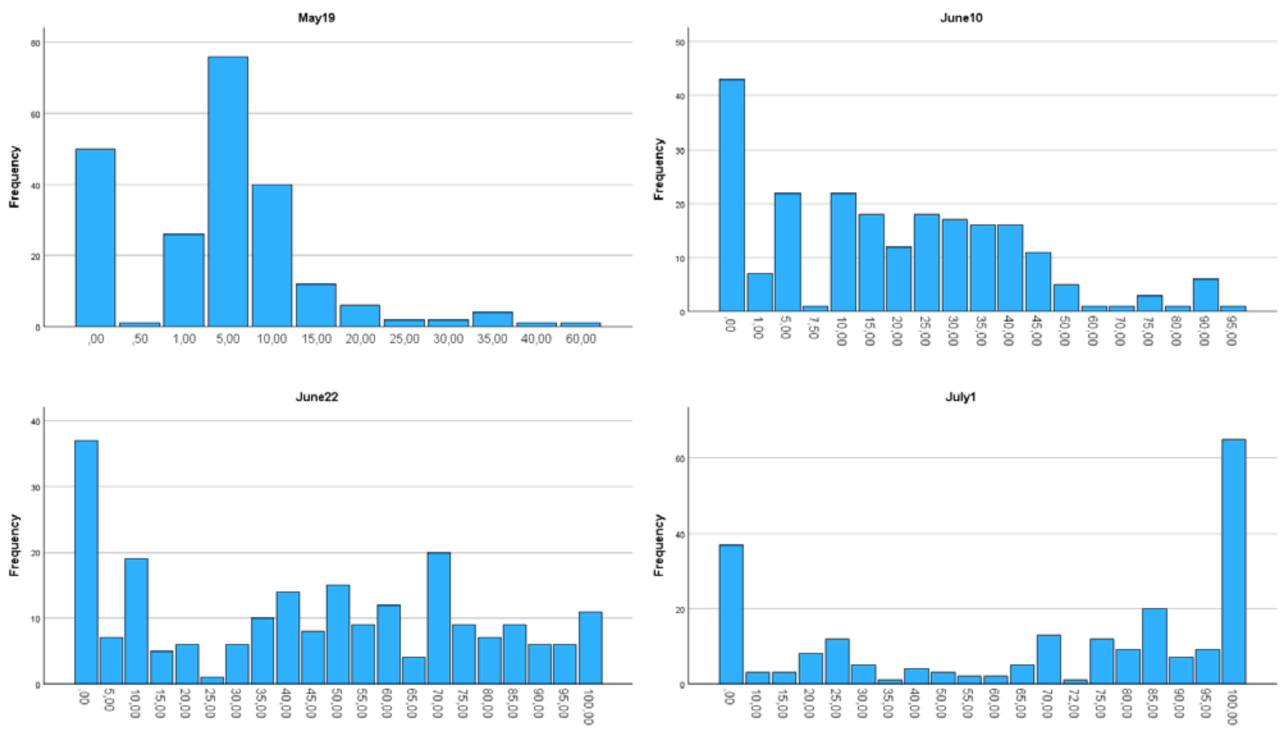

Figure 1. Spring green-up frequency distribution of genotypes.

Table 5. Means, standard deviations, and ranges for spring green-up of hybrid zoysia grass genotypes developed from crosses of *Z. japonica* with *Z. matrella* along with parental lines and five commercial zoysia grass cultivars (Emerald, Empire, JaMur, Zenith, and Zeon) in Isparta, Türkiye.

	Commercial Cultivars		Parental Lines		Hybrid lines			
			Z. japonica	*Z. matrella*	*Z. japonica*♀ x *Z. matrella*♂		*Z. matrella*♀ x *Z. japonica*♂	
	X̄ ± SE	m-M	X̄ ± SE	X̄ ± σ	X̄ ± SE	m-M	X̄ ± SE	m-M
May 19	11.2±2.49	1-25	0.0±0.00	0.5±0.00	7.40±0.57	0-40	6.03±0.39	0-60
June 10	30.0±6.53	5-75	10.0±1.15	7.5±1.44	21.80±1.48	0-95	21.78±1.04	0-90
June 22	61.0±7.51	10-100	35.0±1.73	15.0±1.73	42.63±2.09	0-100	44.51±1.62	0-100
July 1	80.0±6.45	25-100	71.7±1.15	30.0±1.73	61.19±2.50	0-100	63.25±1.91	0-100

X̄: Mean; SE: Standart Error; m: Minimum; M: Maximum

4. Conclusion

This study represents one of the first comprehensive investigations into the performance of *Zoysia* species in the transitional climate zones of Türkiye. It found that some hybrid zoysia grasses are more resilient to winter cold and green up faster in spring, with 50% showing green-up rates between 76% and 100%, outperforming commercial cultivars. These Turkish-origin local hybrids have strong potential for reducing water usage in green areas and may reduce dependency on imported turfgrass.

Since the study was conducted only in Isparta, the findings may not be generalizable to other regions. Further studies are needed in both transitional and different climatic zones. Evaluating the performance of these hybrids in different climatic and soil conditions may help to better understand the general adaptation potential of the zoysia grasses. Moreover, additional research should be done on the long-term performance of these hybrids, especially their resilience to deficient irrigation conditions and climate change.

Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

M.Ç: Conceptualization, methodology, investigation, resources, data curation, formal analysis, visualization, writing – original draft, writing – review & editing, project administration. S.S.M: Conceptualization, methodology, resources, visualization, writing – original draft, writing – review & editing.

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