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Cold Tolerance of Hybrid Bermudagrass in a Cool-season, Semiarid Climate

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Abstract. **Cool-season C_3 grasses struggle to tolerate increasing global temperatures rise and require relatively higher rates of scarce water supplies. Common bermudagrass (*Cynodon dactylon*; CBG), African bermudagrass (*C. transvaalensis*; ABG), and their triploid interspecific hybrid [*C. dactylon* (L.) Pers. × *C. transvaalensis* Burtt Davy; HBG] are warm-season C_4 grasses that may be increasingly more suited for northern ecosystems traditionally classified as transitional or cool-season climates. The objective of this study is to compare one CBG, one ABG, and six HBG cultivars to a blend of Kentucky bluegrass (KBG) cultivars for cold tolerance in a cool-season, semiarid climate. Although KBG had a longer growing season than any bermudagrass, all HBG cultivars greened up within the same window of time. The CBG had the shortest growing season of all genotypes. After averaging dates for green up and dormancy in both years, the HBG cultivars Tahoma 31, Iron Cutter, and NorthBridge performed best of all bermudagrasses tested and may provide an alternative to KBG in climates similar to the Utah study location.**

Turfgrass is the principle managed land cover in urban areas, but with increasing global urbanization, its impact on the planet is rising (Robbins and Birkenholtz 2003; Shimoda and Oikawa 2006). Turfgrass can benefit society by providing spaces for entertainment and recreation, improving human health, and supporting environmental processes (Beard and Green 1994; Monteiro 2017; Wentz et al. 2016). In contrast to synthetic grass surfaces, properly managed grass minimizes injuries to users and moderates temperatures (Christensen et al. 2012; Jastifer et al. 2019; Monteiro 2017; Petrass et al. 2015).

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Despite its benefits, turfgrass is under scrutiny due to environmental issues, such as atmospheric pollution (LeMonte et al. 2016). This also includes problems related to high water consumption, especially as higher temperatures and droughts become more common across the globe (Burgin et al. 2022; Caretta and Mukherji 2023; Romero and Dukes 2014; St. Hilaire et al. 2008; Svedin et al. 2021; Wentz et al. 2016; Wherley et al. 2014). Water availability is increasingly limited in the arid and semiarid regions of the United States, India, China, and Africa (Caretta and Mukherji 2023). The US Intermountain West (IMW) is an example with an arid/semiarid, cool-season region where Kentucky bluegrass (*Poa pratensis* L.; KBG) is commonly irrigated as a landscape grass. This region has experienced a megadrought, increasing average temperatures, and tremendous population growth over the past several decades (Carruthers and Vias 2005; Carter and Culp 2010; St. Hilaire et al. 2008). As populations grow and the region becomes warmer and drier, the use of KBG is increasingly scrutinized due primarily to water conservation issues.

The most commonly used lawn grass in the world, and especially in cool-season zones, is KBG (Christians et al. 2017). This species is a cool-season C_3 grass, which thrives in the spring and fall when temperatures are moderate but requires significant water to remain functional, healthy, and visually appealing during hot periods or to emerge from drought-stressed dormancy (Abraham et al. 2008, Beazer 2025; Brede 2000; Bushman et al. 2012; Burgin 2021; Carrow 1994; Fry and Huang 2004; Jazi et al. 2019; Jiang and Huang 2000; Wang and Huang 2004). Although the ability of KBG to recover from drought is important, most turfgrass managers and homeowners prefer avoiding drought-caused dormancy and thus apply relatively high rates of irrigation water.

Bermudagrasses (*Cynodon* spp.) are the most common warm-season C_4 lawn grasses and are known for having relatively low water requirements and quick drought recovery, along with many other benefits (Christians et al. 2017). When common bermudagrass (*Cynodon dactylon*; CBG) and African bermudagrass (*Cynodon transvaalensis;* ABG) are crossed, they produce a triploid interspecific hybrid bermudagrass (*C. dactylon* × *C. transvaalensis* Burtt Davy; HBG), which is sterile. The HBG cultivars are gaining in popularity, especially in high traffic environments, because they can thrive at very low mowing heights, establish and repair themselves quickly, and withstand significant traffic pressure (Pinnix and Miller 2019). Despite their benefits, HBG cultivars have not historically been used in cool-season climate zones, such as in the IMW, as C_4 species do not typically survive under prolonged freezing winter conditions (Anderson and Taliaferro 2002; Xiang et al. 2019). However, turfgrass breeding programs have been working to improve the cold tolerance of bermudagrasses. Some cultivars perform well in the transition zone and some are being tested in cool-season zones (Beazer 2025; Doherty et al. 2024; Gómez de Barreda et al. 2022; Herrmann et al. 2021; Ketchum et al. 2023; Xiang et al. 2022). As climate change results in increasing average global temperatures, the ability of HBG to survive winters and thrive in summers in traditionally cool-season zones is also increasing (Hatfield 2017; Xiang et al. 2019). The HBG cultivars with cold tolerance will potentially allow continued use of lawn grasses in cool-season regions while reducing water consumption.

Although studies have evaluated cold tolerance of HBG (Anderson et al. 2008; Dunne et al. 2019; Earp 2023; Gopinath et al. 2021a, 2021b; Xiang et al. 2019; Xiang et al. 2022), none have compared HBG cultivars to KBG in a decidedly semiarid, cool-season climate to determine differences in performance and dormancy. The objective of this study was to compare six HBG cultivars, one CBG cultivar, one ABG cultivar, and a blend of KBG cultivars for canopy health, growth, and cold tolerance.

Materials and Methods

Establishment. An irrigated field study was conducted at Brigham Young University campus in Provo, UT, USA (40°14′43″N, 111°38′29″W, 1400 m above mean sea level) from Jun 2020 through Dec 2022 (Burgin 2021). The study area is semiarid with a "cool-season" climate, although daytime high temperatures during the summer typically ranged from 30 to 40 °C. Winter nighttime low temperatures during the study period typically ranged from −1 to −11 °C. The area received 314 mm of precipitation in 2021 and 271 mm in 2022, with most of it falling in the winter (Fig. 1; Atmos 41 All-in-One Weather Station, METER Group, Pullman, WA, USA). Average relative humidity for both years was 73% with a range of 19% to 99% (Utah State University 2021 and 2022). This area falls under the US Department of Agriculture Hardiness Zone 7a (US Agricultural Research Service 2023).

Treatments consisted of nine genotypes (Table 1) arranged in a Randomized Complete Block Design (RCBD) with three replications. The KBG comprised a blend of cultivars chosen for known desirable traits and commonly grown throughout BYU campus at the time. Although the blend is performs well, the intent of this study was not necessarily to evaluate the KBG but rather use it as a control against which warm-season grasses may be compared. The ABG and four of the HBG cultivars (IC, L36, PAT, and T31) were chosen after analysis of National Turfgrass Evaluation Program (NTEP) 2013 bermudagrass test results (Parsons et al. 2018). The averaged location scores for frost tolerance, winter survival, winter dormancy, mowing quality, percent green cover, drought tolerance, and spring green up were ranked (Supplemental Table 1). Special emphasis was given to cold and drought tolerance-related characteristics to choose the final cultivars for this study and a related drought tolerance study. The CBG and the other HBG cultivars (O66 and NB) were recommended by turfgrass scientists (Wu Y, Hopkins BG, personal communications).

The KBG was established in 2010 over the entire plot area as sod laid over 0.05 m of a constructed sandy loam soil with low organic matter and moderate soil fertility (Supplemental Table 2) sourced locally from a quarry, lying over a compact loam subsoil base. It should also be noted that Kentucky bluegrass is commonly grown in blends of cultivars, while bermudagrass is typically established as a single cultivar (Hopkins BG, personal communication). At the beginning and middle of May 2020, all but the KBG plots were sprayed with glyphosate herbicide, at labeled rates, to kill the existing grass. On 21 May, the dead sod was cut out to a depth of 3 cm. Extra soil, with the same properties as the existing topsoil, was spread over the top of the empty plots to make the ground height uniform with the KBG before planting the bermudagrasses. Each plot measured 1 m × 2 m and was separated from the next with a 0.07-m barrier of bare soil maintained with glyphosate and hand weeding. The grasses were watered one to three times daily to prevent desiccation until they were fully established before the start of the official study, about one year later.

Best Management Practices (Sports Field Management Association Best Management Practices Task Force 2021) were generally followed for soil, nutrient, water, cultural, and pest management. A single zone of irrigation was used for all grasses. Irrigation levels were based off the KBG's evapotranspiration replacement rate, which is slightly higher than that of the bermudagrasses but was still within the realm of optimal irrigation for both grasses. All grasses were mowed at ∼5 cm during establishment every ∼7 d and twice a week during the study at the same height. Plots were fertilized according to soil test annually at rates of 168 (nitrogen), 18 (phosphorus), 105 (potassium), and 28 (sulfur) kg·ha^{-1} applied as slow-release polymer coated urea (Duration, Koch, Wichita, KS, USA) and quick release ammonium sulfate, monoammonium phosphate, and potassium chloride split applied with one-third in the spring at green up of all plots and the remainder in early fall. The nitrogen was applied as 80% quick release and 20% control release. Other than various weeds, which were treated with herbicides [dimethylamine salts of: 2,4-dichlorophenoxyacetic acid; (+)-(R) = 2-(2-methyl-4-chlorophenoxy)propionic acid; and dicamba: 3,6-dichloro-o-anisic acid] as needed before the trial, there were no notable pest pressure problems in the plot area.

Measurements. Canopy health and density were measured weekly by Normalized Difference Vegetative Index (NDVI; Trimble Handheld GreenSeeker, Trimble Agriculture, Sunnyvale, CA, USA). Canopy visual quality ratings for verdure were ranked using a scale from 1 to 9, with 9 representing a healthy, full canopy. The NDVI and verdure ratings were measured between 31 Mar and 8 Dec in 2021. In 2022, NDVI was taken from 28 Mar and 18 Nov NDVI, and 28 Mar and 27 Dec for verdure ratings. Readings were no longer taken when snow consistently covered the plots. Canopy temperature was measured weekly between 22 Jul and 22 Sep for 2021 by forward-looking infrared (FLIR; FLIR E6 thermal imaging camera, FLIR, Wilsonville, OR, USA). The aforementioned canopy measures were typically performed weekly during the late afternoon (between 1500 and 1630 HR) on a day with full sun.

Rooting depth, and shoot and root biomass were measured at the end of the trial in 2021. Root and shoot samples were collected using soil profile samplers and shovels. The biomass samples were rinsed thoroughly, and then separated into paper bags based on sample type. This plant material along with soil samples were then dried at 105 °C in a forced air oven until the materials reached a constant weight. Following analysis, no significant differences among root and shoot measurements were observed. However, some interesting trends were observed so the results can be found in the Supplemental Materials (Supplemental Table 3; Supplemental Figs. 1 and 2).

Statistical analysis. Analysis calculations were performed using JMP Pro 16 and 17 (SAS, Cary, NC, USA). The raw NDVI and verdure ratings were used to determine more specific cold-induced dormancy periods by using an inverse prediction. This was done by limiting spring dates from March through the end of May and winter dates from September through November or December, based on how late readings were taken due to snow covering the study site. A cutoff of 0.6 was used for NDVI, with grass considered nearly or fully dormant below this value. Verdure ratings were similar with a cutoff level of 6, with grass considered nearly or fully dormant below this value. These were based off NTEP's rating system, using a scale of 1 to 9, where 6 or above is generally considered as acceptable (Morris n.d.). The grasses were not completely dormant just below the 0.6 NDVI or the 6 verdure rating levels, but they were considered entering dormancy as they no longer met desirable quality standards. All measurements were evaluated for significance with analysis of variance (ANOVA). Mean separation was determined by Tukey tests for all measurements. Orthogonal comparisons were made by combining the HBG cultivars together and then comparing them against KBG, CBG, and ABG using Tukey tests. The effect of "year" was always significant for all parameters ($P < 0.0001$); therefore, the data from

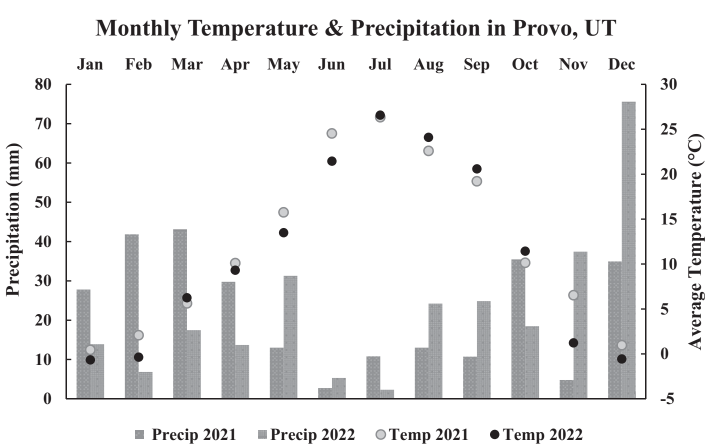

Fig. 1. Average monthly temperatures (°C) and precipitation levels (mm) in Provo, UT, USA, in 2021 and 2022.

Table 1. Cold-tolerance study genotypes.

Species	Cultivar(s)	Abbreviation	Establishment method (date)
Kentucky Bluegrass	Rugby II, Midnight II, Impact	KBG	Sod (Apr 2010)
Common Bermudagrass	Transcontinental™	CBG	Seed (Jun 2020)
African Bermudagrass	OKC 1163	ABG	Sprigs (Jun 2020)
Hybrid Bermudagrass	Iron-Cutter™ (JSC 2-21-18)	IC	Sprigs (Jul 2020)
	Latitude 36™	L36	Plugs (Jun 2020)
	Northbridge™	NB	Plugs (Jun 2020)
	OKC 1666	O66	Sprigs (Jun 2020)
	Patriot (OKC 18-4)	PAT	Sprigs (Jun 2020)
	Tahoma 31® (OKC 1131)	T31	Plugs (Jul 2020)

each year were analyzed separately with year variable omitted from the ANOVA. The interaction between genotype and date was not significant for any parameter ($P > 0.3$), and thus the effects of genotype was averaged across dates for statistical analysis.

Results

Despite being grown in a cool-season climate, all the genotypes in this study survived winter conditions and thrived in summer. Genotype was highly significant ($P < 0.0001$) in each year for NDVI and verdure. There was a strong correlation between NDVI and verdure where the R^2 values in 2021 and 2022 were 0.919 and 0.786, respectively. The warm-season CBG, ABG, and HBG went in and out of cold temperature-induced dormancy earlier and later, respectively, than the cool-season KBG as indicated by NDVI and verdure ratings.

NDVI. There were significant differences for NDVI as a function of genotype (cultivar) and date in both years, but the interaction between these was not significant ($P > 0.3$; Supplemental Fig. 3 and Supplemental Spreadsheet 1). Because the effect of date was not significant across genotypes, the NDVI values were averaged over the growing season (Table 2). There were also no statistical differences between the HBG cultivars in the original model, so they were combined for simpler comparison with the other genotypes. There were significant differences for the orthogonal comparisons between genotypes (Table 2).

The daily average temperatures were also compared with the average NDVI values of each genotype over the growing period of 2021 and 2022 (Supplemental Fig. 3). Although some HBG cultivars scored higher on average than KBG at the peak of summer between June and August, the only specific instance of a HBG scoring higher than KBG was T31 on 7 Jul 2021. When the summer values were averaged together, KBG was significantly outperformed by T31 and NB in both years, and IC in 2021.

The transformed data for the NDVI measurements effectively modeled the dates when each genotype would emerge from dormancy in the spring and go dormant in the fall and winter (Fig. 2; Supplemental Table 4). The genotype was significant for both spring green up and winter dormancy in both years.

The KBG emerged from dormancy and greened up around ordinal day 121 in 2021 and day 118 in 2022, which was numerically earlier than all other genotypes but was not significantly different from any other genotype except CBG in either year (Fig. 2). The CBG greened up the latest around day 153 in 2021 and day 158 in 2022, which was only significantly later than KBG and IC. It was also later than T31 at the $P = 0.0756$ level in 2021 and the $P = 0.0563$ level in 2022. The ABG greened up around day 133 in 2021 and day 134 in 2022 but was not significantly different from any other cultivar. None of the individual HBG cultivars were significantly different from each other.

When orthogonal comparisons were made, the six combined HBG cultivars greened up around day 134 in 2021 and day 135 in 2022. These dates were later than KBG by an average of 13 and 17 d, respectively. The difference was significant at the 0.061 level in 2021 and highly significant at the $P = 0.004$ level in 2022. The CBG greened up significantly later than the averaged HBG cultivars by an average of 19 d in 2021 and 23 d in 2022. The ABG only greened up 1 d earlier than the averaged HBG in both years and, like HBG, was significantly earlier than CBG in both years and significantly later than KBG in 2022.

The KBG entered dormancy around day 354 in 2021 and day 317 in 2022 (Fig. 2; Supplemental Table 4), which was significantly later than all the other genotypes in 2021 but not significantly different from NB, L36, or T31 in 2022. The CBG entered dormancy earliest in both years, around day 257 in 2021 and day 261 in 2022. The ABG reached dormancy around day 261 in 2021 and day 269 in 2022. The CBG and ABG went dormant significantly earlier than KBG in both years and NB in 2022. As with the green up, there were no significant differences between the individual HBG cultivars.

The combined HBG cultivars entered dormancy at approximately day 272 in 2021 and day 284 in 2022, both of which were significantly earlier than KBG by an average of 83 and 33 d, respectively. Although the differences were not significant, the HBGs went dormant later than CBG by an average of 15 d in 2021 and 23 d in 2022, and also later than ABG by an average of 11 d in 2021 and 15 d in 2022.

Verdure (visual quality ratings). Genotype was significant in both years and Date was significant in 2021, but the interaction between these was not significant ($P > 0.3$; Supplemental Spreadsheet 1). As the effect of date was consistent across genotypes, the verdure rating values were averaged (Table 2).

Like NDVI, the verdure data were transformed to effectively model the dates when each genotype would emerge from and enter dormancy (Supplemental Table 4). Results for verdure ratings in 2021 were similar to those of NDVI in terms of spring green up and dormancy (Fig. 3; Supplemental Spreadsheet 1).

The KBG emerged from dormancy and greened up around ordinal day 120 in 2021 and day 116 in 2022, which was earlier than all other genotypes but was not significantly different from any besides CBG in either year (Fig. 3). The CBG greened up the latest at approximately day 152 in 2021 and day

Table 2. Average of weekly Normalized Difference Vegetative Index (NDVI) and visual quality (verdure) in 2021 and 2022, and canopy temperature (°C) in 2021 for Kentucky bluegrass blend of cultivars (KBG), 'Transcontinental' common bermudagrass (CBG), 'OKC1163' African bermudagrass (ABG), and hybrid bermudagrasses (HBG) including IC = Iron Cutter, L36 = Latitude 36, NB = NorthBridge, O66 = OKC1666, PAT = Patriot, and T31 = Tahoma 31. For orthogonal comparisons, all HBG cultivars were averaged together. Genotypes sharing the same lowercase or uppercase letter(s) within a measurement type and year are statistically equivalent.

	NDVI		Verdure		Canopy Temp
	2021	2022	2021	2022	2021
KBG	0.678 A	0.707 A	6.9 A	6.8 A	30.4 B
CBG	0.507 B	0.503 C	5.1 B	4.4 C	32.9 A
ABG	0.570 AB	0.571 BC	5.8 AB	5.3 BC	33.2 A
IC	0.637 A	0.629 AB	6.6 AB	6.1 AB	32.6 AB
L36	0.590 AB	0.618 AB	6.0 AB	5.8 AB	33.0 A
NB	0.623 AB	0.646 AB	6.4 AB	6.3 AB	31.8 AB
O66	0.566 AB	0.582 BC	6.1 AB	5.8 AB	33.9 A
PAT	0.602 AB	0.607 B	6.2 AB	6.4 ABC	32.4 AB
T31	0.637 A	0.639 AB	6.9 A	6.0 AB	32.0 AB
P values	0.0046	0.0001	0.0192	0.0008	0.0019
Orthogonal Comparisons					
KBG	0.678 a	0.707 a	6.9 a	6.8 a	30.4 b
CBG	0.507 c	0.503 c	5.1 b	4.4 c	32.9 a
ABG	0.570 bc	0.571 bc	5.8 ab	5.3 bc	33.2 a
HBG	0.609 ab	0.620 b	6.4 a	6.0 ab	32.6 a
P values	0.0006	<0.0001	0.0027	<0.0001	0.0037

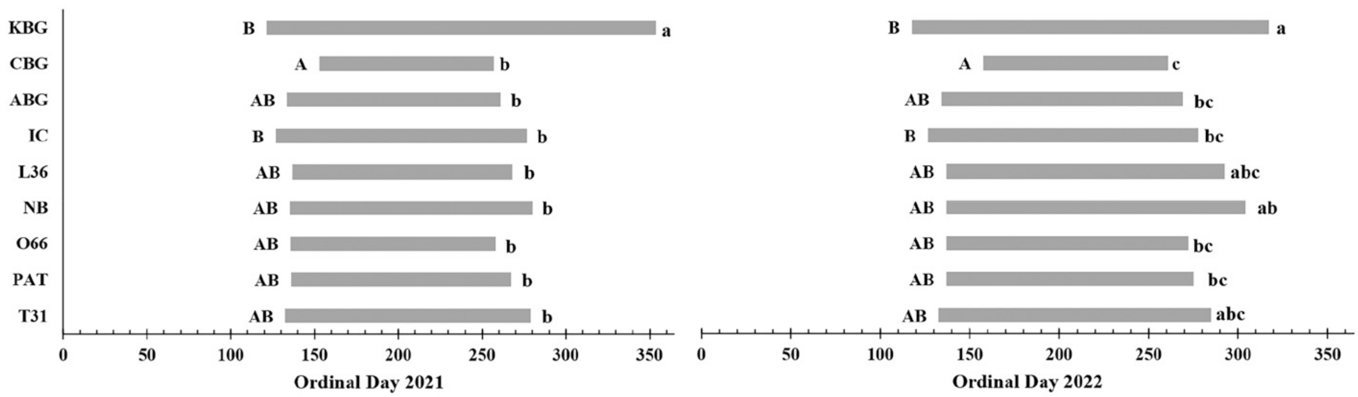

Fig. 2. Modeled growing period for a Kentucky bluegrass blend of cultivars (KBG), 'Transcontinental' common bermudagrass (CBG), OKC1163 African bermudagrass (ABG), and hybrid bermudagrasses (IC = Iron Cutter, L36 = Latitude 36, NB = NorthBridge, O66 = OKC1666, PAT = Patriot, and T31 = Tahoma 31) in 2021 and 2022 based on Normalized Difference Vegetative Index (NDVI). Dates sharing the same letter(s) within the beginning (uppercase letters) and ending (lowercase letters) of each growing season are statistically equivalent.

153 in 2022, which was only significantly later than KBG in both years, IC and T31 in 2022, and IC in 2021 at the $P = 0.0903$ level of significance. The ABG greened up around day 135 in 2021 and day 136 in 2022 but was not significantly different from any other genotype. None of the individual HBG cultivars were significantly different from another.

When orthogonal comparisons were made, the combined HBG cultivars greened up at approximately day 134 in 2021 and day 133 in 2022. These dates were later than KBG by an average of 14 and 17 d, respectively, but the difference was only significant in 2022. The CBG greened up significantly later than the combined HBG cultivars by an average of 18 d in 2021 and 20 d in 2022. The ABG greened up 1 d later than the averaged HBG in 2021 and 3 d later in 2022 and not significantly different from any other genotype in 2021 but was significantly earlier than CBG and significantly later than KBG in 2022.

The KBG entered dormancy around day 346 in 2021 and day 312 in 2022 (Fig. 3; Supplemental Table 4), which was significantly later than all the other genotypes in 2021 but not significantly different from NB or T31 in 2022. The CBG entered dormancy earliest in both years, at approximately day 266 in 2021 and day 251 in 2022. The ABG reached dormancy around day 275 in 2021 and day 268 in 2022. The CBG went dormant significantly earlier than KBG in both years as well as NB, T31, IC, L36, and O66 in 2022. The ABG entered dormancy significantly earlier than KBG in both years but was similar to every other genotype. As with green up, there were no significant differences between the individual HBG cultivars.

The combined HBG cultivars entered dormancy around day 281 in 2021 and day 282 in 2022, both of which were significantly earlier than KBG by an average of 65 d and 30 d, respectively. The HBGs went dormant significantly later than CBG by an average of 15 d in 2021 and 31 d in 2022. The HBGs were also later than ABG by an average of 6 d in 2021 and 14 d in 2022, but the difference was not significant in either year.

Canopy temperature. As expected, there were grass canopy temperature differences by date, as by genotype, but the interaction between these was not significant ($P > 0.3$; Supplemental Spreadsheet 1). The effect of date was consistent across genotypes, therefore the canopy temperatures were averaged (Table 2). The ABG and O66 were consistently among the genotypes with the warmest canopies, whereas KBG, NB, and T31 were the coolest. When all HBGs were combined orthogonally and compared with KBG, CBG, and ABG; genotype was significant. The KBG was 3.8 °C cooler than CBG and ABG, and 3.1 °C cooler than the HBGs combined.

Final ratings. The growing periods of each grass, as measured by NDVI and verdure ratings in both years, were used to rank all genotypes from 1 to 9, with a score of 1 given the top performer and 9 to the worst (Table 3). If cultivars tied, each received the same lowest number. Kentucky bluegrass received the best and lowest possible score of 8 as it emerged from dormancy first and entered dormancy last in all cases (Table 3). On the basis of these rankings, the best bermudagrass cultivars for this region are T31 and IC. Next was NB, followed by essentially a tie among O66, L36, ABG, and PAT. The CBG cultivar Transcontinental scored significantly lower than all other genotypes.

Discussion

This study is unique because it was conducted in a cool-season, semiarid climate, historically deemed unsuitable for warm-season grasses (including bermudagrass). However,

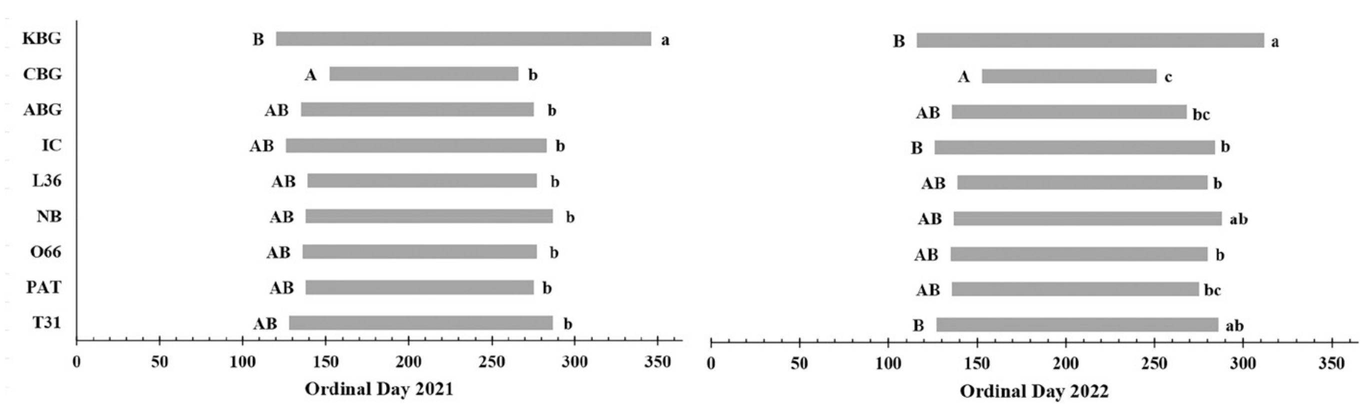

Fig. 3. Modeled growing period for a Kentucky bluegrass blend of cultivars (KBG), 'Transcontinental' common bermudagrass (CBG), OKC1163 African bermudagrass (ABG), and hybrid bermudagrasses (IC = Iron Cutter, L36 = Latitude 36, NB = NorthBridge, O66 = OKC1666, PAT = Patriot, and T31 = Tahoma 31) in 2021 and 2022 based on verdure ratings. Dates sharing the same letter(s) within the beginning (uppercase letters) and ending (lowercase letters) of each growing season are statistically equivalent.

Table 3. Cold-tolerance rankings for genotypes [Kentucky bluegrass blend of cultivars (KBG), 'Transcontinental' common bermudagrass (CBG), OKC1163 African bermudagrass (ABG), and hybrid bermudagrasses (IC = Iron Cutter, L36 = Latitude 36, NB = NorthBridge, O66 = OKC1666, PAT = Patriot, and T31 = Tahoma 31)] based on green up and dormancy as measured by NDVI and verdure ratings over 2 years. The lower the value the longer the growing season.

Rank	Cultivar	Score
1	KBG	8
2	T31	24
3	IC	25
4	NB	31
5	O66	45
6	L36	47
7	ABG	48
7	PAT	48
9	CBG	72

all eight bermudagrass cultivars did reasonably well, and most thrived. The KBG had the longest growing period for both NDVI and verdure ratings in both years, but it is worth noting that all HBGs greened up within the same window of time in the spring. Some HBG cultivars also performed better at the peak of summer, producing significantly higher NDVI values on average. It is known that NDVI values vary by grass species and cultivar, but the verdure ratings over this summer period reported the same significant differences between these genotypes and, as such, provide further support that KBG struggled in the very hottest portions of the trial compared with the bermudagrasses. An earlier dormancy period in the fall may be a fair trade off for overall grass performance and water conservation (Beazer et al. 2023).

On the basis of NTEP ratings for winter kill, drought tolerance, spring green up, and percent green cover in spring, summer, and fall, T31 and IC were the most highly rated cultivars chosen in this research. Although conducted in a different climate and location than the NTEP trials, the results of this study (Table 3) are supportive that these cultivars may be good options for the cool-season portions of Utah and similar climates. Although NB was not evaluated in NTEP, it performed well in these trials and could also be a promising cultivar.

The T31 is a relatively new cultivar, but it has already been a top performer in freezing studies (Gopinath et al. 2021a). Out of four cultivars (Tifway, T31, and two experimental cultivars), T31 performed best in controlled freeze testing and the mean lethal temperature to kill 50% of its population (LT_{50}) was $-9.1\,^{\circ}C$. However, we note that temperatures lower than this (approximately $-25\,^{\circ}C$) were measured at sod farms in Colorado in 2024 with minimal to no winter kill (Hopkins B, personal communication). In a related study, T31 also performed best out of eight cultivars (five experimental and three commercial cultivars, including T31) and had a LT_{50} ranging from -7.8 to $-9.0\,^{\circ}C$ over three rounds (Gopinath et al. 2021b). Only one experimental cultivar was significantly close to T31. It is worth noting that air temperatures dip well below $-9\,^{\circ}C$ in Utah, but our T31 has had virtually no winter kill since establishment.

Some of the cultivars chosen in the study reported herein have recently been used as standards against new experimental types in cold-related testing, such as PAT (Dunne et al. 2019) and T31 (Earp 2023). In a freeze tolerance bermudagrass test, PAT ranked second best of 13 vegetative cultivars and 'Transcontinental' was tied for fourth out of 27 seeded (CBG) cultivars (Anderson et al. 2008).

Xiang et al. (2022) recorded spring green up each year from 2017 to 2019, and out of the three cultivars, L36 had the highest average, followed by NB, and then PAT. However, the order varied by year, and they were all consistently surpassed by new experimental varieties. In a related study, the winter survival of the same three grasses, along with many experimental types, was measured in 2018 (Xiang et al. 2019). PAT had the highest survival rate at 30%, NB had 25%, and L36 had 20%. These results differ from our overall rankings, where NB ranked best, followed by L36, and PAT (Table 3). However, the spring green updates for all three were not significantly different (Figs. 2 and 3).

These data, along with the data provided herein, support the fact that bermudagrasses are unique among most warm-season grasses in their ability to survive and even thrive in a cool-season climate. Further evidence is provided at separate plots of various bermudagrasses (Transcontinental, NorthBridge, Patriot, Latitude 36, and Jackpot) that have been grown on BYU campus since 2007, which have performed similarly to the new plots, generally entering dormancy in early November and greening up at the end of May. Six other warm-season species were also grown in these plots, but the cold temperatures generally killed them. It is also worth noting that all nine of the genotypes observed during the study reported herein also survived the winters over 2022–25, which were often colder than those during this study. For example, the area reached lows of $-14\,^{\circ}C$ in 2022 and $-16\,^{\circ}C$ in 2023 compared with $-11\,^{\circ}C$ and $-10\,^{\circ}C$ in 2020 and 2021, respectively (Provo Weather Records 2025).

Canopy temperature was largely unimportant and insignificant, but it was interesting that the bermudagrasses were $>3\,^{\circ}C$ warmer than KBG. Differences in canopy temperature between C3 and C4 plants have also been observed by other researchers, although the differences vary depending on environmental factors and the type of plant (Culpepper et al. 2019; Kimball and Bernacchi 2006; Shimoda and Oikawa 2006; Still et al. 2014).

The root and shoot results were largely insignificant. In contrast, two HBG cultivars had significantly more shoot and root biomass and root depth than KBG in a related greenhouse study (Burgin et al. 2022). However, the bermudagrasses in the present study were somewhat immature, which may have impacted root growth. In the years following this study, the roots have been measured at much greater depths (~1 m) for the bermudagrasses (Beazer et al. 2023).

Conclusions

Cold-tolerant ABG and HBG cultivars survived the cold winters of Provo, UT, USA and even thrived in the summer. These had a significantly shorter growing season than KBG with an average of 221 d (range of 196–232 d), but longer than CBG with an average of 105 d (range of 98–114 d). The HBG cultivars Tahoma 31, Iron Cutter, and NorthBridge performed best under the conditions of this trial and, as such, may be good options for this and other cool-season, semiarid regions.

The results from this study support our general hypothesis that HBG cultivars are becoming increasingly suited to traditional cool-season climates. Other studies have proven that HBG can maintain acceptable turfgrass quality with less irrigation, thrive at very low mowing heights, establish and repair itself quickly, and withstand significant wear. This suggests that HBG is a feasible replacement for more water-intensive species like KBG in arid and semiarid regions, especially as more cold-tolerant varieties are released and tested.

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