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Warm-Season Legumes – Challenges and Constraints to Adapting Warm-Season Legumes to Transition Zone Climates with Examples from *Arachis*

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Warm-season legumes – Challenges and constraints to adapting warm-season legumes to transition zone climates with examples from *Arachis*

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Key words: *Arachis glabrata*; *Arachis pintoi*; forage breeding; forage legumes; mixed pastures

Abstract

Grass pastures in monoculture are the predominant system in transition zone climates, where warm-season perennial grasses are usually cultivated. Mixed grass-legume pastures are worldwide recognized for having advantages over pure stands, including pasture longevity, N input from biological fixation, efficient nutrient cycling, and greater animal production. The genus *Arachis* encompasses important and successful warm-season forage legume species cultivated in mixed pastures or in pure stands. *Arachis pintoi* and *Arachis glabrata* are potential tropical forage species that can be used in transition zone climates. Mixed pastures with these legumes have been shown to be resilient systems, able to withstand short-term perturbations, like pests, diseases, drought, or flooding. Wide adoption of *A. glabrata* is constrained by its high cost and slow establishment period. This species has low potential to produce seeds, and rhizomes are required for propagation. Although great seed production is verified in some *A. pintoi* genotypes, vegetative propagation is also most often used, since seeds are produced underground, and a large-scale commercial seed production depends on the development of an efficient seed harvester. Developing new cultivars with persistent link between seed and peg is a great challenge for breeders. *A. pintoi* spreads faster than *A. glabrata* in tropical regions, and the genetic variability for lateral expansion and ground cover in mixed stands must be better understood in humid subtropical climates. The evaluation of *Arachis* wild germplasm has already shown genetic variability for traits of interest for use in mixed pastures. Studies have also shown that there is genotype x environment interaction considering tropical and subtropical climates. The greatest chances of success in obtaining more adapted, productive, and faster establishing *Arachis* cultivars for transition zone climates seems to be no longer in the identification of superior wild accessions but in the hybridization and selection through specific breeding programs.

Introduction

Regions located between tropical and temperate climates (latitudes from 20º to 35º North and South) usually present hot summers and winters with medium temperatures, but with frequent occurrence of frosts. In part of these transition climate zones is the humid subtropical climate, additionally characterized by the uniform distribution of rainfall throughout the year (Britannica 2018). In summer, the average temperature is 27ºC (reaching daily maximum of 30 to 38ºC), while in winter the temperature usually fluctuates between 5 and 12ºC in the coldest months. There are records of temperatures in these regions slightly below 0ºC in some winter days.

The cultivation of perennial forage species in these regions is a challenge. Tropical species show full development and growth in the hottest months of the year but are no longer productive with the arrival of winter and with the occurrence of frosts. On the other hand, typically temperate species do not develop or even survive high summer temperatures.

Among tropical forage legumes, species of the genus *Arachis* L. have shown to be quite promising for cultivation in transition zone climates (French et al. 1993). Two species are used prominently in different countries: *Arachis glabrata* Benth. and *Arachis pintoi* Krapov. & W.C. Greg., known as perennial peanut and forage peanut, respectively.

This work aims to present the main limitations and challenges for adaptation and increased adoption of these species in transition zone climates, as well as the characteristics and current uses of *A. glabrata* and *A. pintoi* in agricultural systems.

Characteristics and use

A. glabrata and *A. pintoi* are herbaceous forage legumes, with prostrate growth habit, reaching 20 to 40 cm in height. Both are palatable, have no antinutritional factors, as commonly seen in other legume species and present high nutritional value, with elevated levels of protein and digestibility, including their tender stems, being similar to alfalfa (Terril et al. 1996).

However, they have important genetic and morpho-agronomic differences (Krapovickas and Gregory 2007). *A. glabrata* is a tetraploid species (2n=4x=40) from the Rhizomatosae section. It is characterized by the presence of rhizomes, which guarantee its survival even in adverse conditions, such as frost and drought. On the other hand, seed production, if present, is scarce. *A. pintoi*, in turn, is diploid (2n=2x=20) and belongs to the Caulorrhizae section. Instead of rhizomes, presents stolons with a high number of growth points, capable of rooting in contact with moist soil. A wide range of seed productivity has already been identified in forage peanut genotypes, from the absence to the production of more than 4 tons of seeds per hectare in 18 to 21 months after planting.

Research shows the benefits of forage *Arachis* spp. use in tropical and subtropical animal production systems, most of them due to the biological nitrogen fixation (BNF). The amount of nitrogen fixed in *A. glabrata* and *A. pintoi* is genotype dependent (Miranda et al. 2003; Dubeux et al. 2017) and is directly influenced by its productivity and persistence. BNF by forage legumes is estimated between 110 to 227 kg of nitrogen per hectare annually (Herridge et al. 2008).

Rhizomatous and stoloniferous legumes as perennial and forage peanuts do not necessarily depend on natural reseeding, as they multiply vegetatively, which guarantees the permanence of their population in the pasture. Both are quite palatable and have excellent tolerance to grazing, that is, they can resist defoliation and/or trampling, as they keep their growth points protected and have physiological mechanisms that allow regrowth (Andrade et al. 2015). Therefore, mixed pastures with these legumes have been shown to be resilient systems, also able to withstand short-term perturbations, like pests, diseases, drought, or flooding. Such resilience has also been observed for frosts and low temperatures, eventually under 0ºC. Despite the loss of the aerial biomass, these species can regrowth vigorously as the temperature and precipitation increase.

The forage use of these species in tropical and subtropical regions is consolidated in countries like Brazil, United States, Southeast Asia, Australia, and Argentina. In the United States, *A. glabrata* is widely used to produce hay in the states of Florida, Georgia, and Alabama, estimated in more than 10,000 hectares in 2008 (NRCS 2008). In Brazil, there are more than 80,000 hectares of mixed pastures cultivated in tropical regions (EMBRAPA 2018). In the south of this country (from 22 ºS to 32ºS) it is also found in consortium with grasses and as a cover crop in perennial plantations.

Challenges and constraints

Both forage legumes develop better in regions with temperatures around 25 ºC, but they are able to survive in regions with average temperatures of 18 ºC, with frost occurrences. The natural distribution of *A. glabrata* is wider (13ºS to 28ºS) than *A. pintoi* (13ºS to 17ºS), giving it a better natural adaptation in subtropical climates.

Arachis glabrata

The evaluation of *A. glabrata* genotypes initiated in the 1960s in transition zone climates resulted in at least eleven cultivars released mainly in the United States. The productivity of those cultivars selected for animal systems exceeds 10 Mg ha^{-1} $year^{-1}$ (Quesenberry et al. 2010; Dubeux et al. 2017). Despite the advantages of its use, greater adoption has constraints related, mainly: (i) to use rhizomes for establishment of pasture or hay production areas and (ii) to the slow establishment of cultivars. The nursery for removing rhizomes to establish new areas should remain intact for 12 months and the optimum rate for planting is estimated at 2.5 Mg ha^{-1} (Cathey 2010). Despite mechanized planting, the operationalization of the entire process is laborious and expensive.

It is important to highlight that the released cultivars are the result of the evaluation and selection of the best genotypes, whose tools related to artificial hybridization to generate variability were not used. Among the accessions evaluated, none has been identified as a good seed producer, a limitation of *A. glabrata*. The scarce or null production of seeds brings not only difficulties for cultivation areas, but also makes it difficult to implement genetic improvement programs based on intraspecific hybridization to generate genetic variability. However, there is the possibility of obtaining F1 hybrids that could be artificially generated and evaluated, looking for high heterosis, with selection of the most productive and vigorous ones. Florigraze is probably a natural hybrid originated from cultivated genotypes. Alternatives can also be related to the evaluation of accessions not yet tested in regions of transition zone climates or even the collection of new genotypes in areas of natural occurrence to increase the genetic base. A long-term challenge would be to invest in interspecific hybridization programs. Intersectional crosses between *A. glabrata* and other species of the genus *Arachis* have already been shown to be viable, with fertile hybrids (Mallikarjuna 2002). However, the complexity of the process imposes new difficulties to breeders, because when generating such hybrids, important characters that bring advantages to the cultivation of *A. glabrata* in transition zone climates are altered, such as the loss of rhizomes in F1 hybrids of *A. glabrata* and *Arachis hypogaea* L. (Mallikarjuna and Sastri, 2002).

Arachis pintoi

Unlike *A. glabrata*, most of the released cultivars of *A. pintoi* were evaluated and selected for tropical regions. One of the exceptions is the cultivar Alqueire-1, selected for the Brazilian humid subtropic, but which has shown a high occurrence of viruses. Information about the agronomic performance and persistence of *A. pintoi* in subtropical regions is relatively scarce. Productivity observed in 24 *A. pintoi* accessions, without previous selection, evaluated at latitude 29ºN in the state of Florida (USA) ranged from zero to 9.1 Mg ha^{-1}, with an average of 4.4 Mg ha^{-1} (Carvalho and Quesenberry 2012). In this study, seed production proved to be viable, with values above 1 Mg ha^{-1}.

In tropical regions, dry matter accumulation of released cultivars is greater, varying from 7 to 20 Mg ha^{-1} yr^{-1} in pure stands (PASTO CERTO 2019). However, it should be noted that the evaluation trials and selection of forage peanut genotypes in tropical regions have been carried out continuously for more than 20 years, with the structuring of genetic improvement programs, thus creating the possibility of greater advances in agronomic response within the species.

Leaf loss and death of *A. pintoi* stolons are observed during the winter in subtropical regions, however the plants are able to survive and regrow vigorously, with total recovery of their aerial biomass as the temperature increases. Carvalho and Quesenberry (2012) highlight that "*A. pintoi* can tolerate winters where freezing and frosting are normal occurrences". Therefore, the development of forage peanut cultivars with great seed production and better adapted to the subtropical climate is a very promising strategy.

The Brazilian Agricultural Research Corporation (Embrapa) started the selection of *A. pintoi* genotypes at latitude 31ºS in 2012, according to the Forage Peanut Breeding Program (Assis and Valentim 2013), which aims to develop cultivars of forage peanut for different edaphoclimatic regions of the country. The selected genotypes were artificially crossed to obtain F1 hybrids, which were directed to the generation advance stage to increase homozygosity and obtain lines, which will be evaluated later in such environments. At latitude 31ºS in the state of Rio Grande do Sul (Brazil), wild accessions presented forage accumulation greater than the cultivars Amarillo, Belmonte, and BRS Mandobi and, even, greater than cv. Alqueire-1, selected for the subtropical climate (Naylor Bastiani Perez, personal communication). However, an expansion of agronomic performance of wild accessions from the Germplasm Bank in regions of transition zone climates is still necessary.

The slow establishment observed in *A. glabrata* also occurs in *A. pintoi*, especially when propagated through stolons. However, the great advantage of the latter is the possibility of developing cultivars with great seed productivity and, thus, using greater sowing rates for faster coverage of the area. This strategy, however, comes up against another limitation, which is the difficulty in harvesting the seeds. The fruit is detached from the mother plant when ripe in wild species of the genus *Arachis* and, usually, the harvest is 7-cm deep by digging the soil, which must be sieved to separate the seeds. Therefore, another major challenge for reducing the cost of production and increasing the supply of seed is the development of an efficient mechanized process for harvesting *A. pintoi* seeds (Sampaio et al. 2019). Successful interspecific crosses to obtain hybrids that keep the pegs rigid, even after the pods have matured, is a great challenge for breeders. For that, it would be necessary to obtain hybrids between *A. pintoi* and *A. hypogaea*. Invest in the chromosomal duplication of *A. pintoi* with colchicine first, and then fertilize the plant with the tetraploid species is a strategy (Holbrook et al. 2016).

Conclusions

Wild forage legume accessions from germplasm banks evaluated in transition zone climates have genetic variability and forage potential for use in livestock systems, including the possibility of releasing cultivars propagated by seeds. Making forage peanut seeds available on the market is a major challenge and depends on the performance of a multidisciplinary team to be successful. The demand for forage legume seeds adapted to the subtropical climate, to produce hay and to establish stable and persistent mixed pastures with different grasses, is growing strongly, especially for the benefits from BNF. The greatest chances of success in obtaining more adapted, productive, and faster establishing *Arachis* cultivars for transition zone climates seems to be no longer in the identification of superior wild accessions but in the hybridization and selection through specific breeding programs.

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