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Identification of common bean lines with putative partial resistance to white mold under irrigated conditions

Abstract – The objective of this work was to identify common bean lines with a high-yield potential and partial resistance to white mold. Twelve cultivation and use trials were conducted in the dry season under sprinkler irrigation in areas prone to the disease in the state of Minas Gerais, Brazil. Thirty-six genotypes were evaluated in 12 trials: 6 with 21 *carioca*-type genotypes, and 6 with 15 black-, red-, or purple-seeded genotypes. Based on the Spearman correlation between the white mold score (1–9) and yield, the trials were stratified into scenarios with a significant negative or nonsignificant/positive correlation. Subsequently, linear mixed models were used to estimate genotype effects on yield within each correlation scenario and genotype group. Across the 12 trials, white mold pressure ranged from low to very high. Significant negative correlations were detected in 2 *carioca* trials and in 2 black-, red-, or purple-seeded bean trials. In these 4 trials, the median white mold scores ranged from 2.0 to 8.0, and average yield from 1,279 to 3,246 kg ha^{-1}. Based on field performance and market relevance, two *carioca* lines (CNFCMG 246D and VC35) and one black line (VP34) are the most promising because they combine partial resistance with a high-yield potential.

Index terms: *Phaseolus vulgaris*, *Sclerotinia sclerotiorum*, black bean, *carioca* bean, value for cultivation and use.

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Identificação de linhagens de feijão-comum com potencial para resistência parcial ao mofo-branco em áreas irrigadas

Resumo – O objetivo deste trabalho foi identificar linhagens de feijão-comum com alto potencial produtivo e resistência parcial ao mofo-branco. Foram conduzidos 12 ensaios de valor de cultivo e uso na estação seca sob irrigação em áreas com histórico da doença no estado de Minas Gerais, Brasil. Trinta e seis genótipos foram avaliados em 12 ensaios: 6 com 21 genótipos do tipo carioca, e 6 com 15 genótipos de grãos pretos, vermelhos ou roxos. Com base na correlação de Spearman entre a nota de mofo-branco (1–9) e produtividade, os ensaios foram estratificados em cenários de correlação negativa significativa ou não significativa/positiva. Posteriormente, modelos mistos lineares foram utilizados para estimar os efeitos dos genótipos sobre a produtividade, dentro de cada cenário de correlação e grupo de genótipos. Nos 12 ensaios, a pressão do mofo-branco variou de baixa a muito alta. Correlações negativas significativas foram detectadas em 2 ensaios com feijão-carioca e em 2 com feijões pretos, vermelhos e roxos. Nestes 4 ensaios, a mediana das notas de mofo-branco variou de 2,0 a 8,0, e a produtividade média, de 1.279 a 3.246 kg ha^{-1}. Com base no desempenho em campo e na relevância comercial

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dos grãos, duas linhagens de feijão-carioca (CNFCMG 246D e VC35) e uma de feijão-preto (VP34) são as mais promissoras por combinarem resistência parcial com alto potencial produtivo.

Termos para indexação: *Phaseolus vulgaris*, *Sclerotinia sclerotiorum*, feijão-preto, feijão-carioca, valor de cultivo e uso.

Introduction

Common bean (*Phaseolus vulgaris* L.) production reached 509,000 metric tons in 2024 in the state of Minas Gerais, Brazil (Acompanhamento..., 2025). The *carioca* type was the most widely cultivated, followed by the black type (Teixeira et al., 2024).

About 31% of bean production in the state occurs under irrigation during the fall-winter (dry) season, achieving an average yield of 2,520 kg ha^{-1} (Acompanhamento..., 2025). During this season, the combination of low temperatures and high humidity, resulting from sprinkler irrigation, creates favorable conditions for white mold (WM), caused by the fungus *Sclerotinia sclerotiorum* (Lib.) de Bary (Shahoveisi et al., 2022).

The use of fungicides to control WM can increase bean yield by up to 2.2-fold (Vieira et al., 2010). However, fungicide alone cannot eradicate WM and poses risks to human and environmental health. Several complementary practices can further mitigate yield losses, as follows: use of biofungicides, reduction of plant density, adjustment of nitrogen and irrigation, adoption of no-tillage, and planting of partially resistant cultivars (Vieira et al., 2010; Chacón-Orozco et al., 2020; Lima et al., 2020).

In common bean, resistance to WM is partial and involves both avoidance and physiological mechanisms. Avoidance mechanisms are associated with morphological traits, such as lodging resistance and plant height, as well as with phenological traits, including flowering time, all of which influence the microenvironment of the bean-pathogen interaction (Robison et al., 2018; Teixeira et al., 2024). In contrast, physiological mechanisms encompass biochemical and physical responses of the plant to the pathogen infection (Robison et al., 2018). Under sprinkler-irrigated, dry-season conditions, the avoidance mechanisms appear to play a greater role in partial resistance than physiological mechanisms (Lima et al., 2020).

In the state of Minas Gerais, value for cultivation and use (VCU) trials are conducted to evaluate promising bean lines primarily developed by Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Universidade Federal de Viçosa (UFV), and Universidade Federal de Lavras (UFLA). Findings from these VCU trials provide the foundation for cultivar release decisions in Minas Gerais state (Mencalha et al. 2022).

Previous studies (Lima et al., 2020; Teixeira et al., 2024) selected common bean genotypes for partial resistance to WM, using dry-season VCU trials in disease-prone, irrigated fields. However, because new entries join VCU trials only every two to three years, recently developed lines remain unevaluated. Therefore, the evaluation of lines under sprinkler-irrigated and low-rainfall conditions, targeting cultivar release or integration into breeding programs, is necessary.

The objective of this work was to identify common bean lines with a high-yield potential and partial resistance to WM.

Materials and Methods

VCU trials were conducted during the dry season under sprinkler irrigation in fields naturally infested with *S. sclerotiorum* sclerotia in three municipalities located in the Zona da Mata region, in the southeast of the state of Minas Gerais, Brazil.

According to the Köppen-Geiger's classification, the regional climate is Cwa (Alvares et al., 2013). The typical crop rotation in the experimental fields consisted of common bean during the autumn-winter season, followed by corn during the spring-summer season. The soils are classified Argissolos (Santos et al., 2025), equivalent to Ultisols, according to the USDA soil taxonomy (Soil Survey Staff, 1999).

Following soil preparation (disk plowing to 0.2 m soil depth, and two harrow passes), two sets of trials were established between April and July in adjacent areas: one with carioca bean genotypes; and the other with black-, red-, and purple-seeded bean genotypes.

Using the set of genotypes (Table 1), 12 VCU trials were conducted in the municipalities of Oratórios, Coimbra, and Viçosa: 6 with *carioca*-type beans, and 6 with black/red/purple bean genotypes. In 2016, 2017, and 2018, 6 trials were carried out in Oratórios (20°25'05"S, 42°47'28"W; at 492 m altitude), with 1

Table 1. Common bean (*Phaseolus vulgaris*) genotypes evaluated in the trials for value for cultivation use, their institution of origin, growth habit, and life cycle.

Genotype	Institution of origin[1]	Type of growth habit[2]	Life cycle[3]
	Carioca type		
VC34	UFV	III	N
VC35	UFV	III	N
VC36	UFV	III	N
VC37	UFV	III	N
VC38	UFV	III	N
VC39	UFV	III	N
CXI-1	UFLA	III	N
CXII-13	UFLA	III	N
CXII-15	UFLA	III	N
CXII-16	UFLA	III	N
CXI-26	UFLA	III	N
RCPVIII-1	UFLA	II	N
CNFCMG 126M	UFLA/EMBRAPA	II	N
CNFCMG 134M	UFLA/EMBRAPA	III	N
CNFCMG 198D	UFLA/EMBRAPA	II	N
CNFCMG 246D	UFLA/EMBRAPA	II	N
CNFC 10762	EMBRAPA	II	N
CNFC 11948	EMBRAPA	II	N
'Pérola'	EMBRAPA	III	N
'BRS Estilo'	EMBRAPA	II	N
'BRSMG Uai'	UFV/UFLA/EMBRAPA/EPAMIG	II	N
	Black type		
VP22	UFV	II	N
VP33	UFV	II	N
VP34	UFV	II	N
CNFP 10974	EMBRAPA	II	I
CNFP 11979	EMBRAPA	II	N
CNFP 15194	EMBRAPA	II	N
CNFP 15677	EMBRAPA	II	N
CNFP 15680	EMBRAPA	II	N
'BRS Campeiro'	EMBRAPA	II	I
'BRS Esteio'	EMBRAPA	II	N
	Red and purple types		
VR 19	UFV	II	I
VR 20	UFV	II	E/I
VR 21	UFV	III	I
'Ouro Vermelho'	UFV/UFLA/EMBRAPA/EPAMIG	III	I
'BRSMG Tesouro'	UFV/UFLA/EMBRAPA/EPAMIG	II	I/N

[1]UFV, Universidade Federal de Viçosa; UFLA, Universidade Federal de Lavras; EMBRAPA, Empresa Brasileira de Pesquisa Agropecuária; and EPAMIG, Empresa de Pesquisa Agropecuária de Minas Gerais. [2]III, prostrate, or semiprostrate stems, and branches with pods concentrated at the base of the canopy; and II, narrow canopy with pods distributed along the stems. [3]N, normal (81-91 days); I, intermediate (71-80 days); and E, early (60-70 days).

trial from each bean group established annually. In 2017, 6 additional trials were conducted: 2 in Coimbra (20°49'44"S, 42°45'56"W, at 713 m altitude) and 4 distributed equally in two sites in Viçosa – Viçosa1 (20°45'14"S, 42°52'55"W, at 648 m altitude) and Viçosa2 (20°44'49"S, 42°50'30"W, at 655 m altitude), with 1 trial from each bean group conducted at each site.

The evaluated genotypes are presented together with data on their institutions of origin, growth habits, and life cycles (Table 1). The *carioca*-type bean trial comprised 21 genotypes, whereas the black/red/purple bean trials comprised 10 black bean genotypes, 4 red bean genotypes, and the purple-seeded cultivar BRSMG Tesouro. Commercial cultivars were included as checks.

A randomized complete block design with three replicates was applied. Each plot consisted of two 4.0 m long rows spaced at 0.5 m apart, with 15 seed sown per meter. To minimize border effects, a single row of the Pérola bean cultivar was sown along each side of the trial area.

All trials received a basal fertilization of 350 kg ha^{-1} of the N-P-K (8-28-16) formula, followed by 150 kg ha^{-1} urea (45% N) as top-dressing, and 90−100 g ha^{-1} molybdenum (as sodium molybdate) applied to leaves at the V_4 growth stage (third trifoliate leaf).

Phytosanitary management (fungicide, insecticide, and herbicide application) complied with the label recommendations for common bean. Fungicide treatment consisted of two applications of 500 g kg^{-1} azoxystrobin (Amistar WG, Syngenta Proteção de Cultivos Ltda., São Paulo, SP, Brazil) at the V_4 growth stage. Insect pests were controlled with two to three applications of 700 g kg^{-1} imidacloprid (Evidence WG, Bayer S.A., São Paulo, SP, Brazil) during the vegetative stage. The herbicide, containing 250 g L^{-1} fomesafen (Flex SL, Syngenta Proteção de Cultivos Ltda., São Paulo, SP, Brazil) and 250 g L^{-1} fluazifop-p-butyl (Fusilade EW, Syngenta Proteção de Cultivos Ltda., São Paulo, SP, Brazil), was applied during post-emergence control.

Sprinkler irrigation was performed using overhead nozzles (approximately 1.5 m aboveground). Water was supplied every 2 days from sowing to seedling emergence, and weekly (about 40 mm per application) thereafter until 4 to 7 days before harvest.

Lodging was assessed before harvest on a 1–9 scale, where 1 represents "no lodging" and 9 is the "complete lodging" of all plants (Soule et al., 2011). This score was used as an additional selection criterion because it effectively distinguishes partially resistant from susceptible genotypes, as previously reported by Lima et al. (2020) and Teixeira et al. (2024).

At harvest, WM was visually scored on a 1–9 scale according to Miklas et al. (2001), where 1 represents noninfected plants; and 2 to 9, infected plants (IP) and/or infected tissues (IT) at different percentages. Specifically: 2, 1−20% IP and/or 1−5% IT; 3, 21−30% IP and/or 6−10% IT; 4, 31−40% IP and/or 11−20% IT; 5, 41−50% IP and/or 21−30% IT; 6, 51−60% IP and/or 31−40% IT; 7, 61−70% IP and/or 41−50% IT; 8, 71−80% IP and/or 51−60% IT; and 9, 81–100% IP and/or 61–100% IT. Seed yield was estimated from an area of 4.0 m^2 based on seed weight adjusted to 13% moisture.

To assess WM pressure in each trial, the overall median WM score across genotypes was calculated and classified as follows: 2.0, low; 2.1−3.0, low/moderate; 3.1−4.0, moderate; 4.1−5.0, moderate/high; 5.1−6.0, high; and ≥6.1, very high (Lima et al., 2020).

The analysis of variance was performed separately for seed yield in each trial. The correlations between the scores obtained for WM and yield or lodging were assessed across all 12 trials using the Spearman rank correlation. Within each bean group, trials were categorized into two distinct scenarios, based on their WM score-yield correlations, as follows: significant negative; and nonsignificant or significant positive. For both scenarios, genotype effects on yield were evaluated using linear mixed models via the "lmer" function of the "lme4" package (Bates et al., 2015). Genotype was treated as a fixed effect, and trials and blocks (nested within trials), as random effects. Model assumptions were verified through residual plots, and Levene's and Shapiro-Wilk's tests were used for homogeneity of variances and normality, respectively. The statistical significance of the fixed effect was determined by the analysis of variance function from the lmerTest package (Kuznetsova et al., 2017), and genotype means were grouped using the Scott-Knott test, at 5% probability, via the ScottKnott package (Jelihovschi et al., 2014). Lodging and WM scores were summarized with box plots stratified by bean group and WM score-yield correlation scenarios.

All analyses were performed in the R, version 4.4.3, software (R Core Team, 2024).

Results and Discussion

A wide gradient of WM pressure, from low to very high, was observed across the trials (Table 2). The coefficient of variation (CV) for seed yield ranged from 12 to 20% across trials, indicating a moderate to high experimental precision. The 6 trials with WM scores higher or equal to 6.5 were associated with lower overall yields and exhibited significant genotypic effects on yield.

In the *carioca* bean trials, WM and lodging scores were positively and significantly correlated with coefficients ranging from 0.44 to 0.70, across all locations. Similarly, significant positive correlations were detected across four locations of the black/red/purple bean trials, with coefficients ranging from 0.60 to 0.77. These findings corroborate the close association between lodging and WM severity previously reported by Lima et al. (2020). This relationship is likely bidirectional: lodging promotes WM development by trapping humidity and reducing the canopy aeration (Reich & Chatterton, 2023), whereas WM infection weakens the structure of plants, increasing their susceptibility to lodging (Ender & Kelly, 2005).

Significant negative correlations of moderate to high magnitude between the WM score and seed yield were observed in only four of the 12 trials, all conducted in 2017 under conditions from moderate/high to very high WM pressure. This fact contrasts with the findings of Lima et al. (2020), who reported significant negative correlations from moderate to very high magnitude (r = -0.43 to -0.86) between WM incidence (or WM score) and yield in 10 of 14 trials, even under conditions of low/moderate pressure. Most of these discrepancies stem likely from differences in baseline disease pressure between the two studies. While five trials experienced low WM pressure in the present study, the lowest pressure reported by Lima et al. (2020) was low/moderate and occurred in a single trial. Overall, both studies align with the observations of Ramasubramaniam et al. (2008), who observed that WM incidence below 20% does not reduce bean yield because plants are able to compensate for disease-induced damage.

Regardless of the WM score-yield correlation scenario, linear mixed models showed that the *carioca* genotype significantly affected yield ($p<0.001$), with VC35, VC37, 246D (CNFCMG 246D), CXI-1, and RCPVIII-1 consistently ranking among the highest-yielding genotypes (Figure 1). Notably, lines VC35

Table 2. White mold (WM) pressure and score, seed yield, and correlations across six trials for two common bean (*Phaseolus vulgaris*) groups.

Trial (year and municipality)	WM[(1)] pressure	WM score range (1-9)	r[(2)]	Seed yield (kg ha^{-1})			r[(4)]
				Range	CV[(3)] (%)	F genotype	
Carioca genotype							
2016 - Oratórios	L	1.0-5.0	0.50***	1,580-3,775	15	7.57***	0.21^{ns}
2017 - Oratórios	H	3.0-7.0	0.55***	1,279-2,696	16	3.81***	-0.63***
2017 - Viçosa1	M/H	2.0-6.5	0.70***	1,268-2,892	12	6.60***	-0.07^{ns}
2017 - Viçosa2	L	1.0-2.0	0.44***	2,308-3,569	17	1.33^{ns}	0.41***
2017 - Coimbra	VH	5.0-7.0	0.59***	1,414-2,497	17	2.87**	-0.55***
2018 - Oratórios	M	2.0-5.5	0.62***	1,852-3,243	18	2.14*	-0.10^{ns}
Black/red/purple genotype							
2016 - Oratórios	L	1.0-4.0	0.60***	1,902-3,655	16	4.42***	0.32*
2017 - Oratórios	H	2.0-7.0	0.77***	1,658-3,246	18	3.60 **	-0.45**
2017 - Viçosa1	M	2.0-7.5	0.68***	1,402-3,243	14	8.52***	-0.23^{ns}
2017 - Viçosa2	L	2.0-3.0	0.22^{ns}	2,233-3,254	14	1.57^{ns}	-0.04^{ns}
2017 - Coimbra	M/H	2.5-8.0	0.27^{ns}	1,719-3,112	15	4.00***	-0.67***
2018 - Oratórios	L	1.0-5.5	0.62***	2,100-3,157	20	1.38^{ns}	-0.07 ^{ns}

[(1)]WM pressure using the scores: 2.0, low (L); 3.1–4.0, moderate (M); 4.1–5.0, moderate/high (M/H); 5.1–6.0, high (H); and ≥ 6.1, very high (VH). [(2)]r, WM score-lodging correlations according to the Spearman test. [(3)]CV, coefficient of variation. [(4)]r, WM score-yield correlations according to the Spearman test. *, **, and *** Significant at 5, 1, and 0.1% probability, respectively. [ns]Nonsignificant.

and 246D, both with a normal life cycle (Table 1), exhibited the smallest yield variation between the two correlation scenarios (Figure 1). These findings indicate that even under high or very high WM pressure (Table 2), these two genotypes sustained minimal yield reductions, showing tolerance to the disease. Across both scenarios, the type-II line 246D displayed lower WM scores (Figure 2 A and B) and lodging (Figure 2 C and D) than the type-III line VC35. Although type-II genotypes are typically associated with greater avoidance mechanisms (Schwartz & Singh, 2013), partial resistance has been documented in type-III genotypes under irrigated dry-season conditions in Brazil (Lima et al., 2020; Teixeira et al., 2024). Therefore, the *carioca*-type lines VC35 and 246D were identified as the most promising genotypes for partial resistance to WM.

The check cultivars Pérola, BRSMG Uai, and BRS Estilo were top yielders only when the WM score was negatively correlated with yield (Figure 1), which aligns

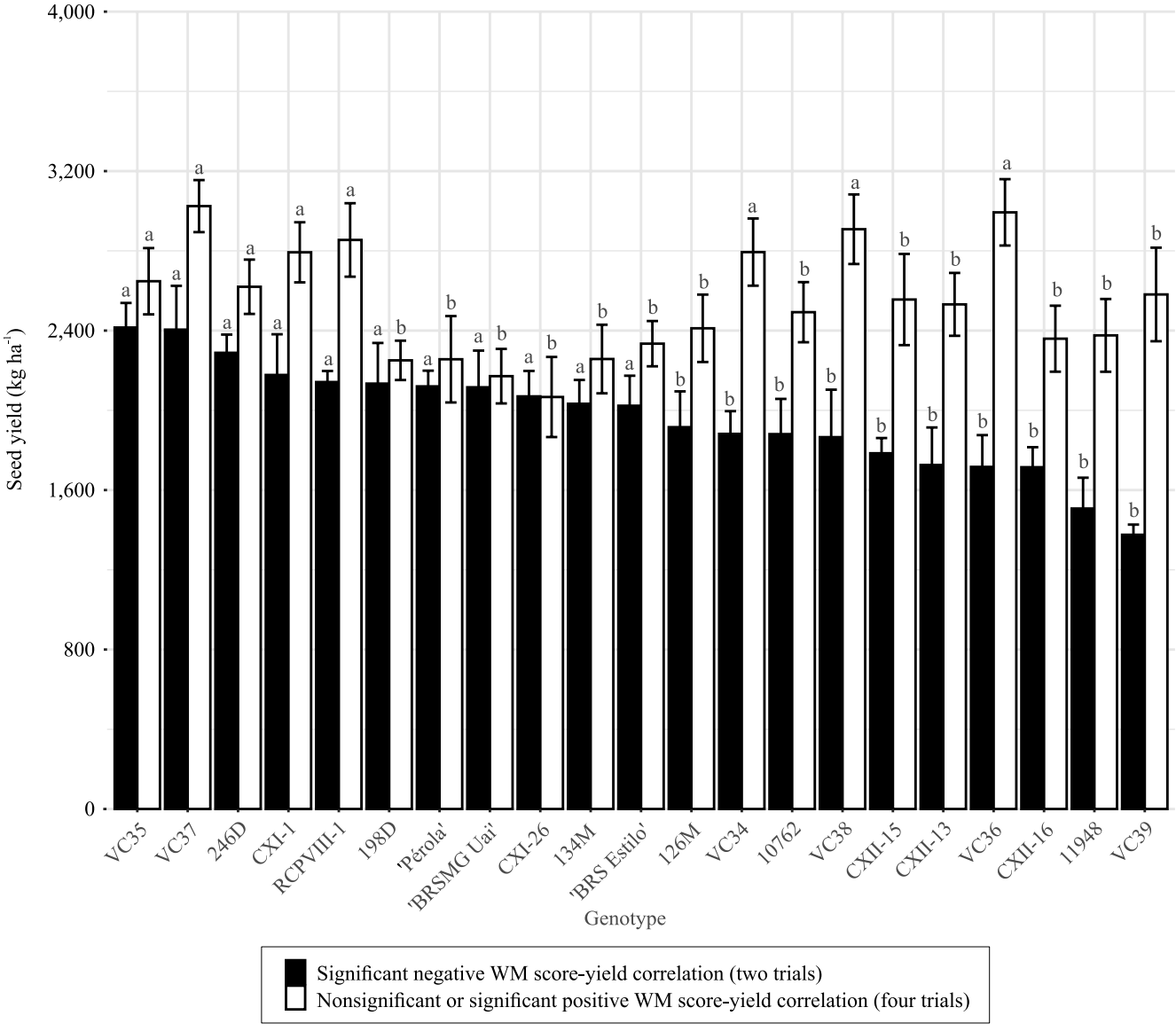

Figure 1. Seed yield (mean ± SE) of 21 *carioca* bean (*Phaseolus vulgaris*) genotypes across six value for cultivation and use trials. Genotypes are grouped according to the presence (black bars, two trials, n = 126) or absence (white bars, four trials, n=252) of significant negative correlations between white mold (WM) score and yield. Within each group, means with equal letters belong to the same group according to the Scott-Knott test, at 5% probability.

with the intermediate WM resistance reported by Lima et al. (2020). However, in a field trial inoculated with *S. sclerotiorum* isolate UFLA 3, Pérola, and BRS Estilo were more resistant to WM than BRSMG Uai (Abreu et al., 2022). Conversely, under conditions from low to moderate/high disease pressure (Table 2), 8 lines outyielded the check cultivars (Figure 1), showing greater yield potential under lower disease pressure.

CNFC 11948 and VC39, both characterized by a normal life cycle (Table 1), were among the lowest-yielding *carioca* genotypes. This trend was most pronounced under the significant negative correlation scenario (Figure 1), where both genotypes exhibited high WM (Figure 2 A) and lodging (Figure 2 C) scores. This pronounced susceptibility positions them as ideal reference genotypes for screening partial WM resistance. In this context, VC39 is especially valuable, due to its prostrate type-III growth habit. Conversely, the semi-upright type II-line CNFC 11948, commercially released as BRS FC402 cultivar (Melo et al., 2017), should be avoided in irrigated dry-season plantings in fields with a history of WM.

In the black/red/purple bean trials, significant genotypic effects on yield were detected only when WM score was negatively correlated with yield ($p<0.001$; $p=0.069$ otherwise). Overall, WM pressure

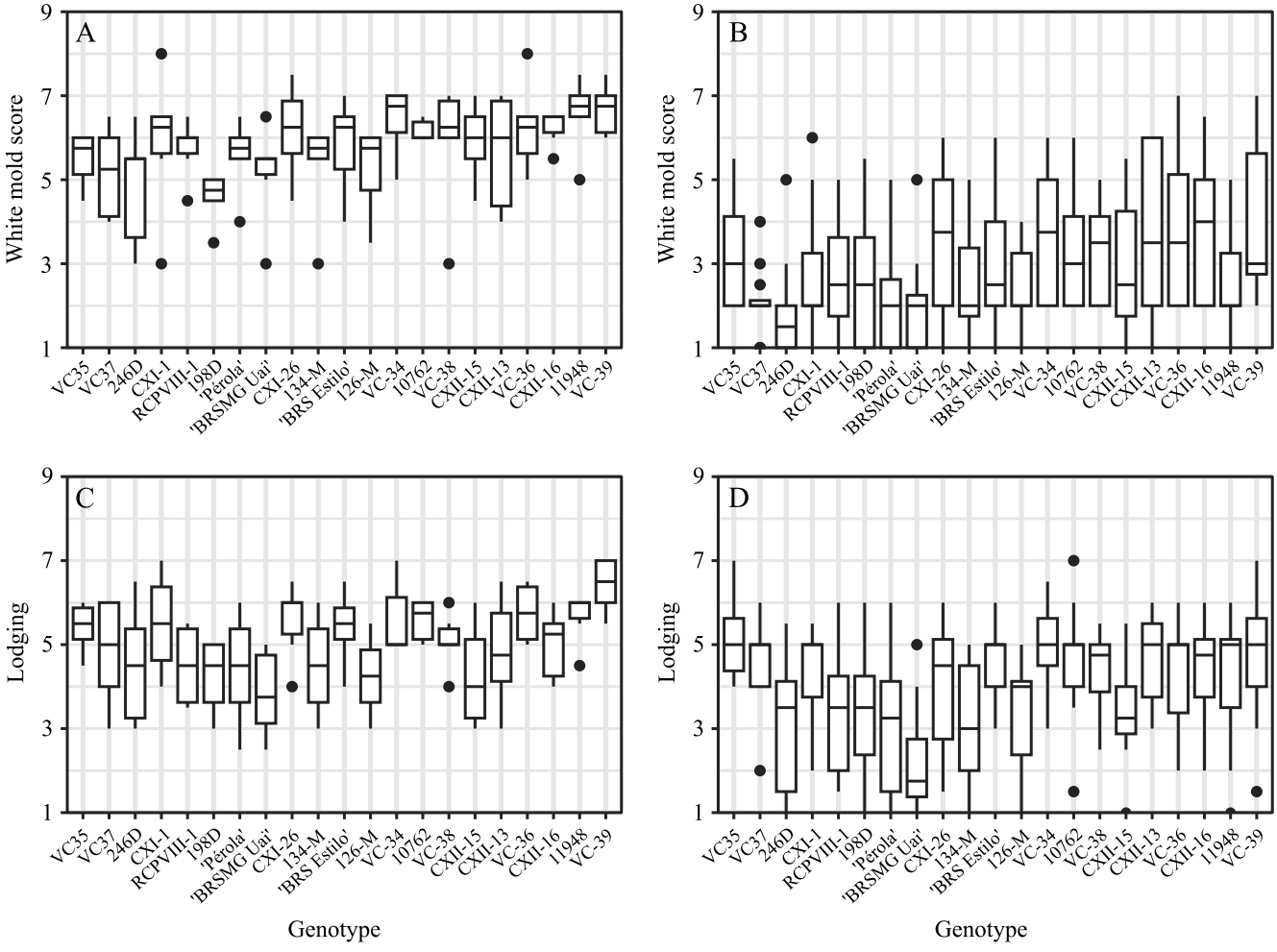

Figure 2. Box plots of white mold (A and B) and lodging (C and D) scores for 21 *carioca* bean (*Phaseolus vulgaris*) genotypes. Figures A and C show data from two trials with significant negative white mold (WM) score-yield correlations (n=126), while Figures B and D show data from four trials without significant negative correlations (n=252). The boxes display the median (center line) and interquartile range (IQR) from the 25th to 75th percentile. Whiskers extend to the minimum and maximum values within 1.5 × IQR, and dots represent outliers.

was lower than in the *carioca* trials (Table 2), resulting in smaller yield differences between the two correlation scenarios (Figure 3). This lower-disease pressure was likely due to a lower proportion of type-III genotypes (Table 1), which are generally more susceptible to WM (Schwartz & Singh, 2013; Lima et al., 2020) than those in the *carioca* trials. Under moderate/high or high-disease pressure (Table 2), seven genotypes ranked among the top yielders (Figure 3). Among them, the normal-cycle, type-II black bean line VP34 was the most promising genotype, combining high yield with partial resistance to WM (Figure 4 A and B) and satisfactory lodging tolerance across both correlation scenarios (Figure 4 C and D).

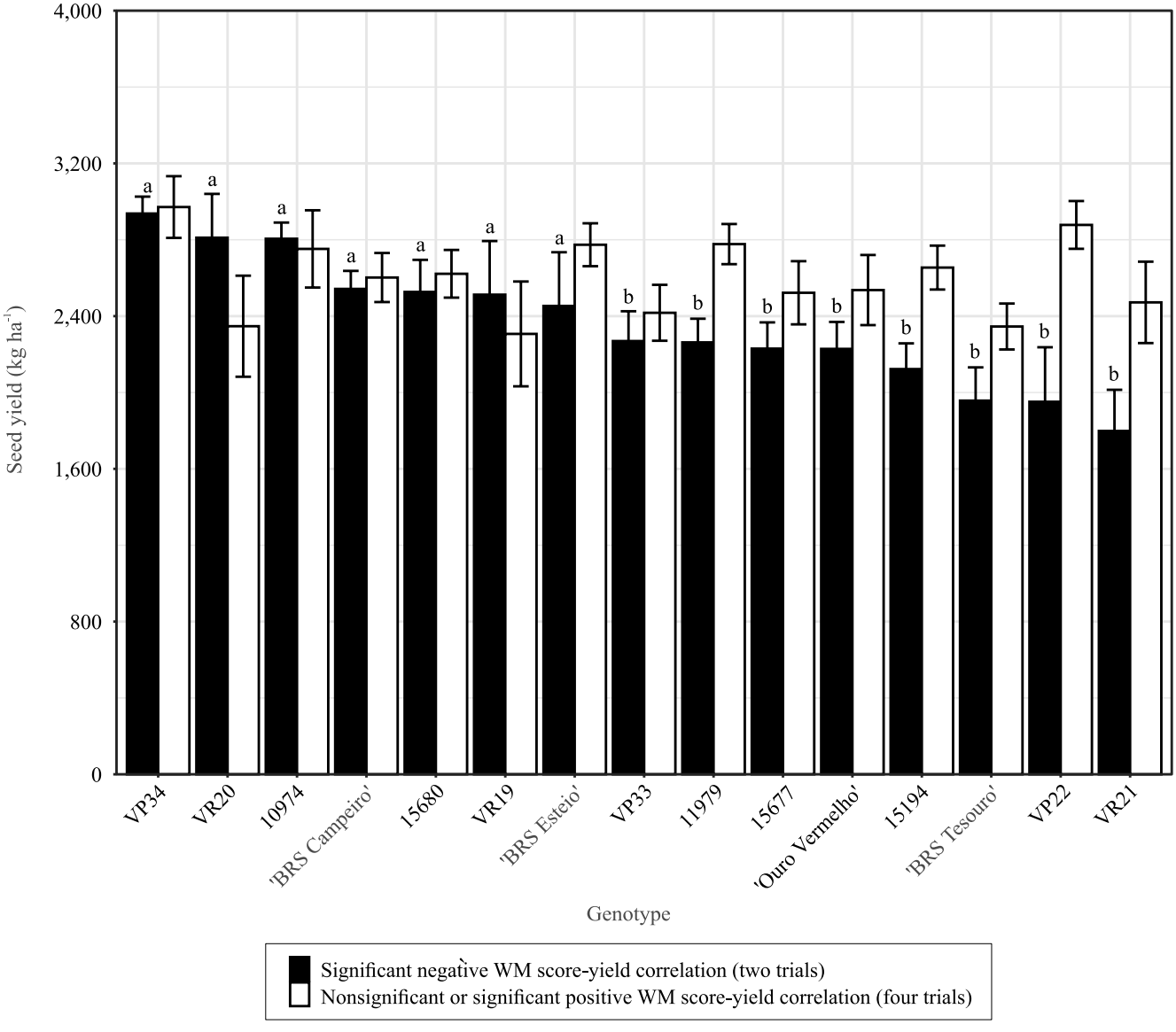

Figure 3. Seed yield (mean ± standard error) of 15 black/red/purple bean (*Phaseolus vulgaris*) genotypes across six value for cultivation and use trials. Genotypes are grouped according to the presence (black bars, two trials, n=90) or absence (white bars, four trials, n=180) of significant negative correlations between white mold (WM) score and yield. For trials with negative significant correlations (black bars), means with equal letters belong to the same group according to the Scott-Knott's test, at 5% probability. White bars without letters mean that genotype effect on yield was nonsignificant in trials without negative correlations.

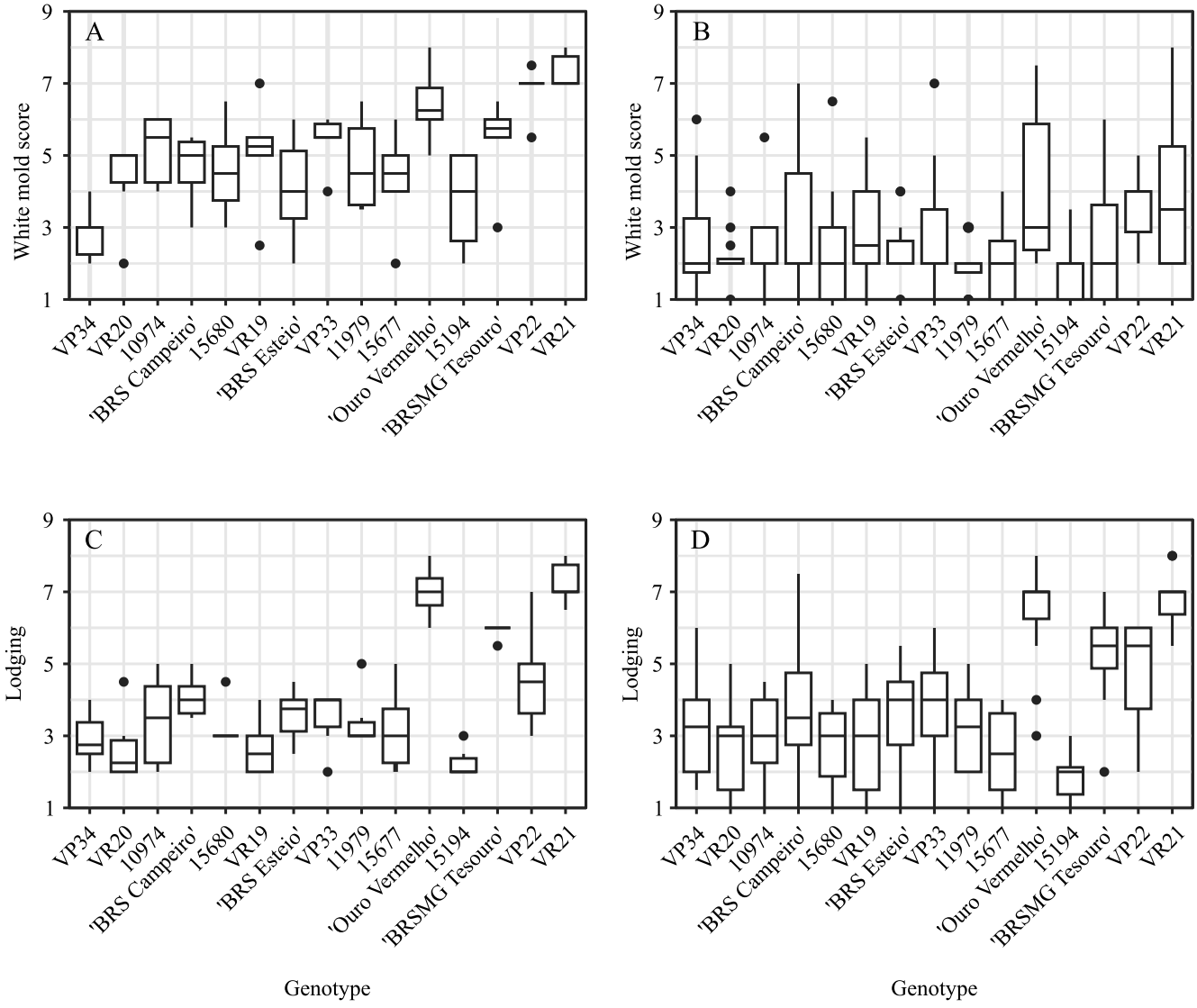

Figure 4. Box plots of white mold (A and B) and lodging (C and D) scores for 15 black/red/purple bean (*Phaseolus vulgaris*) genotypes. Figures A and C show data from two trials with significant negative white mold (WM) score-yield correlations (n=90), while Figures B and D show data from four trials without significant negative correlations (n=180). The boxes display the median (center line) and interquartile range (IQR) from the 25th to 75th percentile. Whiskers extend to the minimum and maximum values within 1.5 x IQR, and dots represent outliers.

Lines VR21 (type III) and VP22 (type II) showed the largest yield gap between correlation scenarios (Figure 3), indicating susceptibility to WM. Under the significant negative correlation scenario, these lines displayed a median 7.0 WM score (Figure 4 A), exceeding that of cultivar Ouro Vermelho, one of the susceptible checks used by Lima et al. (2020). Among the three genotypes, VP22 showed the lowest lodging score. Therefore, VR21 may be a more suitable susceptible reference for screening for partial resistance to WM.

Conclusions

1. The following three common bean (*Phaseolus vulgaris*) lines combined high yield with putative partial resistance to white mold: CNFCMG 246D and VC35 of the *carioca* type and VP34 of the black type.

2. The VC39 *carioca* bean line, the VR21 red bean line, and the VP22 black bean line are susceptible to white mold.

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During the preparation of this work, the authors used ChatGPT in order to improving English. After this use, the authors reviewed and edited the content as needed and takes full responsibility for it.

Conflict of interest statement

The authors declare no conflicts of interest.

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