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Blend ratios and mixtures of brown patch susceptible and resistant tall fescue cultivars

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Abstract

Brown patch (*Rhizoctonia* spp.) is a major disease of turf-type tall fescue (TF) [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.]. Many cool-season turfgrass lawns consist of species mixtures or cultivar blends, but the exact proportion of resistant cultivars in blends and mixtures to effectively reduce disease has not been well documented. A field study was conducted in West Lafayette, IN, and Blacksburg, VA, during 2022 and 2023 to determine the brown patch severity of various blend ratios (0%, 25%, 50%, 75%, and 100% by weight) using a brown patch susceptible and resistant TF cultivar. Additionally, mixtures (90% and 10% by weight, respectively) of TF and Kentucky bluegrass (*Poa pratensis* L.) with a susceptible and resistant TF cultivar were evaluated. Seasonal appearance/turf quality and brown patch severity were visually determined, and area under the disease progress curve (AUDPC) was calculated. Turf quality and brown patch severity were similar at both locations. Additionally, blends and mixtures containing ≥75% of the resistant cultivar maintained higher average visual quality across both locations compared to the susceptible cultivar alone. Between the two mixtures, the inclusion of a resistant TF cultivar maintained higher canopy density and increased the proportion of TF at both locations. Blends and mixtures containing ≥75% of a resistant cultivar reduced brown patch AUDPC by 71% and 83% in 2022 and 2023, respectively, when compared to the 100% susceptible cultivar. This field study reinforces the importance of selecting resistant TF cultivars to reduce seasonal brown patch symptoms in cool-season turfgrass lawns.

1 | INTRODUCTION

Throughout the transition zone and cool-humid regions, turf-type tall fescue (TF) [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] is a popular choice for lawns due to this species attributes for fewer maintenance inputs and superior summer stress performance (Powlen & Bigelow, 2023b; Walker et al., 2007). While TF has many benefits, brown patch (caused by *Rhizoctonia* and *Rhizoctonia*-like species) can severely impact turf quality, density, and health. Selection of a brown patch-resistant TF cultivar can be an effective cultural management strategy to reduce brown patch and reliance on fungicide applications (Powlen et al., 2024; Sykes et al., 2020).

Abbreviations: AUDPC, area under the disease progress curve; AUTQC, area under the turf quality curve; BPR, brown patch resistant; BPS, brown patch susceptible; KBG, Kentucky bluegrass; TF, tall fescue.

Although complete resistance to brown patch has yet to be observed, differences in cultivar resistance have previously been observed (Bokmeyer et al., 2009; Sykes et al., 2020; Watkins & Meyer, 2004). To determine resistance to brown patch, cultivars and experimental varieties in breeding programs are also compared in national evaluations, such as the National Turfgrass Evaluation Program (US Department of Agriculture, Beltsville, MD) (Morris et al., 2023). While these evaluations provide invaluable data when comparing varieties across many environments, the potentially unequal spatial distribution of inoculum can present information that may not fully demonstrate the true susceptibility among the varieties and cultivars being evaluated. Current recommendations are to evaluate disease resistance over multiple years, locations, and maintenance programs to determine resistance among varieties and cultivars due to influence from the local environment and specific *Rhizoctonia* species at different geographic locations (Bokmeyer et al., 2009).

For many cool-season turfgrass areas, a blend of more than one cultivar of the same species is recommended to increase the genetic diversity and adaptability of varying micro-environments (Steinke & Ervin, 2013). Careful cultivar selection for a blend composition is critical to ensure persistence and compatibility of desired cultivars in a sward over time. For example, combining a disease-resistant cultivar with a low- or mid-performing cultivar potentially reduces overall seed cost but could yield an overall reduced quality of the turf (Brede, 2004; Lickfeldt et al., 2002; Vargas & Turgeon, 1980). Although previous studies have evaluated the proportion of a drought-tolerant TF cultivar in a blend to reduce irrigation needs during an acute drought (Powlen et al., 2021), there is limited information regarding the necessary proportion of a disease-resistant cultivar in a blend needed to effectively reduce disease.

To further increase genetic diversity and tolerance to abiotic and biotic stresses, Kentucky bluegrass (KBG) (*Poa pratensis* L.) is frequently mixed with TF to combine the strengths of TF with the better mowing and sod-forming characteristics of KBG. This mixture is typically established using a rate of 5%–10% KBG by seed weight since 10% KBG provides a roughly equal number of TF and KBG seeds (Turgeon, 2008). The influence of seeding rate, overall turf quality, sod strength, wear tolerance, and plant population composition over time and at different mowing heights have been previously evaluated for TF and KBG mixtures (Braun et al., 2022; Brede, 1993; Dunn et al., 2002; Hunt & Dunn, 1993; Macolino et al., 2014; Park et al., 2017; Reynolds et al., 2005). The addition of other species, such as KBG with TF, may help reduce brown patch severity throughout the growing season compared to a TF cultivar or blend alone (Park et al., 2017; Reynolds et al., 2005; Xiang et al., 2019). The primary concern with mixtures is that over time one species may become more dominant over another, thus reducing the species benefits to the sward (Donald, 1963; Dunn et al., 2002). Reynolds et al. (2005) examined various TF:KBG mixture ratios over 3 years in Raleigh, NC, and concluded that the proportion of TF in a mixture will significantly decrease over time. Information is limited regarding the change in species composition of TF:KBG mixtures over time when comparing a brown patch resistant (BPR) and susceptible TF cultivar within that mixture.

Core Ideas

- Increasing the proportion of a resistant tall fescue cultivar in a blend significantly reduced brown patch severity.
- Turfgrass quality increased as the proportion of a resistant tall fescue cultivar increased in a blend.
- A brown patch-resistant cultivar in tall fescue: Kentucky bluegrass mix increased density and fescue composition.
- The proportion of Kentucky bluegrass significantly increased over time in tall fescue: Kentucky bluegrass mixtures.

Although fungicide applications can effectively manage brown patch, establishing TF blends or TF:KBG mixtures containing a disease resistant TF cultivar can be an effective disease management strategy (Clarke et al., 2019; Powlen et al., 2024). The exact amount of a BPR TF cultivar needed to reduce overall symptoms in various locations remains unknown. Thus, a field study was conducted at two locations (Indiana and Virginia) with the objectives of (1) evaluate brown patch susceptibility and seasonal turf quality among various TF blends and TF:KBG mixtures containing BPR and susceptible TF cultivars, and (2) quantify changes in species composition between TF:KBG mixtures containing either a BPR or susceptible TF cultivar after two growing seasons.

2 | MATERIALS AND METHODS

2.1 | Experimental site and management

A replicated field study was conducted at the William H. Daniel Turfgrass Research and Diagnostic Center in West Lafayette, IN (40˚26′31.9″ N; 86˚56′00.3″ W), and at the Virginia Tech Turfgrass Research Center in Blacksburg, VA (37˚12′59.3″ N; 80˚24′39.5″ W), during the 2022 and 2023 growing season. Select variables were also measured during the 2024 growing season at the Indiana location. The soil at the Indiana site was a Starks silt loam (fine silty, mixed, mesic, and Aeric Ocharqualf) with a pH of 7.0, 48 g kg^{-1} organic matter (loss on ignition method), 66 mg kg^{-1} phosphorus (Bray P1 method), and 220 mg kg^{-1} potassium. The Virginia site was a Groseclose silt loam (fine, kaolinitic, mesic typic Hapludult) with a pH of 5.4, 30 g kg^{-1} organic matter, 58 mg kg^{-1} phosphorus, and 170 mg kg^{-1} potassium. Midwest Laboratories (Omaha, NE) conducted soil analysis for both locations.

A range of ratios (0%, 25%, 50%, 75%, and 100% by weight) of a BPR (Raptor III) and brown patch susceptible (BPS) (Kingdom) TF cultivar were seeded at a rate of 294 kg pure live seed (PLS) ha^{-1} on September 12 and September 14, 2021, in Indiana and Virginia, respectively. Cultivars were selected based on results from previous controlled environment study evaluating brown patch resistance among various TF cultivars (Powlen et al., 2024). Additionally, 90% TF and 10% KBG (365ss: Bolt, Legend, and Blue Note) (by weight) of the BPR and BPS TF cultivars were seeded at 294 kg PLS ha^{-1}. All treatments were seeded in 1.2 m by 1.8 m plots (2.2 m^2) arranged in a randomized complete block design with four replications, totaling 28 plots. Prior to renovating for seeding, the study areas consisted of various cool-season turfgrass species and were chemically removed during the summer of 2021. At planting, all plots at the Indiana site were covered with a geotextile germination blanket (A.M. Leonard Inc.) to maintain soil moisture, limit seed movement, and be removed after seedling emergence. Overhead irrigation was regularly applied to maximize germination and reduced as the turf matured.

Once established (approximately 6 weeks after seeding), the study area was mowed approximately every 4–7 days at a height of 7.6 cm with clippings returned. The study areas received supplemental irrigation in the absence of rainfall. From planting until November 2021, all plots received approximately 78.5 kg N, 10.7 kg P, and 34.9 kg K ha^{-1}. Pre- and post-emergent herbicide applications were made in the spring and fall of 2022 and 2023 to manage annual grassy and broadleaf weeds. In Indiana, the study area received approximately 122.5 kg N and 43.8 kg K ha^{-1} $year^{-1}$ split in three equal applications (May [polymer coated urea], September [polymer coated urea], and late October [urea]). In Virginia, the study area received approximately 61.3 kg N, 27.0 kg P, and 50.9 kg K ha^{-1} $year^{-1}$ split in two applications (May [urea] and September [urea]).

At the Indiana site, double point grain (*Secale cereale* L.) inoculation was placed in the center third of each plot on May 31, 2022, and June 5, 2023, using a *Rhizoctonia solani* isolate collected from a TF lawn in West Lafayette, IN (Butler et al., 2019). The Virginia location relied on natural infection due to previous history of brown patch in the study area.

2.2 | Data collection and analysis

Disease susceptibility was estimated visually on a 0–100 linear percent scale every 7–14 days during the summer, where 0 = no plot area affected and 100 = turf within plot was completely affected. Area under the disease progress curve (AUDPC) was calculated to evaluate brown patch severity throughout the growing season using the following equation:

$$\text{AUDPC} = \left\{ \sum_{i=1}^{n-1} \left[\left(y_i + y_{i+1} \right) / 2 \right] \times \left(t_{i+1} - t_i \right) \right\}$$

where $y_i + y_{i+1}$ is the addition of current severity value to previous value, and $t_{i+1} - t_i$ is time between evaluations (Madden et al., 2007).

The relationship of resistant TF in a blend and brown patch AUDPC was modeled in using GraphPad Prism Version 10.1.1 (GraphPad Software Inc.) using an exponential decay model in the following equation:

$$y = \left(y_0 - \text{Plateau} \right) \times \exp\left(-K \times x \right) + \text{Plateau}$$

where y_0 is the y value when x (percent resistant TF) is zero; *Plateau* is the y value at infinite AUDPC; and K is the rate constant. Visual turf quality was rated every 7–14 days on a 1–9 scale, where 1 = dead turf, bare soil, 9 = optimal uniformity, density, and greenness, and 6 = minimally acceptable turf. Area under the turf quality curve (AUTQC) was calculated using the same equation for AUDPC using visual turfgrass quality throughout the growing season for each location. Species composition of the TF:KBG mixtures was determined by extracting two soil cores (10.2-cm diameter) from the upper and lower third of each plot. Soil cores were collected on August 30, and September 7, 2023, for the Virginia and Indiana location, respectively. Soil cores were also collected on July 23, 2024, from the Indiana location. The number of TF and KBG plants in each soil core was counted within 24 h of collection.

To determine brown patch resistance among all treatments, evaluation dates of brown patch severity within each experiment were subject to analysis of variance (ANOVA) using the general linear model procedure (PROC GLM) in SAS System v. 9.4 (SAS Institute). For significant date-by-blend/mixture interactions, treatment means among were separated by Fisher's protected least significant difference (LSD) test ($p < 0.05$). Additionally, brown patch AUDPC, AUTQC, and species composition data were subjected to ANOVA using SAS statistical software to evaluate the factors of treatment, location, and year. Fisher's protected LSD test was used to separate means when F tests were significant ($p < 0.05$).

3 | RESULTS

3.1 | Brown patch severity and AUDPC

A significant ($p < 0.001$) location-by-year-by-treatment interaction occurred for brown patch severity; thus, data were analyzed independently for each year at the different

TABLE 1 Analysis of variance between evaluation dates of visual turf quality and brown patch severity among five tall fescue (TF) blends and two TF: Kentucky bluegrass mixtures during 2022 and 2023 in West Lafayette, IN, and Blacksburg, VA.

		Indiana				Virginia			
		Turf quality		Brown patch severity		Turf quality		Brown patch severity	
Year	Source of variation	*df*[a]	*p* value	*df*	*p* value	*df*	*p* value	*df*	*p* value
2022									
	Block	3	0.9717	3	0.2205	3	0.0865	3	0.3775
	Blend/mixture (G)	6	<0.0001	6	<0.0001	6	<0.0001	6	<0.0001
	Date (D)	16	<0.0001	10	<0.0001	12	<0.0001	15	<0.0001
	G × D	96	<0.0001	60	<0.0001	72	0.3800	90	<0.0001
2023									
	Block	3	0.1444	3	0.2343	3	0.0125	3	0.2762
	G	6	<0.0001	6	<0.0001	6	<0.0001	6	<0.0001
	D	15	<0.0001	10	<0.0001	13	<0.0001	9	<0.0001
	G × D	90	0.0009	60	<0.0001	78	0.0028	54	<0.0001

[a]Degrees of freedom (*df*) of factors and significance level between groups with significance at $p < 0.05$.

locations. Treatment-by-evaluation date interaction was also significant ($p < 0.001$) during both evaluation years in Indiana and Virginia, thus evaluation dates for each year were evaluated independently (Table 1). In Indiana, symptoms of brown patch began on June 20 and were present until August 24, 2022 (Figure 1). The 75% BPR TF, 100% BPR TF, and BPR TF:KBG mixture had similar brown patch severity throughout the study period, except on August 4, 2022, where the 75% BPR TF had more brown patch (20% severity) compared to 100% BPR TF and BPR TF:KBG mixture (≤7.5% severity). Differences between blends containing 50% and 75% resistant TF were not observed throughout evaluation dates during 2022 in Indiana.

In 2023, brown patch symptoms were initially observed on June 30 and continued until September 18 in Indiana (Figure 1). Peak disease (July 6) ranged from 8.9% to 37.0% among all treatments (100% and 0% resistant TF, respectively). All treatments containing BPR TF or KBG reduced disease severity between July 6 and 24 compared to 0% BPR TF. The 75% BPR TF, 100% BPR TF, and BPR TF:KBG mixture also reduced severity compared to 25% BPR and BPS TF:KBG mixture from 6 July to July 16. All treatments recovered on August 7 (<7.5% severity). However, disease favorable environmental conditions (5.1 cm natural rainfall, 85.5% average relative humidity) increased brown patch severity to 15.3% and 18.8% on August 23, 2023, for the BPS TF:KBG mixture and 0% BPR TF. All treatments recovered by September 18, 2023.

In Virginia, brown patch symptoms developed on May 25, 2022, and continued until September 8, 2022 (Figure 1). From initial brown patch severity to July 14, the 0% BPR TF had increased brown patch than all other treatments. The 25% and 50% BPR TF had less brown patch compared to the 0% BPR TF during this time period, and the 75% BPR TF, 100% BPR TF, and BPR TF:KBG mixture had the least. Peak severity (July 21) ranged from 18.8% to 52.5% for the BPR TF:KBG mixture and 0% BPR TF, respectively. The BPR TF:KBG and 100% BPR TF (18.8% and 21.3%, respectively) had significantly less brown patch at peak severity compared to 25% BPR TF and 0% BPR TF (45.0% and 52.5%, respectively). Although all treatments exhibited reduced brown patch severity 28 days following peak severity (August 18), the 0% BPR TF, 25% BPR TF, and BPS TF:KBG mixture had more brown patch (17.5%–23.8% severity) compared to the 75% BPR TF, 100% BPR TF, and BPR TF:KBG mixture (≤7.5% severity). No differences were present after September 8, with all treatments with <5.0% severity.

During 2023, brown patch symptoms were relatively slower to develop in Virginia compared to 2022, with symptoms developing on July 13 and continuing to the final evaluation date on September 14. Similar to 2022, the 0% BPR TF had greater brown patch compared to other treatments evaluated in 2023. By peak severity (August 30), the 0% BPR TF had the most brown patch (32.5% severity) compared to all treatments, followed by the 25% BPR TF and BPS TF:KBG mixture (16.3% and 17.5% respectively), and the 100% BPR TF and BPR TF:KBG mixture having the least severity (≤5.0% severity) at the Virginia location.

Differences in AUDPC between the two locations among treatments were not found, thus data across locations were combined (Table 2). In 2022, the 100% BPR TF reduced brown patch AUDPC by 76% compared to 0% BPR TF (522 vs. 2200, respectively) (Figure 2). Among the treatments, 0% BPR TF had the highest AUDPC value, followed by 25% BPR TF and BPS TF:KBG mixture, then the 50% BPR TF, and the BPR TF:KBG mixture and 100% BPR TF having the lowest AUDPC. Between the two locations, Virginia had a 37% increase in AUDPC during 2022 compared to

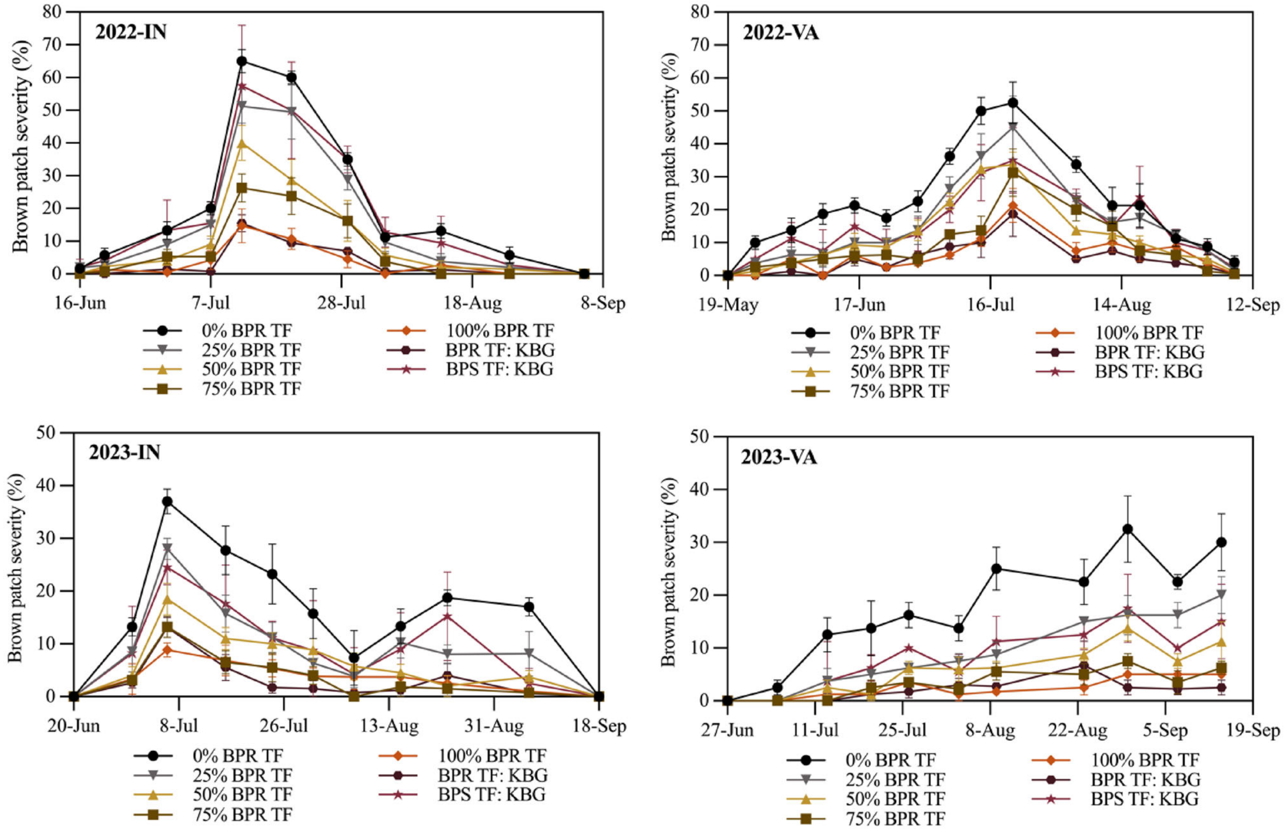

FIGURE 1 Brown patch severity as affected by various tall fescue (TF) blends and TF: Kentucky bluegrass (KBG) mixtures containing brown patch resistant (BPR) (Raptor III) and susceptible (BPS) (Kingdom) TF cultivars in Indiana and Virginia during 2022 and 2023. Data means represent the average of four replications ($n = 4$), and error bars represent the standard error of the mean.

TABLE 2 Analysis of variance of area under the disease progress curve (AUDPC) and area under the turf quality curve (AUTQC) as affected by five tall fescue (TF) blends and two TF: Kentucky bluegrass mixtures containing brown patch resistant and susceptible TF cultivars, two locations (Indiana and Virginia), and 2 years (2022 and 2023).

Source of variation	*df*	AUDPC (*p* value)	AUTQC (*p* value)
Block	3	0.8176	0.4978
Blend/mixture (G)	6	<0.0001	<0.0001
Location (L)	1	<0.0001	<0.0001
G × L	6	0.4736	<0.0001
Year (Y)	1	<0.0001	<0.0001
G × Y	6	0.0023	0.1819
L × Y	1	<0.0001	<0.0001
G × L × Y	6	0.5461	0.9364

Indiana (1470 vs. 924, respectively). During 2023, AUDPC was lower in both locations. Brown patch AUDPC values across locations in 2023 were: 0% BPR TF > 25% BPR TF = BPS TF:KBG mixture > 50% BPR TF > 75% BPR TF = 100% BPR TF = BPR TF:KBG mixture (Figure 2). Indiana had more seasonal brown patch pressure compared to Virginia in 2023, with a 17% increase in brown patch AUDPC (675 vs. 560, respectively). When modeling percent BPR TF in a blend and brown patch AUDPC across locations and years, an exponential decay of the data demonstrated that ≥75% BPR TF was needed for reduced brown patch AUDPC, and minimal differences were observed between the 75% and 100% BPR TF (Figure 3).

3.2 | Turf quality

In Indiana, a significant ($p < 0.05$) treatment by evaluation date interaction occurred in 2022 and 2023, thus evaluation dates were evaluated independently (Table 1). During both study years, differences among treatments were not present until brown patch symptoms were present (Figure 4). In general, blends and mixtures with increased brown patch severity had lower visual quality. The 0% BPR TF fell below minimum acceptable quality (6.0) on June 20, while the 100% BPR TF and BPR TF:KBG mixture maintained acceptable quality until July 12 (Figure 4). By August 4, the 100% BPR TF and BPR TF:KBG mixture increased visual quality ≥7.0, while

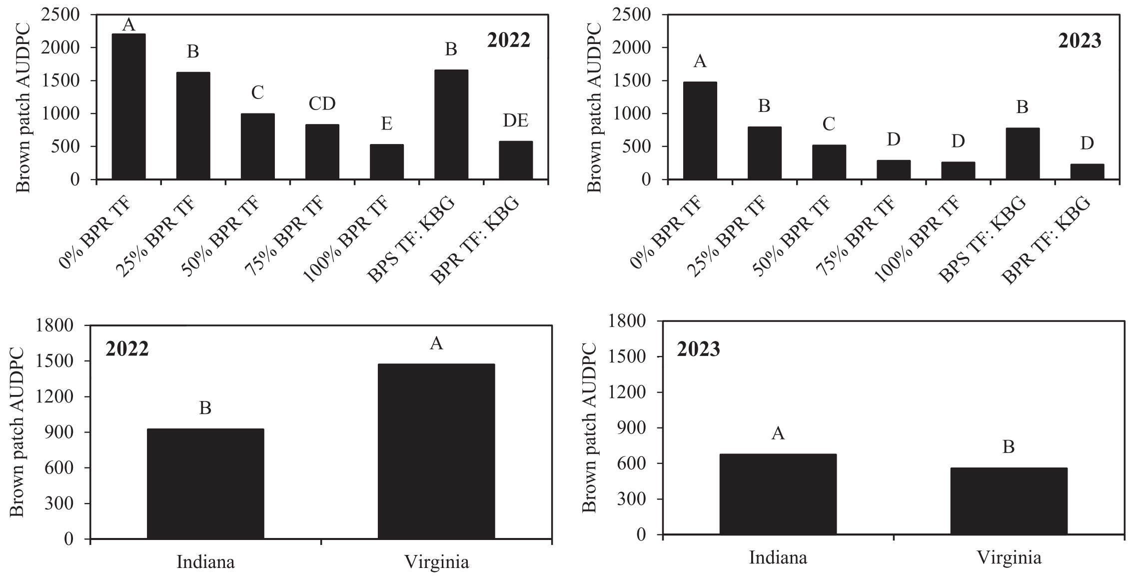

FIGURE 2 Brown patch area under the disease progress curve (AUDPC) among five tall fescue (TF) blends and TF: Kentucky bluegrass (KBG) mixtures containing brown patch resistant (BPR) (Raptor III) and susceptible (BPS) (Kingdom) TF cultivars in West Lafayette, IN, and Blacksburg, VA, during 2022 and 2023. Columns with a common letter are not significantly different according to Fisher's protected least significant difference (LSD) ($p < 0.05$). Means among blends and mixtures represent the average of four replications and two locations ($n = 8$) and means among study locations represent the average of four replications and seven blends and mixtures ($n = 28$).

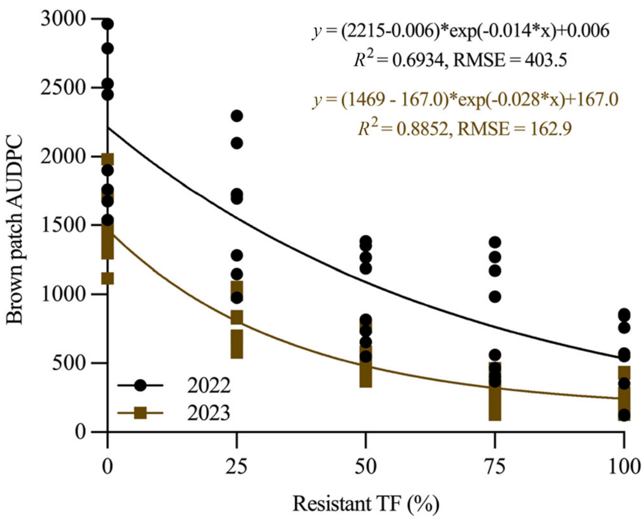

FIGURE 3 Relationship of percent resistant tall fescue (TF) in a blend and brown patch area under the disease progress curve (AUDPC) across locations in 2022 and 2023 as calculated using an exponential decay model (model, R^2, and root mean square error [RMSE] included for 2022 [black] and 2023 [gold]) using GraphPad Prism.

the 0% BPR TF and BPS TF:KBG mixture didn't improve visual quality to >6.0 until early September. In 2023, the 75% and 100% BPR TF maintained acceptable visual quality throughout the growing season. On July 6 (peak brown patch severity), visual quality ranged from 4.6 to 6.6 for 0% BPR TF and 100% BPR TF, respectively. Throughout July, August, and September, visual quality among treatments improved as the turf recovered from brown patch.

In Virginia, visual turf quality during 2022 ranged from 5.5 to 6.7 for 0% BPR TF and BPR TF:KBG mixture, respectively, with treatments containing ≥75% BPR TF and the BPR TF:KBG mixture had increased average visual quality compared to blends with ≤25% BPR TF or the BPS TF:KBG mixture (data not shown). In 2023, visual turf quality among treatments in Virginia were generally consistent from May to late July prior to brown patch symptom development. As brown patch severity increased, visual quality decreased among all treatments, with the 0% BPS TF having the lowest visual quality compared to other treatments after brown patch symptoms developed (late July to mid-September) (Figure 4).

The AUTQC among treatments was analyzed between locations due to a significant location-by-treatment interaction ($p < 0.0001$) (Table 2). In Indiana, the BPR TF:KBG mixture and 100% BPR TF had maintained the highest seasonal visual quality (AUTQC) compared to blends with ≤50% BPR TF and the BPS TF:KBG mixture (Table 3). Across all treatments, the 0% BPR TF maintained the lowest visual quality at both locations. In Virginia, the BPR TF:KBG mixture maintained higher season visual quality compared to blends containing <25% BPR TF and the BPS TF:KBG mixture. For each location, AUTQC increased as AUDPC decreased between the two study years.

3.3 | TF:KBG mixture composition

In 2022, species composition was not measured, but visual observations of the BPS and BPR TF:KBG mixtures in

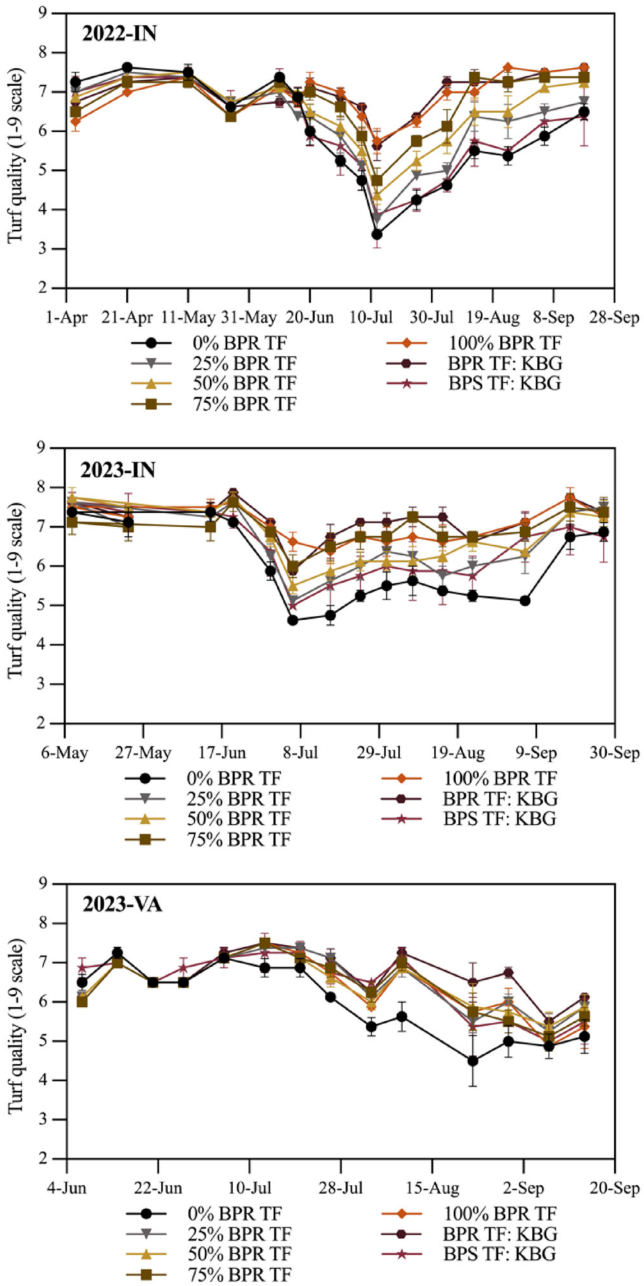

FIGURE 4 Turf quality as affected by various tall fescue (TF) blends and TF: Kentucky bluegrass (KBG) mixtures containing brown patch resistant (BPR) (Raptor III) and susceptible (BPS) (Kingdom) TF cultivars in Indiana during 2022 and 2023, and Virginia during 2023. Data means represent the average of four replications ($n = 4$), and error bars represent the standard error of the mean.

Indiana and Virginia generally consisted of >85% TF prior to brown patch symptoms. When evaluating proportions of TF, KBG, and total canopy density between the two TF:KBG mixtures in late August/early September 2023 in Virginia and Indiana, a treatment by location interaction was not observed, thus data were evaluated between mixtures and locations (Table 4). Across locations, the BPR TF:KBG mixture had 42% greater TF plants (10,482 vs. 6094 plants m^{-2}) and 41% fewer KBG plants (2592 vs. 4366 plants m^{-2}) compared to the BPS TF:KBG mixture. The proportion of TF increased from 58.1% TF in the BPS TF:KBG mixture to 79.4% TF in the BPR TF:KBG mixture. Additionally, canopy density (total plants) increased by 20% with the BPR TF:KBG mixture compared to the BPS TF:KBG mixture (13,074 vs.10,460 plants m^{-2}). Across TF:KBG mixtures, the Indiana location had a greater number of TF and total number of plants. Differences in the amount of KBG plants m^{-2} was not found between locations.

A mixture-by-year interaction was not observed for proportion of TF, KBG, and total canopy density in Indiana during 2023 and 2024 (Table 5). The BPS TF:KBG mixture had more KBG plants and reduced canopy density compared to the BPR TF:KBG mixture when averaged across 2023 and 2024. Additionally, the BPS TF:KBG mixture reduced TF proportion to 50.9% compared to the BPR TF:KBG mixture with 82.0% TF. Between 2023 and 2024, total canopy density remained the same when averaged across mixtures, but KBG increased from 3247 to 4967 plants m^{-2} across locations and reduced TF proportion from 73.6% in 2023 to 59.3% in 2024.

TABLE 3 Area under the turf quality curve (AUTQC) among five tall fescue (TF) blend ratios and two TF: Kentucky bluegrass (KBG) containing brown patch resistant (BPR) and susceptible (BPS) TF cultivars in West Lafayette, IN, and Blacksburg, VA, during 2022 and 2023.

Main effects	Indiana (AUTQC)	Virginia (AUTQC)
Blend/mixture[a]		
0% BPR TF	882e	544c
25% BPR TF	938d	588b
50% BPR TF	972c	598ab
75% BPR TF	1000bc	604ab
100% BPR TF	1021ab	609ab
BPS TF: KBG	917d	588b
BPR TF: KBG	1033a	625a
Year		
2022	1092a	551b
2023	841b	637a

Note: Means in the same column followed by a common letter in each main effect were not significantly different according to Fisher's protected least significant difference (LSD) ($p < 0.05$).

[a]Raptor III was the BPR TF cultivar and Kingdom was the BPS TF cultivar in the blends and mixtures. The KBG was a blend (365ss: Bolt, Legend, and Blue Note).

4 | DISCUSSION AND CONCLUSION

Establishing TF either as a blend or mixture is beneficial to increase genetic diversity and improve adaptability to various environmental conditions. Although previous literature has suggested lack of stability in brown patch resistance among TF cultivars when grown in different environments

TABLE 4 Species composition and canopy density of various turf-type tall fescue (TF): Kentucky bluegrass (KBG) bluegrass mixtures with a brown patch susceptible (BPS) (Kingdom) or resistant (BPR) (Raptor III) TF cultivar following two growing seasons after seeding in West Lafayette, IN, and Blacksburg, VA.

Main effects	TF[a] (plants m^{-2})	KBG (plants m^{-2})	Total (plants m^{-2})	TF proportion (%)
Mixture[b]				
BPS TF:KBG	6094b	4366a	10,460b	58.1b
BPR TF:KBG	10,482a	2592b	13,074a	79.4a
Location				
Indiana	9657a	3248a	12,904a	73.6a
Virginia	6919b	3710a	10,629b	63.9b
	ANOVA			
Source of variation	*p*-value			
Block	0.1178	0.9204	0.2547	0.4126
Mixture (M)	<0.0001	0.0001	0.0002	<0.0001
Location (L)	<0.0001	0.2531	0.0009	0.0028
M × L	0.0568	0.0730	0.6585	0.2216

Note: Means in the same column followed by a common letter in each main effect were not significantly different according to Fisher's protected least significant difference (LSD) ($p < 0.05$).

[a]Populations were recorded on August 30, and September 7, 2023 for the Virginia and Indiana location, respectively.

[b]Raptor III was the BPR TF cultivar and Kingdom was the BPS TF cultivar in the blends and mixtures. The KBG was a blend (365ss: Bolt, Legend, and Blue Note).

TABLE 5 Species composition and canopy density of various turf-type tall fescue (TF): Kentucky bluegrass (KBG) bluegrass mixtures with a brown patch susceptible (BPS) (Kingdom) or resistant (BPR) (Raptor III) TF cultivar during 2023 and 2024 in West Lafayette, IN.

Main effects	TF[a] (plants m^{-2})	KBG (plants m^{-2})	Total (plants m^{-2})	TF proportion (%)
Mixture[b]				
BPS TF:KBG	5877b	5692a	11,570b	50.9b
BPR TF:KBG	11,438a	2522b	13,961a	82.0a
Year				
2023	9657a	3247b	12,904a	73.6a
2024	7659b	4967a	12,626a	59.3b
	ANOVA			
Source of variation	*p*-value			
Block	0.3886	0.2293	0.4416	0.3886
Mixture (M)	<0.0001	<0.0001	0.0014	<0.0001
Year (Y)	0.0053	0.0023	0.6790	0.0006
M × Y	0.8062	0.2070	0.4636	0.1055

Note: Means in the same column followed by a common letter in each main effect were not significantly different according to Fisher's protected least significant difference (LSD) ($p < 0.05$).

[a]Populations were recorded on September 7, 2023 and July 23, 2024.

[b]Raptor III was the BPR TF cultivar and Kingdom was the BPS TF cultivar in the blends and mixtures. The KBG was a blend (365ss: Bolt, Legend, and Blue Note).

(Bokmeyer et al., 2009), differences in resistance of the BPR cultivar were not observed between the two locations (Indiana and Virginia) in this study. Although seasonal brown patch (AUDPC) varied between locations and evaluation years (Virginia greater AUDPC in 2022 and Indiana greater in 2023), cultivar and blend responses were generally consistent between locations. Differences between years and locations could be attributed to differences in local environmental conditions (minimum and maximum air temperature, relative humidity, rainfall) between locations and evaluation years (Fidanza et al., 1996).

In a previous growth chamber study, the BPR TF cultivar (Raptor III) reduced brown patch AUDPC by 37% compared to the BPS cultivar (Kingdom) (Powlen et al., 2024). In this field study using the same TF cultivars, the BPR TF cultivar reduced brown patch AUDPC compared to the BPS TF by 76% (522 vs. 2200, respectively) and 83% (256 vs. 1471, respectively) in 2022 and 2023 when averaged between the two locations. Among the TF blends, the addition of a BPR TF at any proportion (≥25% BPR TF) reduced disease severity compared to the BPS TF cultivar. Thus, even a small addition of a BPR cultivar in a TF blend appears beneficial for disease reductions; however, the most effective reduction of brown patch in this study was the addition of ≥75% BPR TF in a blend or mixture. The addition of other cultivars with moderate to low brown patch resistance may have other desirable characteristics, such as gray leaf spot (*Pyricularia grisea*) resistance, or assisting in reducing the overall cost of the blend.

Although differences in brown patch severity among TF blends were relatively consistent between study locations and evaluation years, cultivar composition could potentially change over time. The BPR TF could increase in density over time (tillers or short rhizomes), improving overall resistance long-term. However, preliminary evaluations 3 years after seeding (2024) in Indiana have shown similar differences as the previous 2 years in brown patch severity among these blends. Limited information is available on the stability of turfgrass blends over time; thus, long-term studies (i.e., ≥5 years) evaluating changes in disease resistance over time are warranted.

Previous studies have found that the addition of other species like KBG to TF cultivar blends reduced brown patch when compared to BPS cultivars (Park et al., 2017; Reynolds et al., 2005; Xiang et al., 2019). The addition of KBG to a BPS TF cultivar in this study improved seasonal visual quality (AUTQC) compared to 0% BPR TF across both years of evaluation in both locations. Further, the addition of KBG to a BPS TF reduced AUDPC by 25% in 2022 and 47% in 2023 compared to the 0% BPR TF. The increased reduction of brown patch during year 2 compared to year 1 could be due to the increase in KBG composition over time.

The potential increase of KBG over time when using a BPS cultivar may be unwanted if a turf stand dominated by TF is desired. Management practices such as mowing, fertilization, and irrigation have been previously shown to impact species population dynamics, especially during the first 4 years after establishment (Davis, 1958; Dunn et al., 2002; Porano et al., 2021). Results from Reynolds et al. (2005) reported that brown patch resistance was primarily due to the resistance of the TF cultivar, and the addition of a KBG cultivar to a susceptible cultivar also improved disease resistance. In the same study, mixing KBG with TF reduced TF stand composition by 50% over 3 years of evaluation. Based on results from the present study, selecting a BPR TF cultivar can reduce changes in species composition over time, with the BPR TF:KBG mixture maintaining greater proportion of TF (79.4% TF) compared to the BPS TF:KBG mixture (58.1% TF) 2 years after establishment across locations. Since the addition of KBG to the BPR TF substantially changed the overall species from year 2 to 3 in Indiana, adding KBG to the BPR TF cultivar may not be warranted if a predominate TF stand is desired.

Although this study only evaluated brown patch resistance using one KBG blend, Park et al. (2017) found brown patch resistance to be influenced by the KBG cultivar. When selecting a KBG cultivar or blend to mix with TF, long-term population dynamics are dependent on KBG cultivar selection and aggressiveness of spreading rhizomes. Although select TF cultivars could have more aggressive spreading habits (rhizomatous TF), the lateral spread of these cultivars compared to KBG is much less (Porano et al., 2021; St. John et al., 2009). In a study by Macolino et al. (2014), the selection of a TF cultivar with increased rhizomatous spreading habit maintained higher proportion of TF over time when compared to slower spreading TF cultivars. Although neither of the TF cultivars in the present study were marketed as lateral spreading, evaluating brown patch resistance among blends and mixtures using TF cultivars with lateral spreading habits and KBG cultivars with different rates of spreading habits warrants further evaluation.

Turfgrass practitioners, sod growers, and other consumers could establish BPR TF cultivars through methods similar to the methods used in this study to get maximum benefit of the host resistance. These cultivars would improve quality and reduce disease (based on these results), and potentially reduce the overall reliance on fungicides. Other methods of introducing these cultivars would be overseeding into existing turfgrass areas. Preliminary findings have found two consecutive years of overseeding BPR TF into existing BPS TF is a viable option for reducing brown patch without completely renovating the turfgrass area (Powlen & Bigelow, 2023a). Regardless, the results of this study demonstrated that prior to establishing TF, turfgrass practitioners and other consumers should evaluate the documented performance of TF cultivars (e.g., National Turfgrass Evaluation Program results) in their geographical region, but also other surrounding locations to confirm resistance across locations. Overall, this study reinforces the importance of selecting and planting resistant cultivars in order to effectively reduce lawn diseases and thereby reduce the reliance on fungicides for brown patch in TF lawns.

AUTHOR CONTRIBUTIONS

Jada S. Powlen: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; validation; visualization; writing—original draft; writing—review and editing. **David S. McCall**: Conceptualization; investigation; validation; visualization; writing—review and editing. **Kevin L. Hensler**: Data curation; investigation; validation; writing—review and editing. **James P. Kerns**: Conceptualization; validation; visualization; writing—review and editing. **Michael A. Fidanza**: Conceptualization; validation; visualization; writing—review and editing. **Cale**

A. Bigelow: Conceptualization; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; visualization; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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