CULTIVAR RELEASE

'IAC SEMPRE VERDE': a wild-derived peanut cultivar highly resistant to foliar diseases

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Abstract: *'IAC Sempre Verde' is a medium-seeded runner-type peanut highly resistant to late leaf spot and rust, the main diseases in peanut cultivation in Brazil. The newly released cultivar showed remarkable yield advantage over controls when diseases were not controlled and represents the first possibility for peanut cultivation under "Organic" management.*

Keywords: Arachis hypogaea, Arachis cardenasii, *foliar diseases, yield, "organic" cultivation*

INTRODUCTION

Peanut production in Brazil is highly concentrated in the state of São Paulo. In 2021/2022, São Paulo produced 630,000 tons of unshelled peanuts (about 90% of the Brazilian peanut production), of which more than 50% were shelled and processed for export (CONAB 2022). The crop has significantly improved in both quality and productivity over the past ten years. Average yields increased from 2.5 to 3.5 t ha^{-1} in a decade, one major factor responsible for this increase being the adoption of runner-type cultivars. With the modern technologies available to growers, the yield potential of the present runner cultivars in Brazil exceeds 6,000 kg ha^{-1} (Godoy et al. 2017). The area planted with peanut has increased from 84,000 to 160,000 hectares from 2009/10 to 2020/21 (CONAB 2022).

The high performance of runner cultivars can only be achieved when the crop is well protected against foliar diseases. Late leaf spot (LLS), caused by *Northopassalora personata* syn. *Cercosporidium personatum* (Berk. & Curt.) Deighton], is the most prevailing disease in Brazilian peanuts, and it can cause yield losses of up to 70%. Rust, caused by *Puccinia arachidis* Speg., is also very important. More sporadic in occurrence, the disease develops very quickly and can cause devastating losses. Control of these diseases involves seven to eight fungicide sprayings during the crop cycle, which imposes a high cost to the production, along with environmental costs. Disease resistance is the best strategy to minimize or reduce the use of agrochemicals and the fuel used in applications. Some cultivars, moderately resistant to foliar diseases are already available in Brazil (Santos et al. 2018, Godoy et al. 2019), these cultivars promote better yield stability, but multiple fungicide applications are still needed.

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High levels of resistance can be found in wild *Arachis* species. However, introgression of wild species resistance into cultivated peanut involves overcoming a ploidy barrier between the mostly diploid wild species and the cultivated tetraploid. The complexity of this process, and linkage drag from wild alleles means that it takes years to obtain lineages derived from interspecific hybrids with desirable agronomic traits. During the 1960s, *Arachis cardenasii*, a wild species with high resistance to pests and diseases was used to obtain interspecific hybrids and develop agronomically adapted peanut lines with introgressed wild species resistances (Simpson et al. 1993, Stalker 2017). Some of these lines, developed in North Carolina State University (USA) were sent to ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), India, where a number of lines with resistance to LLS and rust were selected. One of these lines, ICGV 86687 was introduced to the germplasm collection of Campinas Agronomic Institute (IAC) and used as a source of resistance to foliar diseases (Bertioli et al. 2021). By crossing this introgressed line with a high yielding locally-adapted cultivar, we produced 'IAC Sempre Verde' (meaning "Always Green") recommended for cultivation under "Organic" management.

BREEDING METHOD

The breeding line ICGV 86687 was received from ICRISAT in 1980s. ICGV 86687 is a *fastigiata*-type (*A. hypogaea* subsp. *fastigiata*), dark seeded advanced peanut line, and a sister line of ICGV 86855, progenitor of GPBD-4, a cultivar developed in India, with multiple resistances (Gowda et al. 2002). ICGV 86687 derives from CS 16, a line produced in North Carolina, using a purple-seeded cultivated tetraploid peanut, *A. hypogaea* subsp. *fastigiata* (PI 261942), collected from Paraguay and the wild species *A. cardenasii* GKP 10017 (Bertioli et al. 2021). To follow standard IAC nomenclature, the line was renamed IAC 69007 upon receipt. IAC 69007 was crossed with 'Runner IAC 886', a runner type (*A. hypogaea* subsp. *hypogaea*), high yielding local cultivar, susceptible to foliar diseases, derived from a component line of 'Florunner'. Generations were advanced by single-seed descent, in a total of five generations in field without control of foliar diseases. Selections were made in the district of Pindorama, São Paulo, Brazil, on F_6 progenies for resistance to LLS and rust, growth habit and productivity. Out of the various lines produced, IAC 322 was considered the most promising.

AGRONOMIC PERFORMANCE

Four experiments were carried out in peanut growing areas of São Paulo during three growth seasons, to evaluate the selected line IAC 322 (later named 'IAC Sempre Verde') compared to five control cultivars (IAC 113, IAC 147, IAC 503, IAC 886 and IAC Caiapó), without fungicide application. 'Runner IAC 886', 'IAC 113' and 'IAC 147' are susceptible to late leaf spot and rust, while 'IAC Caiapó' and 'IAC 503' have moderate resistance against both diseases. Each experiment was planted in a randomized complete block design without disease control; and plots consisted of five 4 m rows, spaced 0.90 m apart from each other and containing 75 seeds, with four replications.

Disease was assessed in each plot at 90, 100 and 120 days after sowing (DAS). LLS was the prevalent disease and its severity was rated using a 1–9 visual scale based on defoliation and number of fungal lesions (see Subrahmanyam 1982). LLS was rated in Adamantina (2010/11), Colina (2010/11) and Pindorama (2009/10, 2010/11). Rust was also observed and evaluated using the 1-9 visual scale in Pindorama (2009/10). In the districts of Pindorama, Adamantina and Colina, during the 2010/2011 season, the disease was evaluated in detached leaves (Moraes and Salgado 1982). Ten leaves of each plot were collected from the median part of the primary branches and rated in a 1-5 scale, considering the number and size of the lesions of each leaf. For data comparison and analysis, the values of the three dates of evaluation were plotted to estimate the Area Under the Disease Progress Curve, AUDPC (Tables 1 and 2). The software GENES (Cruz 2013) was used to perform the analyses of variance and Tukey´s tests at 5% probability.

LLS and rust incidence were affected by the location and year of evaluation (Tables 1 and 2). The genotype x environment interaction was significant for AUDPC for both diseases. The AUDPC values observed for LLS on 'IAC Sempre Verde' were significantly lower than the values observed for the five control cultivars tested (Table 1). For the field evaluation of rust (Pindorama 2009/2010), the AUDPC value of 'IAC Sempre Verde' (190.0) was also significantly lower than the values observed for the other cultivars, which ranged from 281.8 to 430.3 (Table 2). In the 2010/2011 trials, performed in Pindorama, Adamantina and Colina, the disease was evaluated in detached leaves. The AUDPC values for 'IAC Sempre Verde' were, in general, lower than the values observed for the five control cultivars, although not significantly different

Table 1. Values of Area Under Disease Progress Curve (AUDPC) for late leaf spot in 'IAC Sempre Verde' and five controls under natural field infestation without disease control

Genotype	Pindorama		Adamantina	Colina
	2009/10	2010/11	2010/11	2010/11
IAC Sempre Verde	164.5 ^{Aa}	180.4 ^{Aa}	324.9 ^{Ba}	324.5 ^{Ba}
IAC 113	293.1 ^{Ab}	369.7 ^{Bb}	420.3 ^{Bb}	531.0 ^{Cb}
IAC 147	317.3 ^{Acb}	382.6 ^{Bb}	441.4 ^{Bcb}	531.0 ^{Cb}
IAC 503	315.2 ^{Acb}	382.6 ^{Bb}	466.2 ^{Ccb}	494.1 ^{Cb}
IAC Caiapó	301.3 ^{Acb}	313.7 ^{Ab}	413.2 ^{Bb}	494.1 ^{Cb}
Runner IAC 886	372.0 ^{Ac}	462.8 ^{Bc}	501.5 ^{BCc}	531.0 ^{Cb}
F (G x L)	2.04*			
Average	293.9	348.6	427.9	484.3
Coefficient of variation (%)	7.7	6.4	6.4	11.9

Means followed by the same upper case in rows and lowercase in columns are not significantly different by the Tukey test at 5% probability. F (G x L) – F test for genotype (G) versus locations (L) interaction. * Significant at 5% by the F test.

Table 2. Values of Area Under Disease Progress Curve (AUDPC) for rust in 'IAC Sempre Verde' and five controls under field natural infestation (Pindorama 2009/2010) and three experiments evaluated in detached leaves (Pindorama, Adamantina and Colina 2010/2011)

Genotype	Field		Detached leaves	
	Pindorama		Adamantina	Colina
	2009/10	2010/11	2010/11	2010/11
IAC Sempre Verde	190.0 ^{a}	81.5 ^{Aa}	65.3 ^{Aa}	118.0 ^{Aa}
IAC 113	283.5 ^{b}	144.3 ^{Aab}	80.5 ^{Aba}	243.4 ^{Bb}
IAC 147	307.3 ^{b}	169.0 ^{Bab}	103.5 ^{Aba}	295.0 ^{Cb}
IAC 503	281.8 ^{b}	189.5 ^{Bbc}	72.0 ^{Aa}	118.0 ^{Aa}
IAC Caiapó	305.8 ^{b}	150.0 ^{Bab}	68.5 ^{Aa}	59.0 ^{Aa}
Runner IAC 886	430.3 ^{c}	264.8 ^{Bc}	138.8 ^{Ab}	295.0 ^{Bb}
F (GxL)	7.2**			
Average	299.8	166.5	166.5	188.1
Coefficient of variation (%)	11.6	23.1	23.1	23.3

Means followed by the same upper case in rows and lowercase in columns are not significantly different by the Tukey test at 5% probability. F (G x L) – F test for interaction genotype (G) versus locations (L). ** Significant at 1% by the test F.

from the values observed for some cultivars and locations. Assessments on detached leaves are complementary in the absence of high disease pressure.

Yield of unshelled peanuts was evaluated in each plot and expressed in kg ha^{-1}, except for Colina (2010/11), for which yield data was not available (Table 3). The genotype x environment interaction was not significant (at 5% probability). Without fungicide control, the average yield of the three experiments was significantly higher for 'IAC Sempre Verde' (3,838.8 kg ha^{-1}) than the average yield of the other cultivars, which ranged from 1,346.2 to 2,518.6 kg ha^{-1}.

In 2019 and 2020, the year of 'IAC Sempre Verde' release in Brazil, two experiments were performed in Pindorama and Votuporanga. Productivity and LLS resistance of Sempre Verde were compared with three high-yielding high oleic cultivars, widely grown in São Paulo: 'IAC 503', 'IAC OL 3' and 'IAC OL 5'. Late leaf spot was evaluated at 120 DAS as described above, but with and without foliar disease control. On treated plots, chlorotalonil (Bravonil 720) at the dosage of 2.0 L ha^{-1} of the commercial product and pyraclostrobin and epoxiconazole (Opera) at the dosage of 0.6 L ha^{-1} of the commercial product were applied 45 DAS and then, every 15 days to a total of six applications. The experiments were carried out in a split-plot scheme, in randomized block designs, and plots consisted of four 5 m rows, spaced 0.90 m apart and containing 100 seeds, with four replications. Cultivars were arranged into main plots and the chemical control of foliar diseases (with or without) into the sub-plots. The software GENES (Cruz 2013) was used to perform the analyses of variance and Tukey´s tests at 5% probability.

Under the field conditions tested, 'IAC Sempre Verde' was consistently more resistant to LLS than the three local cultivars tested (Table 4) and had good yield performance under no spray conditions (Table 5). In the presence of chemical control, the yield of the high oleic cultivars increased significantly, in contrast to 'IAC Sempre Verde'. However, it is important to note that 'IAC Sempre Verde' was as productive as 'IAC OL 5', with fungicide application (Table 5). Its remarkable resistance to foliar diseases and yielding capacity under high disease pressure motivated us to recommend using this cultivar in low cost, fungicide-suppressed environments or to be used in "Organic" cropping systems. It has been registered in Brazil as 'IAC Sempre Verde', under the number RNC 41535.

TECHNOLOGICAL TRAITS

'IAC Sempre Verde' is of runner growth type (*Arachis hypogaea* subsp. *hypogaea*), has a growth cycle of 130-140 days (from planting to harvesting) and two seeded pods. Seeds are small to medium in size (52 g of 100-seed weight), red testa, moderate reticulation and 47-48% oil content. No objective sensorial evaluation was performed with 'IAC

Table 3. Grain yield (kg ha^{-1}) in trials carried out without chemical control of foliar diseases

Genotype	Yield (kg ha^{-1})			
	Pindorama	Adamantina	Pindorama	Average
	2009/10	2010/11	2010/11	kg ha^{-1}
IAC Sempre Verde	4666.8	3586.0	3263.8	3838.8 ^{a}
IAC 113	2169.5	2047.5	1347.3	1854.8 ^{bc}
IAC 147	2700.3	2672.3	1244.5	2205.7 ^{b}
IAC 503	1755.3	2633.5	1383.5	1924.1 ^{bc}
IAC Caiapó	2617.0	3225.0	1713.8	2518.6 ^{b}
Runner IAC 886	1261.0	2036.0	741.5	1346.2 ^{c}
F (G x L)	8.11			
Means	2528.3	2700.0	1615.7	2281.3
Coefficient of variation (%)	22.7	18.0	28.6	

Means followed by the same letter in columns are not significantly different by the Tukey test at 5% probability. F (G x L) – F test for interaction genotype (G) versus locations (L). ns - not significant at 5% by the test F.

Table 4. Values of LLS susceptibility (1-9 score) in 'IAC Sempre Verde' and three local cultivars under field natural infestation. Experiments were performed in two environments (Pindorama and Votuporanga) in the 2019/2020 season with and without fungicide application. Sprayings were done at 45 days after sowing (DAS) and every 15 days (D)

Genotype	Pindorama 2019/2020		Votuporanga 2019/2020	
	No control	45DAS+15D	No control	45DAS+15D
IAC Sempre Verde	5.5 ^{a}	2.8 ^{a}	4.1 ^{a}	2.0 ^{a}
IAC 503	7.5 ^{b}	4.6 ^{b}	7.2 ^{b}	4.0 ^{b}
IAC OL 3	9.0 ^{c}	7.4 ^{c}	8.9 ^{c}	5.5 ^{c}
IAC OL 5	8.6 ^{bc}	5.4 ^{b}	7.8 ^{bc}	3.0 ^{ab}

Means followed by the same letter in columns are not significantly different by the Tukey test at 5% probability.

Table 5. Average pod yield (kg ha^{-1}) from 'IAC Sempre Verde' and three local cultivars. Experiments were performed in two environments (Pindorama and Votuporanga) in the 2019/2020 season with and without fungicide application. Sprayings were done at 45 days after sowing (DAS) and every 15 days (D)

Genotype	Pindorama 2019/2020		Votuporanga 2019/2020	
	No control	45 DAS + 15D	No control	45 DAS + 15D
IAC Sempre Verde	3296.4 ^{a}	4366.0 ^{a}	5386.4 ^{a}	5646.7 ^{b}
IAC 503	1990.5 ^{b}	4247.6 ^{a}	3515.7 ^{b}	5653.5 ^{b}
IAC OL 3	1180.0 ^{b}	3831.4 ^{a}	3509.5 ^{b}	6946.4 ^{a}
IAC OL 5	1673.5 ^{b}	3412.5 ^{a}	4457.8 ^{a}	6248.5 ^{ab}
Average	2035.1	3964.4	4217.4	6123.8
CV (%)	18.1	16.9	8.8	9.5

Means followed by the same letter in columns are not significantly different by the Tukey test at 5% probability. CV - coefficient of variation (%).

Sempre Verde', but in preliminary subjective testing in the candy industry, it was reported that the kernels have flavor and taste resembling runner peanuts. The cultivation of 'IAC Sempre Verde' allows the lowering of inputs and offers a unique opportunity to growers of "Organic" peanuts. The need for fungicide applications to control foliar diseases is a severe constraint for growing "Organic" peanuts, and 'IAC Sempre Verde' presents the first possibility available to growers of cultivation without chemical control combined with remarkable yield performance.

Seed production

IAC Sempre Verde was registered in Registro Nacional de Cultivares (Ministry of Agriculture, Brazil) in 2021; IAC is the creator and maintainer of the cultivar, and produces the genetic (breeder's) seeds.

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