Communication

Partial Resistance to Asian Soybean Rust in South Brazilian Soybean Cultivars: Genotypic Variation and Implications for Management

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ABSTRACT

The state of Rio Grande do Sul (RS) is the third-largest soybean producer in Brazil. Over the past fifteen years, the cultivated area in the state has expanded by 65%, particularly in its southern region. To assess the partial resistance levels of different soybean cultivars to Asian soybean rust (ASR), this study was conducted under field conditions during two growing seasons (2013/14 and 2014/15), evaluating 22 cultivars in southern RS. Although all cultivars were susceptible to the pathogen, disease severity varied significantly among genotypes and between crop years. The highest ASR severity at the R5.3 growth stage was 76.7% in 2013/14 and reached 100% (complete defoliation) in 2014/15. In contrast, the lowest severity was observed in the cultivar TMG 7062 IPRO, with 4.3% in 2013/14 and 8.3% in 2014/15. These findings highlight substantial differences in the levels of partial resistance to ASR among soybean cultivars. In conclusion, the use of cultivars with higher levels of partial resistance represents a viable and reliable strategy for managing ASR in southern RS. However, in seasons with highly favorable environmental conditions for disease development, additional integrated disease management practices may be necessary for most cultivars.

KEYWORDS: *Glycine max*; *Phakopsora pachyrhizi*; integrated management; genetic resistance; partial resistance; disease control

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INTRODUCTION

Soybean (*Glycine max*) is one of the main agricultural crops in Brazil. Its grains are used for both animal and human consumption, as well as for biofuel production [1]. Diseases are among the main factors limiting high yields of this crop, especially ASR, caused by *Phakopsora pachyrhizi* (Sydow & P. Sydow) [2].

The main strategies employed for ASR management include reducing the initial inoculum through a soybean-free period, complemented by slowing the disease progress rate through early sowing, the use of cultivars with high partial resistance, and preventive fungicide applications [3,4]. Cultivars with a high level of partial resistance to the disease are already in use, but developing cultivars with complete resistance that are also commercially competitive remains a challenge for breeding programs [5]. Currently, some commercial cultivars carrying resistance genes (*Rpp*), which delay the onset of the epidemic, are also available [6]. Soybean plants showing complete resistance to ASR have also been developed using transgenic techniques [7], but they are not yet commercially available to growers.

In Brazil, the state of RS is one of the largest soybean producers, harvesting 19.6 million tons in the 2023/2024 season, which accounted for 13% of the national production [8]. Over the past fifteen years, the cropped area with soybean in RS has increased by 65% [8], mainly in the southern region of the state, a region traditionally dedicated to rice cultivation and livestock farming. The cultivars used in this expanding area are, generally, the same as those sown in the traditional soybean-producing regions [9]. However, the environment in southern RS differs from the traditional soybean areas, including in terms of the expected behavior of the pathogen inoculum [10]. Therefore, information on the partial resistance levels of cultivars under these specific conditions is valuable for soybean growers as well as for plant breeders. Considering this, we evaluated the partial resistance levels of twenty-two soybean cultivars to ASR based on disease severity data collected under field conditions.

MATERIAL AND METHODS

The experiments were conducted at the Palma Agricultural Center, part of the Federal University of Pelotas, located in the municipality of Capão do Leão, RS (31°48'06.5"S; 52°30'19.4"W). The treatments consisted of soybean cultivars (Table 1), selected based on their maturity group and regional recommendation for cultivation. The cultivars were selected for the experiment based on their availability to farmers in RS and their status as either among the most widely used or recently released cultivars. The experimental design was a randomized complete block design with three replications. Each experimental unit consisted of five rows spaced 0.45 m apart and 5 m in length, totaling 11.25 m^2, with a useful area of 5.4 m^2 (3 rows × 4 m). The experiments were carried out during the 2013/14 (experiment 1) and 2014/15 (experiment 2) growing seasons. Sowing was performed using a seeding rate of 10 seeds per linear meter. Soybean crop management followed technical recommendations [9], except for the omission of fungicide applications.

Table 1. Characteristics, technology (RR1—resistance to glyphosate, Intact—resistance to glyphosate and pest attack), maturity group (5, earlier maturation and 7, later maturation), growth habit (determined and undetermined) and resistance against ASR (R—resistant, S—susceptible, NI—no information) of the soybean cultivars used in the experiments.

Cultivar	Technology	Maturity Group	Growth Habit	Resistance against ASR
BMX MAGNA RR	RR1	6.4	undetermined	S
BMX PONTA IPRO	Intact	6.6	undetermined	S
BMX POTENCIA RR	RR1	6.7	undetermined	S
BMX VALENTE RR	RR1	6.8	undetermined	S
CD 2590 IPRO	Intact	5.9	determined	S
CD 2611 IPRO	Intact	6.1	undetermined	S
CD 2694 IPRO	Intact	6.9	determined	S
CD 2737 RR	RR1	7.3	undetermined	S
NA 5909 RG SUL	RR1	6.4	undetermined	S
NS 5959 IPRO *	Intact	5.9	undetermined	S
NS 6211 RR *	RR1	np	determined	NI
NS 6767 RR *	RR1	6.2	undetermined	S
NS 6909 IPRO *	Intact	6.3	undetermined	S
NS 7000 IPRO *	Intact	6.7	undetermined	S
P 95 R 51 *	RR1	np	undetermined	S
P 95 Y 72 *	RR1	np	undetermined	S
TEC 6029 IPRO	Intact	5.7	undetermined	S
TMG 1067 RR *	RR1	6.7	determined	S
TMG 1266 RR	RR1	6.6	undetermined	S
TMG 7062 IPRO	Intact	6.2	undetermined	R
SYN 1059 RR	RR1	5.9	undetermined	S
SYN 1163 RR	RR1	6.3	undetermined	S

* Information obtained from the company producing the seed. np = not provided.

Plant inoculation was not performed, as disease occurrence resulted from the natural inoculum present in the environment. ASR monitoring began after seedling emergence and was conducted fortnightly during the vegetative stages and weekly during the reproductive stage. Disease severity was assessed at three random points within the useful area of each plot, with each point represented by at least 10 plants. Severity data were expressed as the percentage of total leaf area affected by the disease, using a diagrammatic scale [11]. Disease severity was always assessed by the same previously trained evaluator. In this study, we present the ASR severity data collected at the R5.3 phenological stage [12]. This phenological stage was chosen because the most susceptible cultivars reached 100% defoliation at this point; therefore, we standardized this stage across all cultivars. As previous statistical analyses indicated significant interactions between growing seasons, we chose to perform separate analyses for each season. Data were tested for homogeneity of variances using Bartlett's test and then subjected to analysis of variance (ANOVA) using R software version 4.2.1 (R Development Core Team, 2022). Means were grouped using the Scott-Knot test (α = 0.99). Considering genotypes as a fixed effect, the following parameters were estimated: phenotypic variance (σ_p^2), environmental variance (σ_e^2), quadratic component (ϕ_g), coefficient of phenotypic variation ($CV_p = (\sigma_p^2)^{0.5}/\mu$) and heritability in the broad sense ($H^2 = \phi_g/\sigma_p^2$) [13].

RESULTS AND DISCUSSION

ASR severities for each soybean cultivar in both crop seasons are presented in Table 2. In the 2013/14 season, ASR severity ranged from 4.3% to 76.7%; however, 54% of the genotypes showed ASR severity equal to or greater than 40%. According to the Scott-Knott criterion, cultivars were grouped into four distinct categories, as follows: (i) The first group included the most susceptible cultivars (TEC 6029 IPRO, CD 2590 IPRO, P95R51, and P95Y72), which showed ASR severity higher than 70.0%; (ii) The second group included cultivars with intermediate severity, ranging from 53.3% to 40.0% (NS 7000 IPRO, SYN 1059 RR, TMG 1067 IPRO, CD 2611 IPRO, NS 6767 RR, NA 5909 RG SUL, NS 6211 RR, and SYN 1163 RR); (iii) The third group, characterized by ASR severity between 35.0% and 21.7%, comprised the cultivars NS 6909 IPRO, NS 5959 IPRO, TMG 1266 RR, BMX POTÊNCIA RR, and BMX MAGNA RR; (iv) Finally, the fourth group consisted of cultivars with lower ASR severity, below 15.0% (CD 2737 RR, BMX PONTA IPRO, CD 2694 IPRO, BMX VALENTE RR, and TMG 7062 IPRO).

Table 2. Severity, in percentage of leaf area, of ASR (*Phakopsora pachyrhizi*) in soybean genotypes grown in the 2013/14 and 2014/15 seasons.

Cultivar	Severity of ASR (%) [1]	
	2013/14	2014/15
TEC 6029 IPRO	76.67 a	73.33 b
CD 2590 IPRO	73.33 a	100.00 a
P 95 R 51	73.33 a	63.33 b
P 95 Y 72	70.00 a	80.00 b
NS 7000 IPRO	53.33 b	43.33 c
SYN 1059 RR	50.00 b	63.33 b
TMG 1067 RR	50.00 b	70.00 b
CD 2611 IPRO	48.33 b	70.00 b
NS 6767 RR	46.67 b	100.00 a
NA 5909 RG SUL	40.00 b	60.00 b
NS 6211 RR	40.00 b	100.00 a
SYN 1163 RR	40.00 b	66.67 b
NS 6909 IPRO	35.00 c	70.00 b
NS 5959 IPRO	33.33 c	70.00 b
TMG 1266 RR	25.00 c	53.33 c
BMX POTENCIA RR	23.33 c	50.00 c
BMX MAGNA RR	21.67 c	43.33 c
CD 2737 RR	15.00 d	33.33 c
BMX PONTA IPRO	15.00 d	36.67 c
CD 2694 IPRO	11.67 d	38.33 c
BMX VALENTE RR	10.00 d	43.33 c
TMG 7062 IPRO	4.33 d	8.33 d

[1] Means followed by the same letter do not differ from each other ($p > 0.01$) according to Scott Knott's test.

For the 2014/15 crop season, the data were reasonably consistent with those obtained in 2013/14. Once again, four distinct groups can be identified: (i) The first group was composed of cultivars showing the greatest susceptibility (CD 2590 IPRO, NS 6211 RR, and NS 6767 RR), all of which exhibited 100% ASR severity (complete defoliation); (ii) The second group included the cultivars P95Y72, TEC 6029 IPRO, CD 2611 IPRO, NS 5959 IPRO, NS 6909 IPRO, TMG 1067 IPRO, SYN 1163 RR, P95R51, SYN 1059

RR, and NA 5909 RG SUL, which showed ASR severity ranging from 80.0% to 60.0%; (iii) The third group comprised the cultivars TMG 1266 RR, BMX POTÊNCIA RR, BMX MAGNA RR, NS 7000 IPRO, BMX VALENTE RR, CD 2694 IPRO, BMX PONTA IPRO, and CD 2737 RR, with ASR severity between 53.3% and 33.3%; (iv) Finally, the fourth group included only the cultivar TMG 7062 IPRO, which showed the lowest ASR severity at 8.3%.

In general, the partial resistance levels of the cultivars were consistent across the evaluated years. Some differences were observed, mainly due to variations in inoculum potential at the beginning of reproductive phase and environmental conditions between growing seasons. In 2014/15, the higher ASR severity, reaching up to 100%, was most likely driven by favorable environmental conditions. These are characterized by increased rainfall regularly distributed over the growing seasons, as well as maximum temperatures lower than those recorded in 2013/14 (Figure 1). Most of the maximum and minimum temperatures recorded in 2014/15 fell within the range considered ideal for *P. pachyrhizi* infection, between 15 °C and 28 °C [14]. These observations are consistent with previous studies, which report that the most severe epidemics occur in high-rainfall areas and that disease development is significantly affected by the relatively long dry periods common in southern Brazil [15]. Under conditions more favorable to the disease, most cultivars that were classified in group 4 during the first season (CD 2737 RR, BMX PONTA IPRO, CD 2694 IPRO, and BMX VALENTE RR) shifted to group 3. This indicates that, under high disease pressure, the partial resistance present in these genotypes was insufficient to maintain low disease severity.

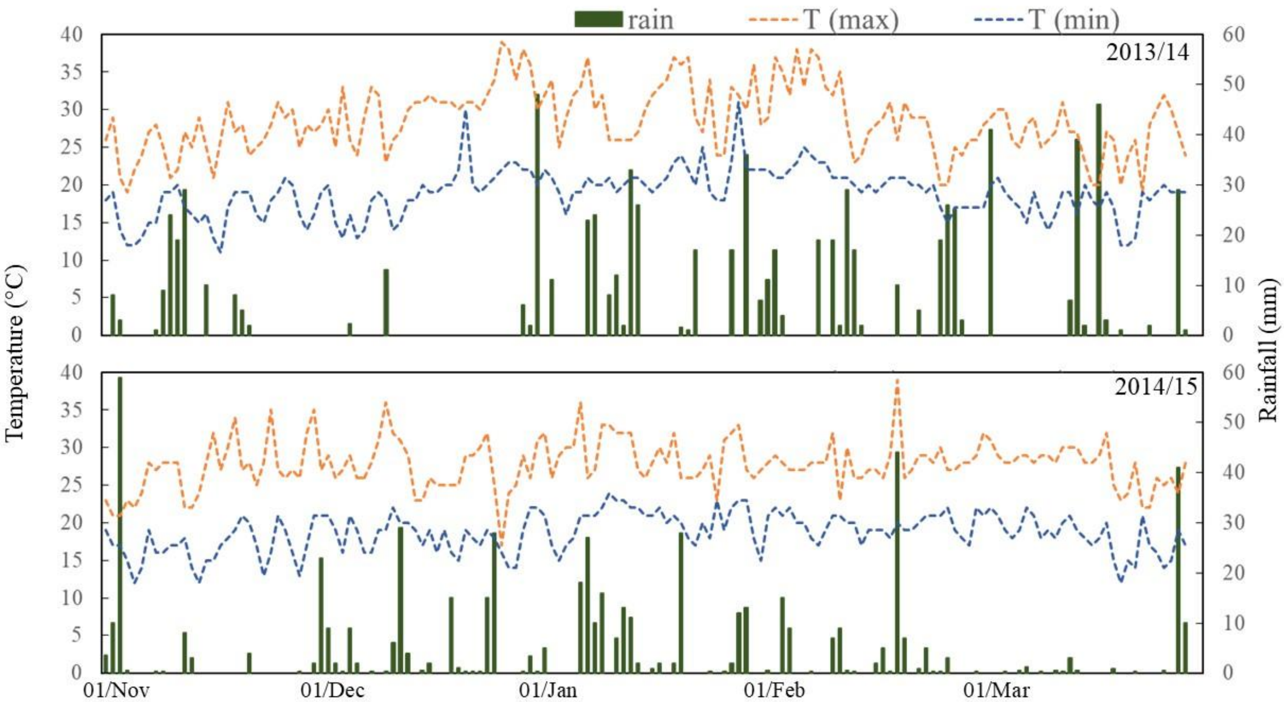

Figure 1. Rainfall (green columns), maximum (Tmax; orange dotted line) and minimum (Tmin; blue dotted line) temperatures recorded daily during the soybean growing cycles in the two seasons (2013/14 and 2014/15). This period covers the time from sowing to the final disease severity assessment.

Interestingly, these results highlight the potential resistance of certain cultivars, as they consistently exhibited the highest levels of partial resistance across both seasons, maintaining low ASR severity even under varying environmental conditions. A similar pattern was observed for the other cultivars: intermediate ones maintained moderate severity levels, while the more susceptible cultivars continued to show high severity.

The results reveal significant variation in partial resistance among soybean cultivars, indicating that using cultivars with higher partial resistance, in combination with strategies to reduce initial inoculum pressure, can make ASR management easier and more cost-effective. The level of partial resistance may also enhance the efficacy of chemical control (fungicides), particularly when disease onset is delayed due to lower inoculum pressure in the field. Although fungicide efficacy was not evaluated on these cultivars during our experiments, studies across various scenarios suggest that partial resistance can enhance disease control. Additionally, simulations show that adopting ASR-resistant cultivars can reduce control costs by nearly 50%, playing a crucial role in sustainable soybean production and stabilizing the global market [16]. Beyond cost savings, widespread use of these resistant cultivars also helps address economic disparities and mitigates environmental risks [17].

Additionally, cultivars with high partial resistance may allow for greater flexibility in the timing of the first fungicide application, enabling it to be scheduled according to specific conditions such as favorable environmental conditions, high regional inoculum pressure, or pathogen detection in or near the area, and even permitting longer intervals between sprays due to slower disease progress. Therefore, using cultivars with high partial resistance to the predominant disease in a region can be an important strategy and economically viable by reducing fungicide demand. This becomes more relevant if consider weather-related disease risk. A study comparing two rain-based disease severity thresholds and two leaf wetness-temperature thresholds across 29 experiments in Brazil revealed that although yields rose with more sprays, economic analysis showed no significant profit differences [18]. According authors, given its simplicity and profitability, the rain-based system is a strong candidate for managing ASR in Brazil.

Estimates of Φ_g, σ_e^2, $\sigma_p^2$and H^2 obtained from the mathematical expectations of the average squares (2013/14 and 2014/15 season) are summarized in Table 3.

Table 3. Estimates of phenotypic variance (σ_p^2), quadratic component (ϕ_g), environmental variance (σ_e^2) and heritability (H^2) calculated for resistance to ASR in soybean cultivars.

Components of Variation (2013/14)			
σ_p^2	ϕ_g	σ_e^2	H^2
499.67	420.67	79.0	0.84
Components of Variation (2014/15)			
σ_p^2	ϕ_g	σ_e^2	H^2
563.87	466.37	97.5	0.82

High broad-sense heritability (H^2) values for ASR, ranging from 82% to 84%, were observed in the experiments. These values indicate notable genetic variability among the evaluated cultivars and a relatively limited influence of the environment on phenotype expression [19]. However, it is important to highlight that this study was conducted over only two growing seasons in the same region. To obtain more robust data, evaluations across multiple locations are desirable, to clearly define the high broad-sense heritability. The incorporation of partial resistance into commercial cultivars is particularly desirable, as it offers greater stability in response to the genetic plasticity of the pathogen (*Phakopsora pachyrhizi*) [20,21]. Moreover, partial resistance serves as an additional strategy to safeguard technologies that rely on single major resistance genes.

Based on the experimental results, a wide variation in the levels of partial resistance to ASR was observed among cultivars in the southern region of RS. The cultivar TMG 7062 IPRO showed the lowest severity in both crop seasons, likely due to the presence of the *Rpp* gene, which confers partial resistance to rust [22]. Although some *Rpp* genes produces TIR-NBS-LRR protein that confers race-specific resistance to *Phakopsora pachyrhizi* [23], the pathogen diversity and virulence enhance adaptability and evolution, threatening the durability of ASR-resistant soybean cultivars [24]. Even though highly virulent Brazilian ASR isolates caused susceptible phenotypes in single-gene resistance sources, *Rpp*-pyramided lines showed strong resistance with minimal sporulation, making them valuable for breeding broad-spectrum, high-resistance soybeans [25–27].

This approach is very interestingly in the southern region of RS, located between latitudes 30° and 34°S, is an expanding soybean production area in Brazil. This region is characterized by cold winters and milder temperatures during the growing season, conditions that, according to Pivonia and Yang [10], reduce fungal survival and are unfavorable for ASR development. These epidemiological conditions result in lower inoculum pressure of *Phakopsora pachyrhizi*, enabling effective disease management through the use of cultivars with higher levels of partial resistance and/or the presence of major resistance genes (*Rpp*). This study was conducted to highlight the relevance of partial resistance to ASR in delaying epidemic development in expanding soybean production areas, rather than to recommend specific cultivars. However, it is highly useful to conduct new experiments with recently released cultivars to provide updated information on the current status of partial resistance, which may support growers in selecting cultivars. In this sense, it is also important to evaluate the number of fungicide applications required to keep the disease below the damage threshold, as well as to assess whether the use of a forecasting system would be more effective for cultivars with high partial resistance. This, in turn, enhances the efficiency of fungicide-based chemical control.

CONCLUSIONS

The results of this study demonstrate that the use of cultivars with high partial resistance against ASR in the southern region of RS is effective and represents a valuable strategy to be explored in breeding programs. Moreover, the incorporation of *Rpp* genes can further enhance the development of cultivars exhibiting stronger partial resistance to the disease.

DATA AVAILABILITY

The dataset of the study is available from the authors upon reasonable request.

AUTHOR CONTRIBUTIONS

Conceptualization, PCP, LJD; Formal Analysis, PCP, KdRD, JVdAF; Experimentation: PCP, KdRD, TNM, IR; Writing—Original Draft Preparation, PCP; Writing—Review & Editing, KdRD, JVdAF, LJD.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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