Flowering dynamics and seed production of *Arachis pintoi* and *Arachis repens* in the Brazilian Cerrados

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Abstract

Thirty-two accessions of the *Caulorrhizae* section of the genus *Arachis* were evaluated at 2 different sites in the Brazilian Cerrados, in terms of flowering period and intensity, seed yield and distribution in the soil profile. Flowering occurred between October and May with the accessions differing in the distribution, intensity and period of flowering. They exhibited a cyclic flowering pattern, with various peaks of production of flowers. Differences in maximum flowering intensity were also observed among sites. The average seed yield 18 months after planting was 948 kg/ha at Location 1 (lowland area) and 327 kg/ha at Location 2 (well drained area). The accessions exhibited great variability for this trait, with an average broad-sense heritability (H^2) value of 0.73. While 99% of the seeds were concentrated in the first 6 cm of the soil profile, seeds were recovered to 9 cm depth at Location 1 and to 12 cm at Location 2. Genetic variability was also observed for this trait.

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Introduction

The genus *Arachis* is a member of family *Fabaceae*, tribe *Aeschynomeneae* and subtribe *Stylosanthinae*. It is endemic in South America and, at present, 69 species have been described (Krapovickas and Gregory 1994).

Several species of *Arachis* have potential to be incorporated into forage systems, notably *Arachis glabrata* (section *Rhizomatozae*), *A. pintoi* and *A. repens* (both section *Caulorrhizae*). These last 2 species, along with *A. glabrata*, appear as the most promising, since they produce large amounts of high quality forage and are prolific seeders (Valls and Simpson 1994). *A. pintoi* and *A. repens* (Krapovickas and Gregory 1994) are herbaceous, perennial plants, endemic in Brazil. They are considered multi-purpose legumes, being grown for forage, erosion control and ornamental purposes and as ground cover in orchards, forests and low-tillage systems.

The species of the *Caulorrhizae* section differ widely in terms of seed production. While most of the germplasm of *A. pintoi* can produce high seed yields under natural conditions, *A. repens* rarely produces any seeds, even though it produces abundant blooms (Valls 1992; Pizarro *et al.* 1992; Cook *et al.* 1994).

Most of the agronomic data already published on these species was obtained in studies conducted under the coordination of, or with germplasm distributed by, the International Center for Tropical Agriculture (CIAT), and represents data exclusively from only the originally collected accession (GK 12787 or CIAT 17434 or BRA–013251). These results have stimulated the distribution of this accession to several countries, and resulted in the release of *Arachis pintoi* selected from GK 12787 (CIAT 17434 or BRA–013251) in a number of countries, including Australia, Colombia, Costa Rica and Honduras and more recently Brazil.

Pizarro *et al.* (1992; 1993) in Brazil and Argel and Valério (1993) in Costa Rica demonstrated great variability in seed yield among accessions of *A. pintoi*, while Ferguson (1994) reported seed yields of 7300 kg/ha in Colombia, on highly fertile soils. In Australia, Cook and Franklin (1988) reported seed yields of 1400 kg/ha in cv. Amarillo, 12 months after sowing, while Cook and Loch (1993) obtained seed yields of 2800 kg/ha in a commercial seed crop.

The geocarpic characteristic of the genus, with seed-set below the soil surface, makes seed harvesting difficult and labour-intensive. At harvesting, 97% of the seeds are not attached to the plant, so the top 10 cm of the soil profile is revolved and screened on a sieve to collect the seed (Ferguson *et al.* 1992).

The selection of sites with favourable climatic conditions, and fine-textured soils with medium to high fertility and high organic matter levels, could lead to high seed yields. The association of the seed fields with other perennial crops, and the development of equipment to mechanise the seed-harvesting process, are some of the strategies that will be employed for commercial seed production of *A. pintoi* and *A. repens*.

The objective of this research was to evaluate characteristics related to the flowering dynamics (period and intensity), seed yield and distribution in the soil profile of 32 accessions of section *Caulorrhizae* planted at 2 different sites in the Brazilian Cerrados.

Materials and methods

The work was conducted at the Cerrados Research Center (CPAC) of the Brazilian Agricultural Research Corporation (EMBRAPA), located in Planaltina, DF (15° 35′ 30″S, 47° 42′ 30″W; elevation 1000 masl). Average annual temperature is 21.9°C, with average annual precipitation of 1540 mm, mostly occurring during October – April.

Two experiments were established in an Akuult (low humic gley – Location 1) and in an Ustox (yellow red latosol – Location 2) with 26 accessions of *A. pintoi* and 6 of *A. repens*. Physical and chemical characteristics of the soils are presented in Table 1. Supplementary fertiliser (44 kg/ha P and 50 kg/ha K) was applied before planting.

The experimental design was a randomised block with 2 replications. Plots measured 3.75 m x 4.5 m (16.875 m^2), and contained 4 rows with inter-row spacing of 0.75 m and intra-row spacing of 0.5 m. Plots were established vegetatively in December 1993. A list of the accessions, identification codes and sites of collection is presented in Table 2. During the first year, the area was mowed every 3 weeks in the rainy season (Oct – Apr) and every 6 weeks in the dry season (May – Sep).

Flowering dynamics

Flowering was observed from October to August. However, the data presented in detail in this research relate only to the period December – August, commencing 1 year after planting. Flower counts were taken every week in an area of 0.0625 m² (0.25 m x 0.25 m), randomly chosen in each plot. Numbers of flowers/m² for the different accessions at both sites were plotted against time to determine their flowering patterns and flowering was related to rainfall and average minimum temperature.

Table 1. Physical and chemical characteristics of the low humic gley soil (Location 1) and the yellow red latosol (Location 2).

Location	Physical characteristics					
	% clay	% silt	% sand	Textural class		
1	48	26	26	Clay		
2	62	20	18	Clay		
	Chemical characteristics					
	$pH(H_2O)$	Al[1]	Ca+Mg[1]	P[2]	K[2]	H+Al[1]	OM[3]
1	5.3	0.97	4.34	5.7	77	9.46	0.20
2	4.7	0.56	2.90	1.0	38	6.24	0.18

[1] meq/100cc.
[2] mg/L.
[3] % of organic matter.

Seed yield

Eighteen months after planting, plots were sampled to assess seed production. Soil samples to a depth of 0.25 m from an area of 0.5 m x 0.5 m were taken. The soil was screened on a sieve with a 5 mm mesh to remove the pods, which were then dried at room temperature for 3 weeks and weighed. Calculations were made to determine yields per hectare. The numbers reported in this research represent the whole fruit (pericarp + seed).

Seed distribution in the soil profile

The 12 accessions with superior agronomic performance, in terms of dry matter (data not presented) and seed yield, were selected to evaluate the seed distribution in the soil profile. At both locations, 5 samples were taken in each plot, totalling 10 samples per location.

Soil samples were taken using a soil core sampler (8.9 cm) (Soil moisture Equipment Corporation, model nº 212, Santa Barbara, CA, USA) to a depth of 15 cm, and divided into 5 layers of 3 cm each. The soil was screened on a sieve with a 5 mm mesh to remove the pods, which were then dried at room temperature for 3 weeks and weighed. Yields of whole fruit (pericarp + seed) per hectare for the different layers were determined.

Statistical analyses

Statistical analyses were performed using the statistical package SAS (SAS Institute Inc. 1985). Seed yield data were analysed, initially, by location, and then a combined analysis including both locations was performed. Duncan's test was used to test differences between means at $P<0.05$.

The statistical model used to perform the analysis by location was as follows:

Table 2. Identification code and site of collection of the *A. pintoi* and *A. repens* accessions.

Species/ Brazil code (BRA)	Site of collection[1] (State and County)	Lat. (S)	Long. (W)	Elevation (masl)
A. pintoi				
013251	BA (Belmonte-Boca do Córrego)	15°52′	39°08′	50
015121	GO (Formosa - Faz. Genipapo)	15°26′	47°21′	700
015598	DF (Guará - QI 7)	15°49′	47°58′	1080
030252	MG (Berilo - Rio Araçuaí)	16°57′	42°28′	360
030261	MG (Araçuaí - Faz. Vera Cruz)	-	-	270
030325	MG (Itacarambi)	15°07′	44°08′	510
030333	GO (Formosa - próximo Itiquira)	-	-	-
030368	MG (Unaí - Ribeirão Tamboril)	16°18′	46°58′	630
030376	MG (Unaí - Rib. Água Branca)	16°19′	46°51′	580
030481	MG (Paracatu - Rib. B. Égua)	16°52′	46°35′	550
030503	MG (Unaí - Rio Preto)	16°41′	46°29′	540
030511	MG (Bonfinópolis de Minas)	16°42′	46°25′	560
030520	MG (Bonfinópolis de Minas)	16°44′	46°12′	580
030546	MG (Riachinho - Corr. Amendoim)	16°12′	46°01′	550
030601	MG (Montalvânia - Rio Coxá)	14°25′	44°22′	510
030619	MG (Montalvânia)	14°20′	44°25′	560
030872	GO (Monte Alegre de Goiás)	13°18′	46°48′	510
030899	GO (Galheiros - Rio Manso)	13°18′	46°42′	500
030929	GO (Campos Belos - saída sul)	13°02′	46°45′	610
030988	GO (Nova Roma - Faz. Ouro)	16°51′	46°52′	490
031003	GO (Flores de Goiás - Rio Macaco)	14°27′	47°00′	480
031135	GO (Formosa - Rio Paranã)	15°17′	47°23′	650
031143	MG (Planaltina-DF)	17°03′	42°21′	360
031836	GO (Senador Canedo - EMGOPA)	-	-	-
031844	MT (Lucas do Rio Verde)	13°03′	55°55′	300
031852	GO (origem desconhecida)	-	-	-
A. repens				
012106	RS (Alpestre - Farinhas)	27°12′	53°10′	300
029220	MG (Januária)	15°10′	44°22′	420
030082	MG (Lagoa dos Patos)	17°03′	44°46′	530
030597	MG (Itacarambí)	-	-	510
031127	MT (Primavera do Leste)	15°34′	54°23′	760
031861	BA (Unknown origin)	-	-	-

[1]BA = Bahia; DF = Distrito Federal; Go = Goiás; MG = Minas Gerais; MT = Mato Grosso do Sul; RS = Rio Grande do Sul.

$Y_{ij} = \mu + G_i + Bk_j + e_{ij}$

where μ = mean of the population, G_i = accession effect, Bk_j = block effect and e_{ij} = experimental error.

The statistical model used to perform the combined analysis, proposed by Vencovsky and Barriga (1992), was as follows:

$Y_{ij} = \mu + G_i + L_j + (GL)_{ij} + Bk_{(j)} + e_{ijk}$

where μ = mean of the population, G_i = accession effect, L_j = location effect, $(GL)_{ij}$ = effect of accession x location, $Bk_{(j)}$ = effect of block within location and e_{ijk} = experimental error. In this model, all effects were considered fixed, with the exception of the experimental error. All effects were tested against the experimental error.

Two different analyses were performed to study seed distribution in the soil profile. To determine differences among seed depths at each location, a split-plot model was used. In this analysis, accessions were assigned to the main plot and seed depths were allocated to the subplots. Duncan's test was used to determine differences between means at $P<0.05$. The statistical model used to perform this analysis, proposed by Steele and Torrie (1980), was as follows:

$Y_{ijk} = \mu + G_i + B_k + e_{ik} + P_j + P_j(G_i) + e_{(i)jk}$

where μ = mean of the population, G_i = accession effect, B_k = block effect, e_{ik} = error associated with accessions, P_j = depth effect, $P_j(G_i)$ = effect of depths within accessions and $e_{(i)jk}$ = effect of accession x depth within blocks.

The second analysis was performed to compare accessions in terms of their seed distributions down the soil profile by location. A profile analysis, proposed by Colwell (1978), was used. In this type of analysis, differences among accessions were detected, performing a variance analysis that defined the orthogonal polynomial tendency for the parameter values of the following equation:

$Y = P_0 + P_1x + P_2x^2 + P_3x^3$, where Y is seed yield, and x is the depth. When $x = 0$, depths are not considered, and $Y = P_0$, *i.e.*, the overall seed yield mean. Only linear effects were considered in this work.

Results

Flowering dynamics

Arachis pintoi and *A. repens* exhibited cyclic flowering, with flowering spikes appearing from October to May. The most intense periods of spike production were observed in November, December and January, for most accessions.

Location 1. Overall, a large flowering spike was observed in late November – early December, followed by other small spikes in mid-December and early January. On February 7, a further small flowering spike was observed, with very few flowers produced subsequently (Figure 1).

Average flower number was 455/m², varying from 0 in BRA–012106 (*A. repens*) to 1350/m² in BRA–030333, from November through May.

Individual flowering curves for BRA–013251, 015121, 015598, 030252, 030333, 030601, 030872, 031135, 031143 and 031852, which showed superior agronomic performance, are presented in Figure 2. BRA–013251 produced 2 large flowering spikes during early December and January. In February and April, the spikes were small, and flowering ceased in mid-April. BRA–015121 displayed a large spike in late November and early December, and small spikes in early January and February, and mid-March. Flowering stopped in late March. BRA–015598 presented 5 flowering spikes, the most significant being in mid-December and early January. Flowering extended until late May. BRA–030252, 030601 and 030872 produced only low numbers of flowers with small spikes in late November, and early December and January. Flowering ceased in February for BRA–030252 and BRA–030601, and in early March for BRA–030872. BRA–030333 displayed an intense bloom, with significant spikes in November and early January. This accession stopped flowering in March. BRA–031135, 031143 and 031852 had similar flowering curves. Spikes were observed in late November, early and mid-December, early January and February, while flowering ceased in March.

Location 2. Considering all accessions, the first flowering spike was observed in mid-December, followed by a large spike in early January. Other small flowering spikes were observed in February and March (Figure 1) and flowering stopped in mid-May.

Average flower number was 323 flowers/m², ranging from 11 (BRA–030619) to 883 (BRA–013251) flowers. At this site all accessions flowered, including BRA–012106, which did not bloom at Location 1.

Accession BRA–013251 produced 6 flowering spikes, and continued to flower until late April

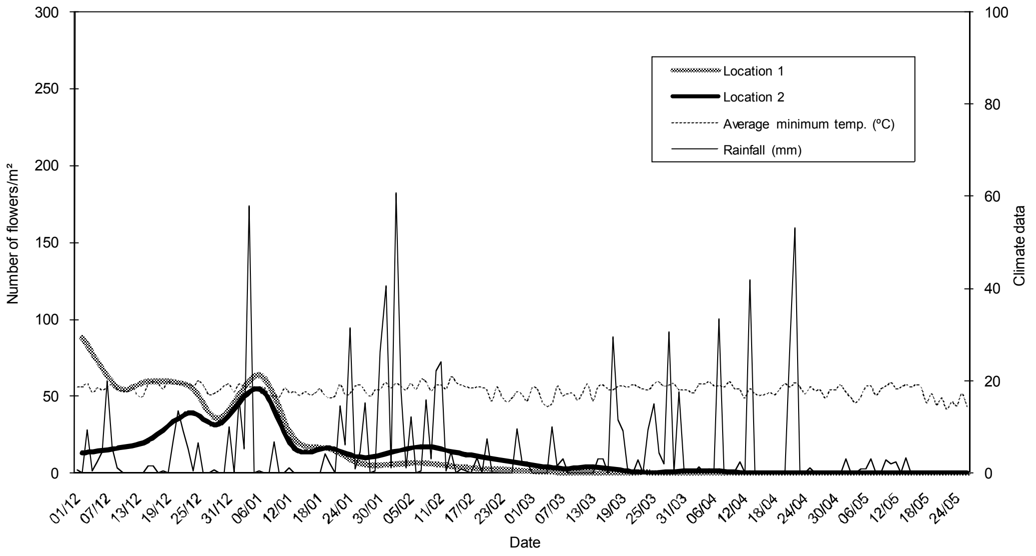

Figure 1. Average flowering dynamics of 32 *Arachis* accessions at 2 different locations in the Brazilian Cerrados.

(Figure 3). BRA–015121 produced 3 spikes, the first in mid-December, a large one in early January and another small one in mid-February. Flowering stopped in early March.

BRA–15598 presented a single significant flowering spike in mid-January and ceased flowering in late April (Figure 3). The flowering curves of BRA–030252 and 030601 were similar, with spikes in mid-December, early January and February and flowering ending in early March. BRA–030333 and BRA–030872 displayed 2 large spikes in December and February. BRA–030872 stopped flowering in early March and BRA–030333 in May.

The flowering curves for BRA–031135 and 031143 were similar, with spikes in mid-December and early January. Flowering ceased in early March. BRA–031852 displayed 7 different spikes and produced flowers until mid-May (Figure 3).

Seed yield

Location 1. Mean seed yield was 949 kg/ha, with a range from zero (BRA–012106) to 3708 kg/ha (BRA–030325). About 40% of the accessions produced above the average seed yield (Table 3).

The *Arachis pintoi* accessions were the most productive, with BRA–030325, BRA–030601 and BRA–030376 producing in excess of 2000 kg/ha.

The broad sense heritability (H^2) of seed yield was 0.87, which indicates, again, the presence of a large genetic variability for this trait.

Location 2. Observed seed yields were lower than at Location 1, with mean seed yield of 328 kg/ha, and a range from zero to 1242 kg/ha. Only BRA–031135 produced above 1000 kg/ha (Table 3). *A. pintoi* yields were superior to *A. repens*, with BRA–031135, 030601, 015121, 030376, 030252, 030929, 030988 and 031143 being the higher-yielding accessions.

The estimate of the broad sense heritability (H^2) was lower (0.60) than that for Location 1.

Combined analysis. Results of the combined analysis (multi-location) showed differences for accessions, locations and the interaction of accession by location. Average seed yield was 638 kg/ha with a range of zero to 2086 kg/ha. Average seed yield at Location 1 exceeded ($P<0.05$) that at Location 2 (Table 3). The most productive accessions were BRA–030325 and BRA–030601. *Arachis pintoi* accessions presented an average seed yield of 768 kg/ha, which was 10 times the average for *A. repens* accessions.

The H^2 value estimated by the combined analysis was 0.25, a much lower value than those observed when the data were analysed by location.

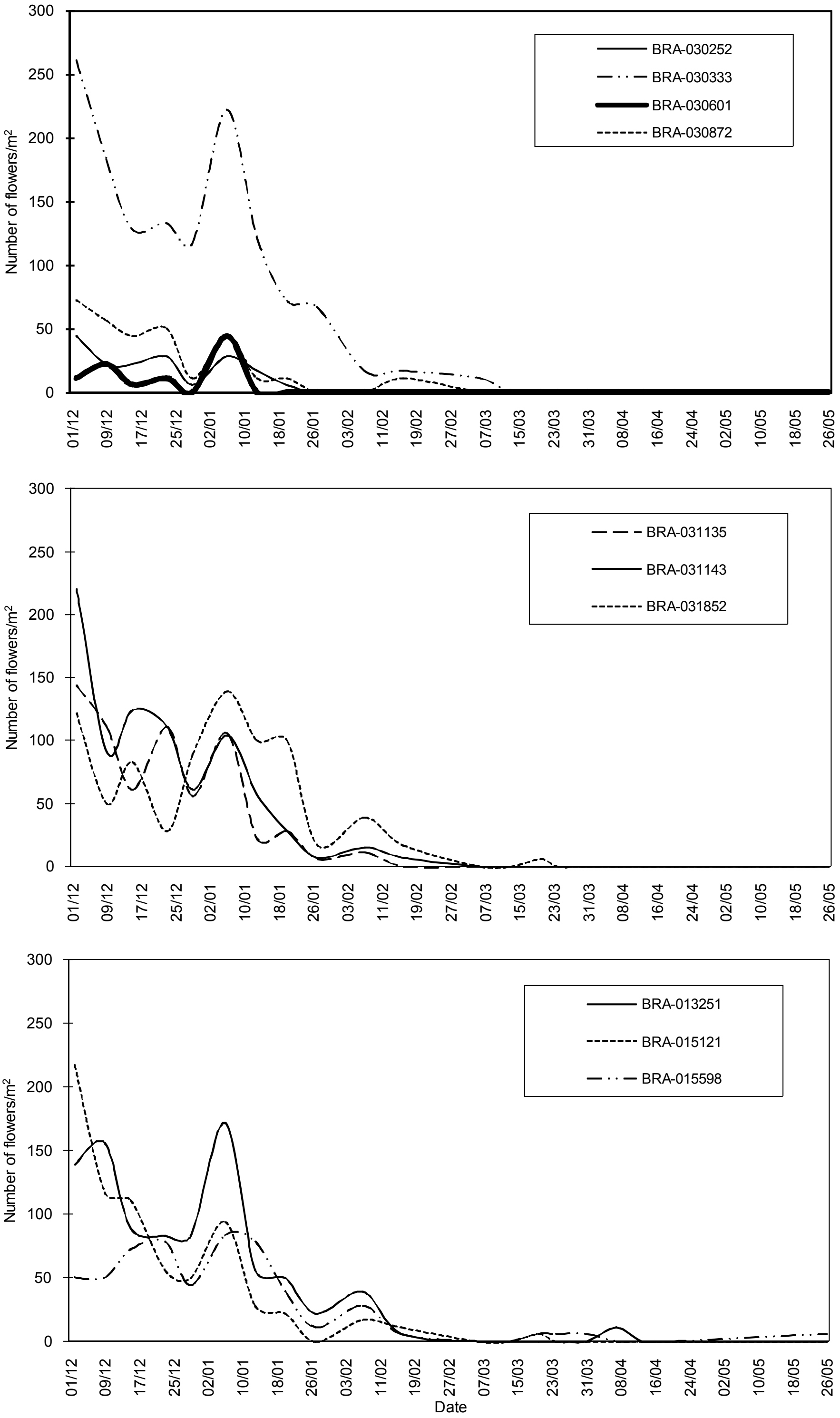

Figure 2. Flowering dynamics of *Arachis pintoi* accessions in an Akuult (low humic gley - Location 1) in the Brazilian Cerrados.

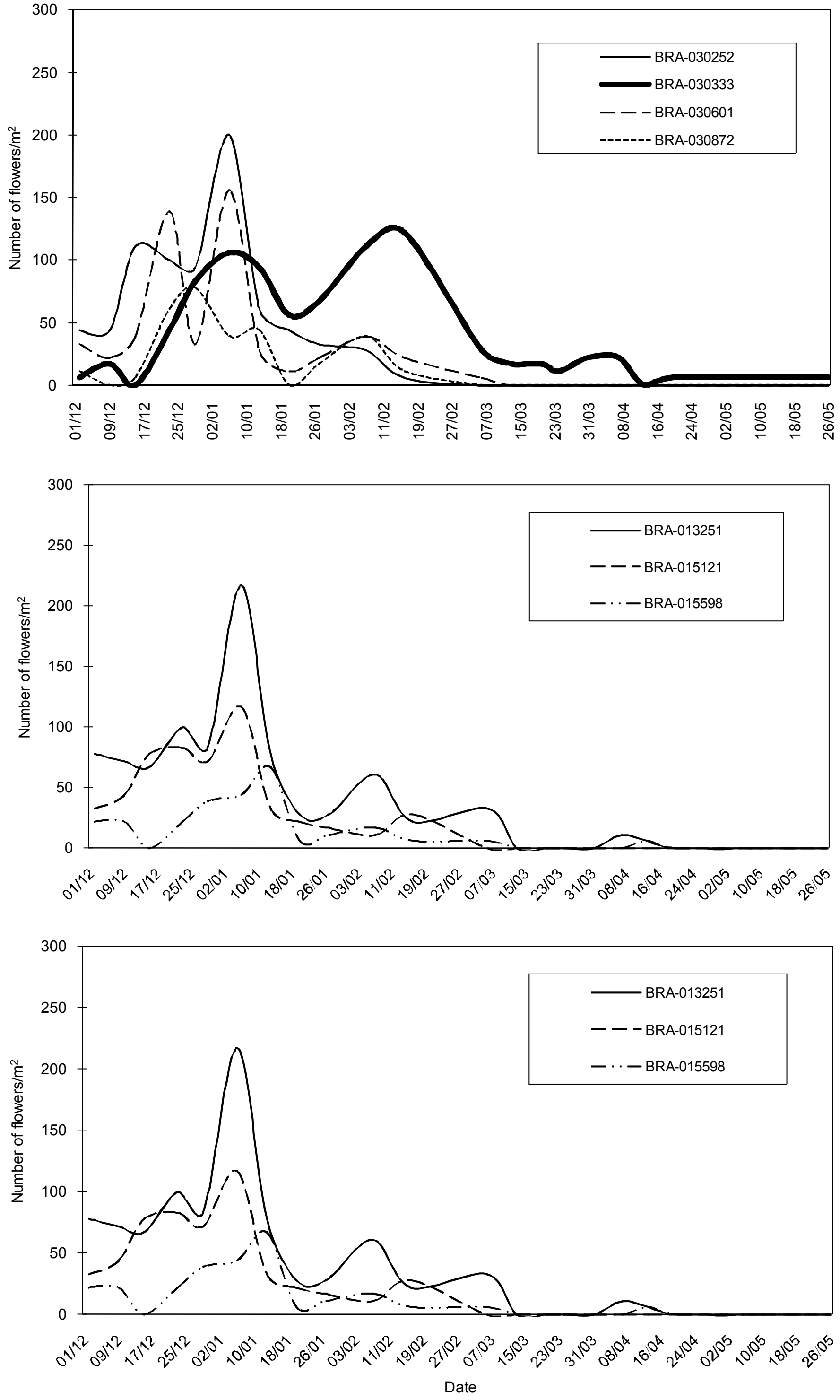

Figure 3. Flowering dynamics of *Arachis pintoi* accessions in an Ustox soil (yellow red latosol - Location 2) in the Brazilian Cerrados.

Table 3. Mean seed yields of *Arachis pintoi* and *Arachis repens* accessions in an Akuult soil (Location 1) and an Ustox soil (Location 2) in the Brazilian Cerrados.

Accession	Species	Seed yield (kg/ha)		
		Location 1	Location 2	Combined (L1+L2)
013251	*A. pintoi*	1306	364	835
015121	*A. pintoi*	1564	847	1205
015598	*A. pintoi*	240	13	126
030252	*A. pintoi*	1824	671	1248
030261	*A. pintoi*	1112	478	795
030325	*A. pintoi*	3708	465	2086
030333	*A. pintoi*	1262	434	848
030368	*A. pintoi*	884	282	583
030376	*A. pintoi*	2026	840	1433
030481	*A. pintoi*	1136	137	637
030503	*A. pintoi*	612	116	364
030511	*A. pintoi*	976	463	719
030520	*A. pintoi*	572	212	392
030546	*A. pintoi*	628	96	362
030601	*A. pintoi*	2712	876	1794
030619	*A. pintoi*	1522	447	985
030872	*A. pintoi*	508	149	328
030899	*A. pintoi*	90	46	68
030929	*A. pintoi*	1750	642	1196
030988	*A. pintoi*	828	626	727
031003	*A. pintoi*	394	98	246
031135	*A. pintoi*	1628	1242	1435
031143	*A. pintoi*	1616	608	1112
031836	*A. pintoi*	174	8	91
031844	*A. pintoi*	130	19	74
031852	*A. pintoi*	436	116	276
A. pintoi mean		1140	396	768
012106	*A. repens*	0	0	0
029220	*A. repens*	126	21	73
030082	*A. repens*	164	112	138
030597	*A. repens*	364	41	203
031127	*A. repens*	18	2	10
031861	*A. repens*	52	6	29
A. repens mean		121	30	75
Overall mean		949	328	638
LSD (P<0.05)		1048	751	672

Seed distribution in the soil profile

Percentage of total seed yield in each soil layer for the 12 accessions that presented overall best agronomic performance, at both locations, is presented in Table 4. Approximately 99% of the seeds were concentrated in the 0 – 6 cm layer, at both locations. At Location 1, no seeds were found below 9 cm depth, while a single accession (BRA–030325) produced seeds below 9 cm depth at Location 2. While there were differences between accessions in the proportions of seed in the 0 – 3 and 3 – 6 cm horizons, overall there was about 60% in the 0 – 3 cm horizon and 39% in the 3 – 6 cm horizon. This represented about 1110 kg/ha and 760 kg/ha, respectively (Table 5).

The reduction in seed yield down the soil profile showed a linear relationship (Table 6), with a larger average linear coefficient for Location 1 (-111.69) than for Location 2 (-81.35).

At Location 1, BRA–015598 presented the lowest linear coefficient, followed by BRA–031852, 030252, 030872, 030325, 013251 and 031143 (Table 6). At Location 2, a similar trend was observed, with BRA–015598 and BRA–031852 presenting the lowest linear coefficients.

Discussion

This study has highlighted the wide variation in flowering pattern, seed yield and seed distribution in the soil profile of accessions of *Arachis pintoi* and *Arachis repens*. The findings indicate that there is considerable scope for selection within the germplasm when embarking on

Table 4. Percentage of total seed yield of 12 accessions of *Arachis pintoi* in different layers of an Akuult soil (Location 1) and an Ustox soil (Location 2) in the Brazilian Cerrados.

Accession	Location 1					Location 2				
	0-3cm	3-6cm	6-9cm	9-12cm	12-15cm	0-3cm	3-6cm	6-9cm	9-12cm	12-15cm
013251	53	47	0	0	0	71	29	0	0	0
015121	52	48	0	0	0	46	54	0	0	0
015598	92	8	0	0	0	60	40	0	0	0
030252	54	45	1	0	0	49	48	3	0	0
030325	37	58	5	0	0	59	38	0	3	0
030333	69	31	0	0	0	82	18	0	0	0
030376	97	3	0	0	0	86	14	0	0	0
030601	36	59	5	0	0	35	65	0	0	0
030872	60	39	2	0	0	54	46	0	0	0
031135	56	44	0	0	0	71	29	0	0	0
031143	30	67	3	0	0	54	46	0	0	0
031852	66	34	0	0	0	61	39	0	0	0
Mean	58.5	40.2	1.3	0	0	60.7	38.9	0.2	0.2	0

Table 5. Mean seed yield by soil layer of 12 accessions of *Arachis pintoi* in an Akuult soil (Location 1) and an Ustox soil (Location 2) in the Brazilian Cerrados.

Soil depth	Seed yield	
	Location 1	Location 2
(cm)	(kg/ha)	
0–3	1288a[1]	931a
3–6	934b	580b
6–9	28c	6c
9–12	0c	2c
12–15	0c	0c

[1] Within columns, values followed by different letters differ ($P<0.05$).

Table 6. Average linear correlation coefficients of seed profile distribution for 12 accessions of *A. pintoi* in an Akuult soil (Location 1) and an Ustox soil (Location 2) in the Brazilian Cerrados.

Accessions	Linear coefficient (P1)	
	Location 1	Location 2
013251	-95.56ab[1]	-64.69abc
015121	-201.02cd	-76.72abc
015598	-36.48a	-20.61a
030252	-70.90ab	-116.13cde
030325	-75.18ab	-44.71ab
030333	-117.37b	-86.81bcd
030376	-245.19d	-143.09de
030601	-123.83bc	-82.59bc
030872	-71.01ab	-44.71ab
031135	-210.71d	-164.25e
031143	-107.97ab	-94.98bcd
031852	-48.62ab	-36.88ab
Mean	-111.69B	-81.35A[2]

[1] Within columns, values followed by the same lower case letter do not differ ($P<0.05$).
[2] Overall means followed by different upper case letters differ ($P<0.05$).

breeding programs to enhance various characteristics of this genus.

Flowering dynamics

Knowledge of the processes related to plant development of *A. pintoi* and *A. repens* is extremely important for successful adoption of these species as forage crops. According to Hopkinson (1981), to understand the development of plants and their control which allows appropriate management for seed production, it is necessary to consider the morphology of the plant, the flowering physiology and the dynamics between the plant species and the environment at the time of flowering.

The reproductive stage of most tropical and subtropical forage legumes is influenced by photoperiod, temperature and humidity (Hopkinson 1981). Most of the available information on environmental factors which control flowering among *Arachis* species is reported for *Arachis hypogaea*. Wynne *et al.* (1973) showed a positive correlation between emergence of the first flower and temperature in *A. hypogaea,* while Bagnall and King (1991) concluded that exposure to high temperatures (25 – 30°C) hastened the appearance of the first flower in Spanish, Valencia and Virginia cultivars of *A. hypogaea*, regardless of daylength.

New evidence suggests that both temperature and photoperiod influence the control of the development of peanut (*A. hypogaea*). Temperature affects the phenology, and photoperiod affects the reproductive efficiency and distribution of plant assimilates. Bell and Harch (1991) suggested that the influence of photoperiod occurred predominantly with short days.

A. pintoi is classed as a neutral plant with respect to photoperiod under tropical conditions, blooming several times during the year (Argel and Pizarro 1992). Cook *et al*. (1990) observed that *A. pintoi* cv. Amarillo began to flower 3 – 4 weeks after emergence, and continued to flower until the end of the growing season, with peaks occurring after high rainfall events. However, Cook and Loch (1993) reported that *A. pintoi* cv. Amarillo, growing under subtropical conditions in south Queensland (Australia), did not flower during the cold period (May – September). These authors also stated that regular plant cuts during the rainy season resulted in intense flowering.

In our study, great variability was observed among the accessions in terms of flowering period, intensity and distribution. Overall, our findings tend to support those of Cook and Loch (1993), as flowering extended from October to May at both locations. There were variations in maximum flowering intensity at the 2 locations, being earlier (Nov – Dec) at Location 1 than at Location 2 (Dec – Jan) (Figure 1). This difference could be related to the different environmental conditions, since Location 1 presents greater water availability in the soil and lower overnight temperatures.

Flowering dynamics and total number of flowers observed in this study were very similar to those obtained by Peñaloza (1995), who studied the behaviour of 16 accessions of *A. pintoi* and 2 of *A. repens* in Planaltina (Brazil). According to that author, maximum flowering intensity occurred between November 15 and January 11, and was associated with an increase in average temperature and relative humidity. The total numbers of flowers/m² were similar to those observed in this work, ranging from 550 to 2900/m².

Since *Arachis pintoi* and *A. repens* are considered neutral plants with respect to photoperiod under tropical conditions, it appears that the increase in average minimum temperature associated with the increase in relative humidity, as a consequence of rainfall occurrences at the beginning of the rainy season (summer), activated the flowering process in both species in the conditions of Planaltina (Brazil). As the minimum average temperature decreased, with the approach of winter, a reduction in flowering was observed, with cessation in May, at both locations evaluated.

Seed production

According to Barcellos and Vilela (1994), the poor adoption of tropical forage legumes in Brazil is a reflection of the low production and supply of commercial seeds, combined with the lack of credibility with producers. For legumes, seed production has particular importance because it can be related to persistence. A species with high seed production might have an advantage over one lacking this characteristic, because in theory, pasture establishment by seed is simpler and cheaper than when vegetative material is used. In addition, a good soil seed supply is insurance against loss of stands following dry years.

Ribeiro (1994) highlighted specific problems associated with seed production in tropical legumes. These problems are exacerbated by the natural conditions experienced in the tropics. This viewpoint had been expressed by Hopkinson (1981), who stressed that, while grasses produce high seed yields, with problems related to the harvesting process, the problem with legumes is low seed yields.

The average seed production observed in this work was 638 kg/ha (Table 3), with higher yields at Location 1 than at Location 2 (949 *vs* 328 kg/ha). However, the highest flowering intensity was not associated with higher seed yields. Significant differences were observed among accessions, indicating that there is genetic variability for this trait. The observed differences among locations suggest that, when a seed-multiplication exercise is planned, the choice of site could have a significant impact on the yields obtained. Moreover, the significant interaction between accession and location indicates that the relative performance of different accessions would depend on the growing site. Therefore, cultivar recommendation must take this factor into account.

The average broad-sense heritability (H^2) was 0.73, suggesting that the observed variance among the accessions is related to genetic factors, and therefore can be transmitted to the progeny. In the case of the combined analysis, the estimated H^2 (0.25) was smaller than those for the individual locations. These results are not unexpected, since, in the case of the individual location analyses, the genetic variance can be overestimated by the variance of the accession x location interaction. In the combined analysis, this variance component can be isolated, thus reducing the genetic variance, and consequently the value of H^2 (Ramalho *et al*. 2000). Furthermore, because this should be a quantitative trait, controlled for many loci and highly influenced by the environment, high values of H^2 were not expected. However, these H^2 values confirm the existence of genetic variability for this trait, allowing improvements by a breeding program.

Arachis seed yields displayed in this study were comparable with those of the most common forage legumes commercially used in the tropics, and for some accessions were comparable with those obtained by other authors working with *A. pintoi* in the tropics. In Australia, Cook and Franklin (1988) reported mechanised harvest yields for cv. Amarillo of 1400 kg/ha 12 months after planting, and Cook and Loch (1993) recorded an average production of 2800 kg/ha. In Costa Rica (4260 mm annual rainfall), Diulgheroff *et al*. (1990) obtained seed yields of 1950 kg/ha 12 months after sowing cv. Maní Forrajero perenne. Again in Costa Rica, Argel and Valerio (1993) reported average yields of 590, 540, 500 and 520 kg/ha for accessions CIAT 17434, 18744 and 18748, at 8, 12, 16 and 20 months after sowing, respectively. Rincon *et al*. (1992) stated that seed yields of 2000 kg/ha were obtained for the same cultivar Maní Forrajero perenne in mixed pasture with *Brachiaria* under grazing.

In the literature, *Arachis repens* is reported as producing little or no seed. However, some accessions in our study produced more than 100 kg/ha of seeds, which indicates opportunities for selection to improve the propagation of this species.

A notable characteristic, that differentiates the genus *Arachis* from most other legumes in relation to seed production, is production of the seeds below ground. In *Arachis hypogaea*, a domesticated species of the genus, the seeds produced are fixed to the plant by a rigid structure called a 'peg', which facilitates their harvest. However, in *A. pintoi* and *A. repens*, as the fruit matures the 'peg' dehydrates, becoming dry and disintegrating. Therefore, at harvest, the majority of fruits are separated from the plant and dispersed in the soil. These factors make seed harvesting in *A. pintoi* and *A. repens* very labour-intensive. It is necessary to revolve and screen on a sieve the first 10 cm of the soil layer. Since soil density equals 1 g/cm³, an average of 1000 t of soil must be processed to harvest 1 ha of *Arachis*. Any practice, that allows a reduction in the volume of soil which must be handled, will greatly reduce the costs of seed harvest.

Cook and Franklin (1988), in studying the management practices of seed production and harvest of *A. pintoi* cv. Amarillo, concluded that, on average, 94% of the seeds were located in the first 5 cm of soil, with up to 99% in the 0 – 10 cm layer. Ferguson *et al*. (1992) examined the distribution of seeds in the soil profile of a single accession at 3 locations in Colombia with different soil types, and concluded that 90% of the seed produced was located in the upper 10 cm of soil, with 70 – 80% within the first 5 cm. These results were independent of soil texture, age of the crop, location and yield.

Evaluating 3 accessions of *A. pintoi* in Costa Rica, Argel and Valério (1993) obtained results similar to those mentioned above for cv. Amarillo and BRA–012122, with 95 and 97%, respectively, of their seeds in the top 10 cm of soil. However, BRA–015121 had only 82% of the seeds in this soil layer.

Our results reinforce these findings, with 99% of the seeds in the 0 – 6 cm soil layer, and 60% in the 0 – 3 cm horizon for the 12 accessions of *A. pintoi* evaluated, at both locations. We concluded that distribution of seeds in the soil profile was genetically controlled, as these 12 accessions behaved differently with respect to this characteristic, with some accessions having a greater percentage of seed in the upper layers of soil. This information could be used in selection and breeding programs, to obtain material which set seed higher in the soil profile. This would facilitate harvesting and reduce production costs.

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