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Review Article

Cratylia argentea – review of a tropical shrub legume: Biology and agronomy[1]

Cratylia argentea – *revisión de una leguminosa tropical arbustiva: Biología y agronomía*

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Abstract

A comprehensive review, based on about 170 references, synthesizing research and development about *Cratylia argentea*, is presented to expand interest in its dissemination and use in animal production systems. The species has been widely evaluated, mainly in tropical America, with the objective to develop it as a shrub legume and an alternative to the fertility-demanding species, *Leucaena leucocephala* and *Gliricidia sepium*. The review on cratylia is presented in 2 separate parts covering biology and agronomy and quality and utilization. This paper focuses on the (1) description of the species, (2) biogeography and information on germplasm collections and genetic diversity, synthesis, (3) discussion of results from agronomic research, reproductive biology, seed production and (4) multipurpose uses of cratylia. Some strengths of the species as a forage shrub are adaptation to the acid, infertile soils that prevail in the tropics and drought tolerance in subhumid climates with a pronounced dry season. Major shortcomings are slow establishment and rapidly declining seed quality. Research resulted in the release of a blend of 2 germplasm accessions (CIAT 18516 and CIAT 18668) as a commercial forage legume cultivar in Costa Rica and Colombia. Finally, recommendations for future research are proposed.

Keywords: Adaptation, cultivar, genetic variability, performance, seed production.

Resumen

Se presenta una reseña, basada en cerca de 170 referencias, que sintetiza la investigación y el desarrollo de *Cratylia argentea*, con miras a incrementar el interés en su difusión y uso en sistemas de producción animal. La especie ha sido evaluada ampliamente, principalmente en América tropical, con el objetivo de desarrollarla como una leguminosa arbustiva para regiones tropicales con suelos ácidos y de baja fertilidad, como alternativa a *Leucaena leucocephala* y *Gliricidia sepium* que requieren suelos de mayor fertilidad. La revisión sobre *Cratylia* se divide en dos partes separadas; biología y agronomía, y calidad y utilización. Este artículo se concentra en: (1) la descripción de la especie, (2) su biogeografía e información sobre colecciones de germoplasma y diversidad genética, (3) una síntesis y discusión de resultados de investigación agronómica, biología reproductiva y producción de semillas y (4) su uso como especie multipropósito. Algunas fortalezas particulares de esta leñosa son su adaptación a los suelos ácidos de baja fertilidad que prevalecen en los trópicos y la tolerancia a la sequía en climas subhúmedos con una estación seca pronunciada. Las principales deficiencias son su lento establecimiento y la rápida disminución de la viabilidad de las semillas. Las investigaciones realizadas en la región culminaron en la liberación de una mezcla de dos accesiones (CIAT 18516 y 18668) de cratylia como cultivar comercial en Costa Rica y Colombia. Esta parte de la reseña concluye con sugerencias para futuras investigaciones.

Palabras clave: Adaptación, cultivar, producción de semilla, rendimiento, variabilidad genética.

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[1]This review article is dedicated to the memory of Dr. Jorge Ramos de Otero, Brazilian pioneer in research on tropical forage plants in the 1940s and 1950s, and the first to recognize the potential of *Cratylia argentea*.

Introduction

Until a few decades ago, *Cratylia argentea* (Desv.) Kuntze was mainly known under its synonym, *Cratylia floribunda* Benth. Otero (1952) highlighted its potential as a tropical forage over 70 years ago because of its drought tolerance and high protein concentration. Interest in the species for evaluation and cultivar development by researchers increased when seed became available after the first systematic forage germplasm collecting activities in Brazil, mainly in the 1970s. Since then, *C. argentea* has been the subject of numerous research projects and of a comprehensive review of research conducted in tropical America in the period 1978–1995 (Pizarro and Coradin 1996).

The objective of this review on biology and agronomy, genetic resources, reproductive biology, germplasm evaluation, cultivar development and alternative uses of *C. argentea* is to contribute to the continuing interest of the research and development (R&D) community in the species while giving credit to the many scientists involved in research on this legume. Wherever possible, accessible literature as information sources is used and some thoughts on future research needs are presented.

In this paper *C. argentea* is mostly referred to as cratylia, its common name in English. In Brazil, depending on the region, several common names can be found in the literature, such as camaratuba[2], cipó-malumbe, cipó-prata, cipó-de-manacá, copada, cratília, fava-de-papagaio, feijão bravo, feijão-de-boi and mucunã-de-prata. Cratilia is increasingly being used as the common name in Spanish-speaking countries.

Taxonomy and morphological description

Cratylia Mart. ex Benth. is a small neotropical genus closely related to genera such as *Canavalia* Adans., *Dioclea* Kunth and *Galactia* P. Browne, belonging to the family Fabaceae (alt. Leguminosae), subfamily Faboideae, tribe Phaseoleae, subtribe Diocleinae. Seven species of *Cratylia* are currently recognized: *C. argentea* (Desv.) Kuntze; *C. bahiensis* L. P. Queiroz; *C. hypargyraea* Mart. ex Benth.; *C. intermedia* (Hassl.) L. P. Queiroz & R. Monteiro; *C. isopetala* (Lam.) L. P. Queiroz; *C. mollis* Mart. ex Benth.; and *C. spectabilis* Tul. (GRIN 2023).

It is now known that there are 2 distinct morphotypes of *C. argentea*. The common shrub is represented by the commercial Costa Rican *C. argentea* cultivar 'Veraniega' (Veraniega), also released as *C. argentea* cultivar 'Veranera' (Veranera) in Colombia, selected from 2 accessions of germplasm (CIAT 18516 and CIAT 18668) collected in central Brazil. The other morphotype called 'Yapacaní' (Yapacaní) is a strongly climbing herbaceous vine, which is so far only known from a few populations in central Bolivia. Unless differently stated, the following description refers to the shrub morphotype. It is based on Cook et al. (2020), complemented with some descriptive elements taken from Pizarro and Coradin (2016) and Queiroz (2020), and illustrated in Figure 1.

Cratylia is a perennial, deep-rooting, erect shrub reaching between 1.5 and 3 m in height. Well established plants have an extraordinarily strong plant crown with numerous regrowth meristem points at ground level and below. When associated with taller vegetation and undisturbed, the shrub can attain a voluble liana habit with a remarkable intertangling of lignified branches. Leaves are stipulate, trifoliolate; leaflets papyraceous, elliptic to broadly ovate; central leaflet generally 9–12 × 6.5–8 cm, the laterals being smaller and slightly asymmetric; indumentum generally silvery-sericeous on the undersurface. Flowers are arranged in an elongated, many-noded pseudoraceme up to >30 cm long; 6–9 flowers per node. Size of flowers ranging from 1.5 to 3 cm (length and width); petals lilac, very rarely white. Pods pubescent, straight, flat, to 20 cm long and 1–2 cm broad, dehiscent, containing 4–8 oval to almost circular flat seeds of about 1.5 cm diameter. Seeds dark yellow to brown, when maturing under high-humidity conditions, dark brown. About 4,500 seeds per kg.

Observations in plant introduction nurseries showed that plant age and genotype seem to have an effect on the intensity of the silvery pubescence on the undersurface of leaflets. Matrangolo et al. (2018a) suggested that hot and sunny environments favor this characteristic.

Unlike the shrub, Yapacaní is a prostrate-climbing vigorously voluble herb with only slightly lignified stems and branches; leaflets are more elongated and completely lack the silvery pubescence on the undersurface.

[2]'Camaratuba' is almost exclusively used for *Cratylia mollis* Mart. ex Benth., a species endemic to the Brazilian northeastern region (*Caatinga* biome) with potential for semi-arid environments (Sousa and Oliveira 1996).

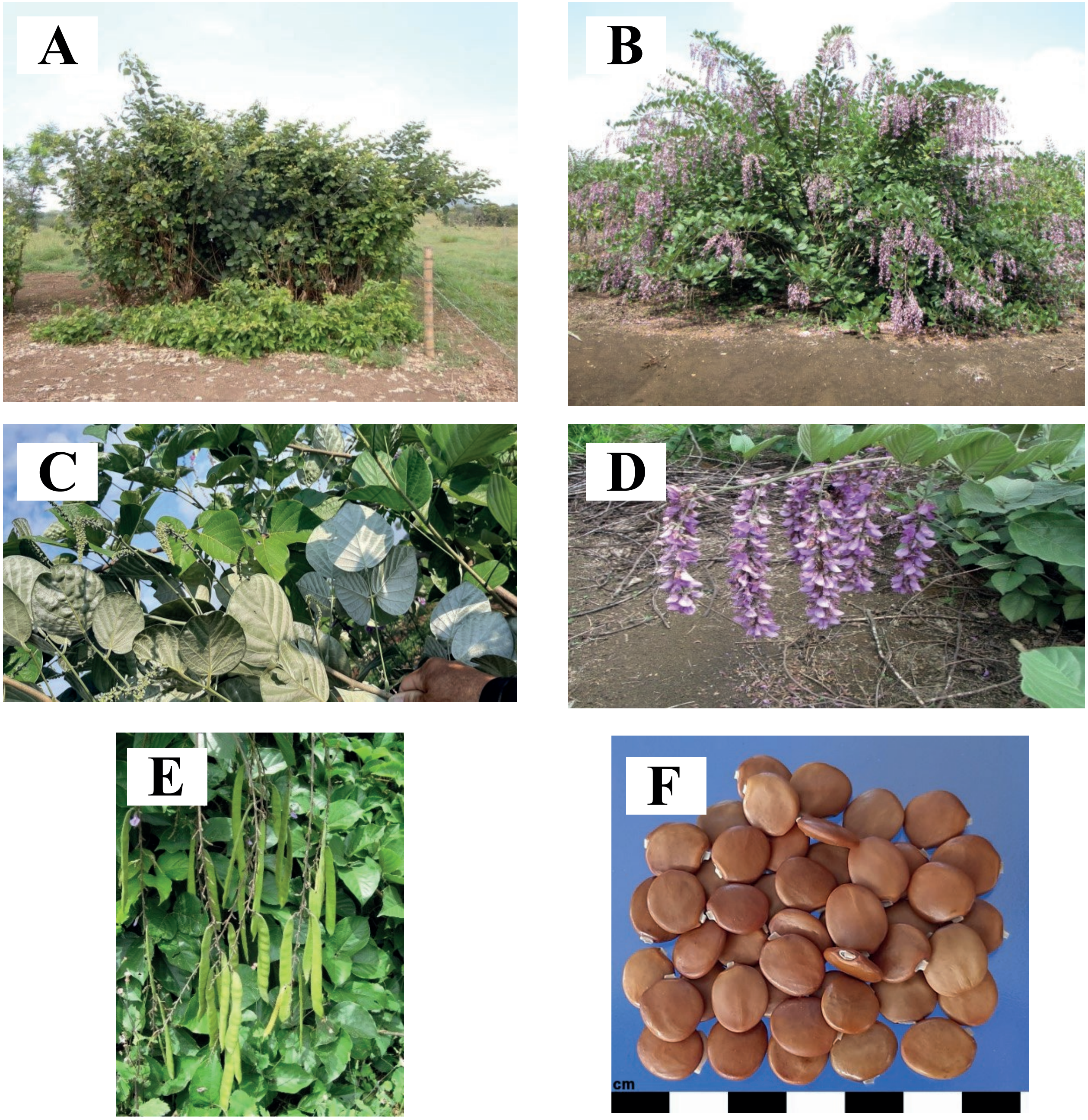

Figure 1. Morphology of *Cratylia argentea*. (A) Erect shrub morphotype vs. prostrate-climbing Yapacaní morphotype (Photograph: R. Schultze-Kraft); (B) Habit of flowering shrub morphotype (Photograph: A. Ciprián, CIAT); (C) Leaflet underside with silvery pubescense vs. upperside without (Photograph A. Ciprián, CIAT); (D) Flowering branch (Photograph: A. Ciprián, CIAT); (E) Fruiting branch (Photograph: A. Ciprián, CIAT); (F) Ripe seeds (Photograph: A. Ciprián, CIAT).

Biogeography

According to a comprehensive study of botanical specimens, *C. argentea* has the widest geographical distribution of the 7 *Cratylia* species (Queiroz and Coradin 1996): It extends from NE Brazil to Bolivia and Peru, south of the Amazon River and east of the Andes, mainly within longitudes 38–77° W and latitudes 07–18° S. The species occurs generally at low elevations (200–800 masl), mainly in open tree and shrub savanna habitats, but has also been found in transition zones to seasonal forest and semi-arid vegetation. Environments where occurrence of cratylia has been recorded are characterized with total rainfall ranges between 1,200 and 3,000 mm/year, a marked dry season of 4–6 months (i.e. <50 mm rainfall/month), often in combination with fire events (Figure 2), where the shrub type is fire tolerant (Figure 2C).

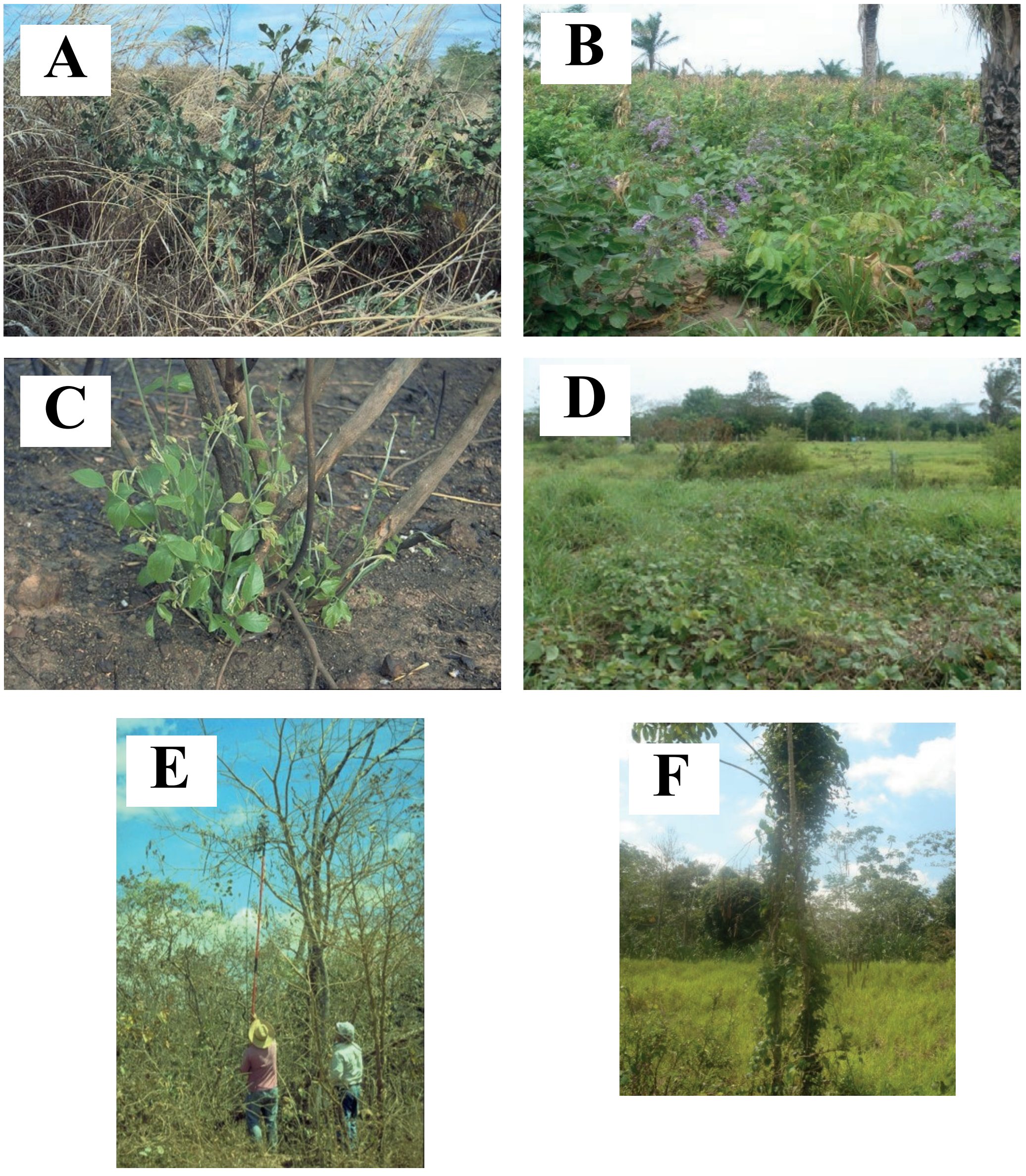

Figure 2. *Cratylia argentea* in its native habitat. (A) Young shrub morphotype, spontaneously growing in a dry Hyparrhenia rufa pasture, Goiás, Brazil (Photograph: R. Schultze-Kraft); (B) Shrub morphotype as part of fallow vegetation in a former maize field, Santa Cruz, Bolivia (Photograph: R. Schultze-Kraft); (C) Regrowth of shrub morphotype after savanna fire in Mato Grosso, Brazil (Photograph: R. Schultze-Kraft); (D) Yapacaní morphotype: Prostrate growth habit, Yapacaní area, Santa Cruz, Bolivia (Photographs: R. Schultze-Kraft); (E) Collecting seed of a shrub morphotype that became a voluble liana in Cerrado vegetation, Goiás, Brazil (Photograph: R. Schultze-Kraft); (F) Yapacaní morphotype climbing when there is a trellis tree (Cecropia sp.), Yapacaní area, Santa Cruz, Bolivia (Photographs: R. Schultze-Kraft).

Within this overall geographic distribution, live material of the Yapacaní morphotype is so far only known from central Bolivia, where it has been found in the western part of Ichilo province, Santa Cruz department, and in the east of adjoining Carrasco province, Cochabamba department (Schultze-Kraft et al. 2006). Unlike the shrub morphotype, the Yapacaní morphotype occurs on soils that are less well-drained.

Genetic resources

Cratylia was one of the legumes with very few germplasm samples collected during the early Brazilian plant exploration activities in the 1960s and 1970s, all of which aimed at a broad spectrum of native legume species with expected forage potential. Those cratylia collections were made in the states of Bahia, Goiás, Maranhão, Minas Gerais, Piauí, São Paulo and Tocantins (Hymowitz 1971; Costa et al. 1978; Rocha et al. 1979; Shock et al. 1979; Sobrinho and Nunes 1996). The evaluation work of José Marcelino Sobrinho in the late 1970s at EMGOPA (Empresa Goiana de Pesquisa Agropecuária) revealed the adaptation of the species to the Cerrado biome (Sobrinho and Nunes 1996) and led to increased interest by other institutions to broaden its germplasm base. Subsequently, new material was collected mainly during joint expeditions conducted by EMBRAPA-CENARGEN and CIAT in the 1980s in Mato Grosso, Goiás and southern Pará, and in the 1990s by Embrapa Recursos Genéticos e Biotecnologia and Embrapa Cerrados, also in cooperation with CIAT, in Goiás, Mato Grosso, Minas Gerais and Tocantins (Queiroz and Coradin 1996; Pizarro et al. 1997). More recently, collections were made in the states of Acre, Ceará, Goiás, Maranhão, Pará and Tocantins (Brasileiro et al. 2018). Based on plant exploration and land-use studies in the Terra Ronca State Park in northeastern Goiás, Mattar et al. (2020) suggested that the State Park be considered a potential *in-situ* conservation area for cratylia populations.

Before 2006, cratylia germplasm had not been collected outside Brazil, except for accession CIAT 22397, collected by E. A. Pizarro in the municipality of Yapacaní, Santa Cruz department, Bolivia in 1995. Since this was the only sample of a prostrate-voluble *C. argentea* morphotype, it triggered interest in further exploring species diversity in Bolivia. Subsequently, several Yapacaní morphotype populations were identified in the Santa Cruz and Cochabamba departments, along with 2 shrub morphotype populations in Santa Cruz (Schultze-Kraft et al. 2006).

A total inventory of *ex-situ* conserved cratylia germplasm is not available. Based mainly on figures presented by Queiroz and Coradin (1996), Pizarro et al. (1997) and Mattar (2018), there might be a total of 100–120 different accessions in the various Brazilian genebanks. The 50 accessions currently registered in the CIAT genebank (bit.ly/3WKEiUG) are duplicates of material conserved at Embrapa Recursos Genéticos e Biotecnologia, Brasília, Brazil. Areas for future collections were prioritized by Queiroz and Coradin (1996). Passport data on the origin of cratylia germplasm using a consolidated inventory will show to what extent these areas should be adjusted.

Genetics and reproductive biology

A chromosome number of 2n=22 was reported for *C. argentea* by Queiroz (1991) and confirmed by Vargas et al. (2007). Based on a preliminary study with a plant population at Embrapa Cerrados, Planaltina, Federal District, Brazil, Queiroz et al. (1997) suggested a mixed mating system of both allogamy and autogamy. Bystricky et al. (2010), however, found that at the CIAT Research Station, Palmira, Colombia, Veranera is largely self-incompatible, pollination being dependent on large insects, mainly the bee species *Xylocopa frontalis* and *Centris* spp. (both, Anthophoridae). A further pollination study conducted with both the Yapacaní and shrub morphotypes at the CIAT Experimental Station at Quilichao, Colombia showed that the Yapacaní morphotype is self-incompatible and that there is pollen flow between the 2 morphotypes (Rivera Hernández 2012).

The occurrence of a few white-flowered plants in otherwise lilac-flowered populations was observed in a site in the species' native habitat in Mato Grosso (Pizarro et al. 1997), in on-farm evaluation of Veraniega in Costa Rica (Mesén Villalobos and Sánchez Ledezma 2008) and in an evaluation plot at CIAT Quilichao (A. Ciprián, pers. comm. 2017). This indicates segregation following natural crosspollination.

Genetic variability

Owing to self-incompatibility as the prevailing breeding mechanism, molecular marker studies revealed more variability within an accession (defined as a sampled population registered in a genebank) than among accessions. Those studies were: (a) the genetic characterization of 47 *C. argentea* accessions in comparison with *C. mollis* using random amplified polymorphic DNA (RAPD) by Andersson et al. (2007); (b) the comparison of 11 *C. argentea* accessions by sequences from internal transcribed spacers (ITS/5.8S) of nuclear ribosomal DNA (Galdino et al. 2010); and (c) the molecular characterization with inter simple sequence repeats (ISSR) markers of 13 accessions from a Brazilian *C. argentea* population (Luz et al. 2015). Andersson et al. (2007) found that the only Yapacaní morphotype accession tested was genetically almost as distant from all shrub morphotype accessions as *C. argentea* from *C. mollis* at the species level. H. G. Suárez Baron (unpublished) conducted a genetic analysis with 11 Yapacaní morphotype accessions, 6 shrub morphotype accessions and 2 *C. mollis* accessions, using both RAPD and ITS molecular markers because of potential taxonomic implications. That study revealed a marked genetic differentiation between the Yapacaní and shrub morphotypes which, however, was not considered large enough – in comparison with the genetic distance between *C. argentea* and *C. mollis* – to suggest that the Yapacaní morphotype might be described as a new *Cratylia* taxon at species level. In both the genetic similarity assessment with RAPD markers and the phylogenetic analysis of ITS/5.8S sequences, significant differences between the Brazilian shrub morphotype accessions and the 2 Bolivian shrub morphotype accessions were detected (H. G. Suárez Baron, unpublished).

Regional research: Overview of species adaptation, evaluation and cultivar development

Information summarizing results from research in tropical America during 1978–1995, with emphasis on *C. argentea*, was presented at an international workshop on the genus *Cratylia* held in Planaltina, Brazil in 1995. The workshop proceedings (Pizarro and Coradin 1996) dealt with biogeography of the genus (Queiroz and Coradin 1996), species evaluation in Brazil (Xavier and Carvalho 1996; Pizarro et al. 1996; Sobrinho and Nunes 1996; Sousa and Oliveira 1996), Colombia (Maass 1996) and Central America and Mexico (Argel 1996) and feed quality and utilization (Lascano 1996). This state-of-the-art document was followed by a literature review (Argel and Lascano 1998) and technical bulletins with focus on Costa Rica (Argel et al. 2001) and Colombia (Lascano et al. 2002; Rincón Castillo et al. 2007). The following paragraphs provide an overview of studies of species adaptation, germplasm evaluation and cultivar development in the respective countries during the past 4 decades. The sequence of country presentation in this overview follows an approximately chronological order in which adaptation and evaluation studies were conducted in the respective countries within regions.

South America

Brazil. The cratylia accession IRI 2496 was mentioned as one of the 6 most promising native legumes that originated from the early (1962–1967) Instituto de Pesquisas IRI collections (Shock et al. 1979). This accession was subsequently "widely distributed with occasional success" in Brazil. There is no recent information on whether this accession is still in production.

Work in the late 1970s and early 1980s at EMGOPA was reported by Sobrinho and Nunes (1996), who highlighted promising results of a genotype from São Domingos, Goiás, on an infertile Oxisol (*Latossolo Vermelho-Amarelo*, LVA) of the Cerrado biome that prevails in that state. Under its accession number CIAT 18516, this genotype was widely tested outside Brazil and subsequently selected as 1 of 2 accessions used to develop Veraniega and Veranera.

Almost simultaneously, research on agronomy and feed value was conducted in the *Zona da Mata* region in the southeast of Minas Gerais state (Xavier et al. 1995; Xavier and Carvalho 1996; Xavier et al. 2003), which led to registration, in 2016, of a line developed from accession CNPGL-28 (origin: Jaíba, Minas Gerais) for release by EMBRAPA Gado de Leite as cultivar 'BRS Ceci' (Cook et al. 2020). Productivity studies were independently initiated in the *Central* region of Minas Gerais in 2010 (Miranda et al. 2011). A summary of the research in that region with focus on phenological and ecological aspects of the species was presented by Matrangolo et al. (2018a).

In the *Cerrado* biome of Central-West Brazil, research on shrub legumes during 5 years in the 1990s at Planaltina, revealed the high potential of the 11-accession collection of cratylia available at that time (Pizarro et al. 1996). Although this triggered further collecting activities (Pizarro et al. 1997), there are no published reports on subsequent germplasm evaluations and cultivar development in the region.

Colombia. Summarizing the evaluations of the cratylia collection available in the second half of the 1980s, Maass (1996) reported that all 11 accessions were well adapted to the acid, infertile soils and the climate of the various sites where the collection was tested. Performance at elevations >1,200 masl was poor. There was no major morphological variation among accessions. CIAT 18668 was considered to be particularly promising.

As a result of this and subsequent research (Corpoica 2002), the Corporación Colombiana de Investigación Agropecuaria (Corpoica, now Agrosavia), released Veranera in November 2002, following the Costa Rican approach of creating a physical mixture of 2 very similar accessions, CIAT 18668 and CIAT 18516. The release bulletin (Lascano et al. 2002) summarizes cratylia research results and presents recommendations for establishment and utilization of the legume.

Andersson et al. (2006) reported variation among 38 accessions at CIAT-Quilichao for phenology, dry matter (DM) production and nutritional quality. Subsequently and at the same site, Peters et al. (2009) compared cratylia germplasm from Bolivia, including 11 Yapacaní and 2 shrub morphotype accessions, with Brazilian shrub accessions. While the Yapacaní morphotype accessions produced considerably less DM than the shrub accessions in both the wet and dry season, there were no yield differences between the 2 Bolivian and the 4 Brazilian shrub morphotype accessions evaluated.

Most R&D activities with Veranera concentrated on the Andean piedmont region (high rainfall with a short dry season) in the Orinoco River basin (Piedemonte Llanero, Meta department) with the focus on dual-purpose cattle farms with acid, infertile soils (Plazas and Lascano 2005; Rincón Castillo et al. 2007). More recently, new shrub germplasm evaluation was conducted at 2 Agrosavia experimental stations in the well-drained Altillanura region (Taluma and Carimagua) with acid, infertile soils and >2.200 mm rainfall/year and a production-limiting dry season of 2–4 months. Cratylia outperformed *Desmodium velutinum*, *Flemingia macrophylla* (flemingia) and *Leucaena diversifolia* germplasm in terms of vigor and forage production (Corpoica 2017). CIAT 22389, the outstanding cratylia accession, was selected for subsequent animal production studies.

In a test of 5 forage tree/shrub species in the acid-soil, high-rainfall region of the Andean piedmont in the Amazon River basin in Piedemonte Amazónico, Caquetá department, where Maass (1996) had reported good adaptation of the species, cratylia (no accession or cultivar mentioned) presented the highest DM production (Suárez et al. 2008). Recently, the species was reported to be present in 32 farms that form part of a silvopastoral project in that region (Parra Celis et al. 2021).

To further assess adaptation to mid-altitude hillside sites, Parra and Gómez-Carabalí (2000) tested a varying number of shrub and tree species and accessions on low-fertility soils at 3 locations in the Cauca and Valle del Cauca departments. Cratylia was outstanding in terms of dry matter production at elevations up to 1,175 masl; accessions mentioned are CIAT 18597, CIAT 18668 and CIAT 18676. Poor growth of cratylia was reported from 1,650 masl in the Antioquia department (Vargas Zapata et al. 2017).

Peru. Published cratylia studies in Peru concentrate on 2 sites in the humid tropics with a 3-month minimum rainfall season and acid, infertile soils: Pucallpa (Ucayali department) and Tarapoto (San Martín department). At the former, in a comparison of 2 cratylia accessions with 5 other shrub legume species considered adapted to acid soils (*Cajanus cajan*, *Codariocalyx gyroides*, *D. velutinum*, flemingia and *Tadehagi triquetrum*), accession CIAT 18957 presented the highest DM production in a 12-wk regrowth cut during the minimum rainfall season (CIAT 1990). Recent work (Medina Dávila 2021), where cratylia was compared with *Erythrina berteroana* and *Leucaena leucocephala* (leucaena), confirmed the good adaptation of cratylia (no cultivar or accession mentioned).

At Tarapoto, accession CIAT 18516 was compared with 3 herbaceous legumes (*Arachis pintoi*, *Centrosema macrocarpum* and *Desmodium ovalifolium*) (Rojas Reátegui 2002). Establishment of cratylia was slow but its DM yields in 12-weekly cuts in both the maximum and minimum rainfall seasons were higher than those of the 3 non-shrub species. More recently, a development project report revealed no advantage of cratylia (no cultivar or accession mentioned) in comparison with leucaena and the non-legume species *Morus alba* and *Moringa oleifera* (Ibazeta Valdivieso et al. 2018).

Venezuela. Evaluating the 10-accession set of cratylia available for research in the second half of the 1990s in El Tigre, Anzoátegui state, Rodríguez and Guevara (2002) found no major differences among accessions for DM production and feed value. Cratylia proved to be well adapted to the sandy, low-fertility soil of the savannas in dry-subhumid eastern Venezuela and was officially recommended for use in the region (Rodríguez et al. 1999; Navarro Díaz et al. 2004), particularly as protein banks (Guevara et al. 2013). Seed distributed to farmers as 'Cratylia' was a mixture of unknown accessions (I. Rodríguez, pers. comm., July 2023).

Bolivia. Based on evaluations at 3 sites in Cochabamba department, cratylia is recommended for use as protein bank for acid soils in the humid tropics of Bolivia (CIF 2009; Gutiérrez 2010). Smallholder-produced seed of Veranera is marketed in the country (E. A. Pizarro, pers. comm., August 2023).

Central America and Caribbean

Costa Rica. An evaluation of 11 accessions of cratylia was carried out by Argel (1996) at Atenas, with fertile soils and a 5–6-month dry season and San Isidro, with acid infertile soils high in Al and a 3–4 month dry season. In terms of DM production, results showed little variability among accessions, including CIAT 18516. This accession was additionally tested at a high-rainfall site in Los Diamantes, Guápiles, where cratylia was first introduced in 1988. Subsequent research led to the release of Veraniega in 2001, a physical 50:50 mixture of accessions CIAT 18516 and CIAT 18668 that had proven to be very similar. The objective of the mixture was to broaden the genetic base of the cultivar. The release bulletin (Argel et al. 2001) summarizes research results and presents recommendations for establishment and utilization of the legume.

Guatemala. According to the only published information available, CIAT 18516 did not grow satisfactorily on a very low-P site at El Subín, Petén (Argel 1996).

Honduras. Although results of adaptation and evaluation studies are not published, based on the performance of cratylia in regions with a pronounced dry season, its use was officially recommended by Dicta (2002).

Caribbean. In a 3-legume shrub comparison in the south of Puerto Rico, establishment growth of cratylia (no accession mentioned) was very slow and DM production at 134 days after transplanting of seedlings considerably lower than for *Calliandra calothyrsus* (calliandra) and leucaena (Crespo et al. 2011). In the northeast of Dominican Republic, cratylia (no accession mentioned) outperformed, in terms of DM production, *Morus alba* (Frías and Valerio 2013).

Mexico. Most of the species' adaptation and evaluation studies were carried out in the state of Veracruz. Based on unpublished work by J. F. Enríquez Quiroz, Argel (1996) reported good performance of accession CIAT 18516 on an acid, infertile soil in the municipality of Isla. In evaluations of accessions CIAT 18516, 18666, 18668 and 18676 in Atzalan (Castillo-Gallegos et al. 2013) and Tlapacoyan (Valles-de la Mora et al. 2014), no major differences among accessions were reported for DM production or forage quality. These experiences in Veracruz were summarized by Valles-de la Mora et al. (2017). The only published evaluation outside Veracruz is a study of 10 legume species in Chetumal, Quintana Roo, where cratylia (no cultivar or accession mentioned), along with *Crotalaria juncea*, showed the highest DM production over this 2-year study (Sosa Rubio et al. 2008).

Africa

Information from research in Africa is essentially limited to the report of a French sponsored network RABAOC-AFRNET (1995) report, according to which accession CIAT 18516 was included in germplasm sets for 2-yr multilocational tests at 18 sites in 9 countries in West and Central Africa (Benin, Central African Republic, Cameroon, Côte d´Ivoire, Ghana, Guinea, Nigeria, Senegal and Togo), along with 5 other shrub legumes (*Cajanus*, *Codariocalyx*, *D. velutinum*, flemingia and leucaena) and a number of herbaceous legumes and grasses. The report does not provide a clear picture on the overall adaptation and agronomic performance of cratylia, which was affected by plant establishment/seed quality problems that prevented inclusion of the species in a combined multilocational analysis. In the few cases where plants were established, remarkable drought tolerance was noted. In Ghana, Barnes (1998) evaluated 13 woody legume species, among them cratylia, which performed poorly. Similarly, cratylia did not stand out among several other woody legume species tested in mid-altitude sites of eastern DR Congo (Dieudonné 2020).

Southeast Asia and China

Within the CIAT-ACIAR Forages for Smallholders Project, cratylia was tested in the 1990s in several SE Asian countries. According to W. Stür (pers. comm., March 2023), the species performed poorly, due to plant establishment problems in combination with low seed quality. Poor performance of cratylia within a forage tree collection (mainly *Leucaena* spp.) tested in a fertile-soil, high-rainfall environment was reported from the Philippines (Gabunada and Stür 1999). Similarly, cratylia performed poorly in a legume comparison trial at 2 sites in Laos (Stür et al. 2010). In Danzhou, Hainan province, China, cratylia was susceptible to low temperatures, which coincide with flowering of the plants and affect seed production (Tang Jun, pers. comm., Sept. 2023).

Ecological adaptation

Soil

Information on soils, to which cratylia is adapted, refers mainly to germplasm collecting sites. In synthesis, soils are well drained, acid (pH 4–7) and of low to medium fertility, values of P ranging 1–60 ppm, Ca+Mg 1–14 meq/100 g, and K 36–480 ppm (Pizarro et al. 1997; Mattar 2018). The considerable variation in soil data, mainly the high values, is probably due to some collections being made in soil fertility-disturbed vegetation, e.g., at roadsides. Field trials have demonstrated that cratylia is adapted over a wide fertility range. However, cratylia is not adapted to poorly drained or seasonally flooded soils nor to soils with a layer that hampers penetration of the taproot (Argel et al. 2001). Gama et al. (2009) reported good growth of cratylia on a Quartzpisamment soil with 90% sand in Mato Grosso do Sul, Brazil.

The above information refers to the cratylia shrub morphotype collected in Brazil. The Yapacaní morphotype (Bolivia) was found on less well-drained soils of medium to high fertility (Schultze-Kraft et al. 2006).

Perdomo (1991) documented differential soil adaptation by comparing the performance of 23 shrub and tree legume species on 2 contrasting soils in a field experiment in southwest Colombia, on a fertile Vertisol with pH 7.7 and 84.6 ppm P at CIAT-Palmira and on an infertile Ultisol with pH 4.0, 5.3 ppm P and 90.8% Al saturation at CIAT-Quilichao. DM production of cratylia accession CIAT 18516 on the Ultisol was only 32% less than that on the Vertisol, while leucaena and *Gliricidia sepium* (gliricidia) produced >99% less DM than on the Vertisol, showing adaptation of cratylia to high Al saturation. Xavier et al. (1998) reported that liming improved growth of cratylia in pot experiments conducted on an infertile Oxisol (LVA) in Minas Gerais, but at the optimum lime dose (1.5 t lime/ha to achieve 90% of maximum DM yield), soil pH was still <5 and Al saturation, 26%. Adaptation of CIAT 18516 to an acid, infertile Oxisol with pH 5.0 and 2.0 ppm P on a farm in the Eastern Plains (*Altillanura*) compared to growth on a Mollisol (formerly classified as Vertisol) at CIAT-Palmira was confirmed in an experiment on growth and chemical composition of 5 shrub legumes (Tiemann et al. 2009).

Climate

Rainfall data at locations where cratylia germplasm was collected and where it was evaluated have been determined based on map coordinates and long-term averages from nearby sites. The annual rainfall range for the Brazilian shrub morphotype is 1,230–2,240 mm, the distribution being monomodal with a dry season of 2–5 months, while the Yapacaní morphotype is from somewhat more humid environments (about 2,700 mm/ yr with 2 dry months). The altitudinal range of collection sites is 100–810 masl. As germplasm evaluation studies in Colombia have shown (Maass 1996; Parra and Gómez-Carabalí 2000), cratylia does not grow well at elevations above 1,200 masl. According to information from Brazil (Sobrinho and Nunes 1996) and China (Tang Jun, pers. comm., Sept. 2023), the species is intolerant of low temperatures.

The drought tolerance of well-established cratylia plants and dry season leaf retention were reported by Argel (1996), which Pizarro et al. (1996) suggested was due to a deep-reaching root system. For 4.5-yr-old plants (CIAT 18516 and 18675), the major root concentration was at 1.3–1.8 m depth. Dry season leaf retention is supported by yield trials (see following sections), in which the dry season portion of cratylia accounted for up to 40% of total annual production.

Agronomy

Establishment and plant growth

Under suitable conditions, healthy cratylia seeds germinate readily. Sanabria et al. (2004) found that seed scarification is not necessary. Initial growth is slow, as first shown by Xavier et al. (1990). This drawback was confirmed, regardless of edaphoclimatic conditions (Mesén Villalobos and Sánchez Ledezma 2008; Gutiérrez 2010; Crespo et al. 2011; Aquino et al. 2020). The general conclusion is that sowing or transplanting must be combined with weed control and sufficient time (7–12 months) allowed until the first cut or grazing. Matrangolo et al. (2018b) suggested that allocation of energy resources to the formation of its root system might be responsible for the slow initial growth of cratylia.

Aquino et al. (2020) evaluated the effects of direct seeding or transplanting of 4-mo old seedlings on establishment of cratylia. After an initial advantage of the transplanted seedlings, 10 months later there was no difference in plant height, regardless of method; labor made up to 86% of the total establishment costs. Similarly, transplants (no age mentioned) had a slight advantage over direct seeding for time to reach 1 m plant height at CIAT-Quilichao (Rosero Alpala et al. 2010).

Optimum plant density for highest cratylia forage production per unit area was found to be: 20,000 plants/ha in Veracruz, Mexico (Enríquez Quiroz et al. 2003); 40,000 plants/ha in Nicaragua (Pasquier Flores and Rojas Vallecillo 2006; Reyes Sánchez et al. 2007); and 111,111 plants/ha in the Andean piedmont region in Colombia (Corpoica 2002). Such large differences are probably due to environmental conditions (soil, climate).

Fertilizer application and rhizobiology

Phosphorous (P) was reported as the nutrient which limited growth of cratylia shoots and roots, affecting also physiological conditions of rhizobium nodules in a pot experiment using an infertile Oxisol (*Latossolo Vermelho-Escuro*, LVE) in Minas Gerais (Purcino and Lynd 1984). From a series of pot experiments on an LVA in the *Zona da Mata* region of Minas Gerais, P fertilizer application and liming improved growth of cratylia (Xavier et al. 1996; 1997; 1998). In particular, liming increased the efficiency of P application. The critical internal P concentration, at which 80% of maximum DM yield was obtained, was 0.14%.

Positive effects of fertilizer application with Ca, N and Mg on biomass production were reported from a field experiment on an infertile, sandy Oxisol in the savanna of eastern Venezuela (Navarro Díaz et al. 2002), although field research in Colombia on 2 contrasting soils did not show clear responses to P, K, Ca, Mg and S fertilizer application (Tiemann et al. 2009).

In field studies in the *Zona da Mata* region of Minas Gerais, Xavier and Carvalho (1996) observed active nodulation in cratylia with native cowpea type rhizobia. Oliveira et al. (1998), however, did not find any superior shoot and root production in a pot experiment with a Minas Gerais LVA where they tested the effect of inoculation with 17 different rhizobium strains, presumably due to the competition and effectiveness of the native cowpea strain. At CIAT-Quilicho, speed of cratylia establishment was not improved when seeds were inoculated with rhizobium (Rosero Alpala et al. 2010). In an inoculation test with 2 *Rhizobium* and 4 *Bradyrhizobium* strains on a sand/vermiculite substrate in the greenhouse, only 1 inoculum, CR52 (BR10257), led to nodulation and subsequent increased plant height after 85 days (Mattar et al. 2018). Among a total of 25 strains, Calazans et al. (2016) identified the same inoculum, CR52, along with CR42, as particularly successful. Argel et al. (2001) recommended inoculation with *Bradyrhizobium* CIAT 3561 or 3564 in Costa Rica.

Crop management

This section focuses on cratylia management for optimization of forage production in cut-and-carry systems, the use most evaluated by researchers. Diversity of options for plant age at first cut, cutting frequency and cutting height is documented in the report on early evaluation trials conducted in Colombia (Maass 1996).

Plant age at first cut. This is the time when plants can be considered established. There are objective criteria to determine when the plant is well established, although some authors chose a particular plant height (1 m; Rosero Alpala et al. 2010) or a particular plant age such as 7 months (Rodríguez and Guevara 2002; Gutiérrez 2010) or 12 months (Lobo and Acuña 2004) as criterion. There was no effect on DM production at 4, 6 and 8 months of the first cut after planting (Argel et al. 2001).

Cutting frequency. Cutting frequency has been a major subject of interest to researchers (Table 1). In summary, there is a tendency for considering 90 days as the suitable overall cutting frequency. The resulting range of cutting intervals recommended in the literature reflects the variation of environmental conditions and subsequent plant growth at the respective study sites. Findings reported should also be interpreted considering pertinent experimental details.

Cutting height. Studies to determine optimum cutting height reported varying results. In Minas Gerais, Xavier et al. (1990) found no yield difference when comparing 20 cm with 40 cm height. Santana and Medina (2005), testing 30, 60 and 90 cm in Colombia, reported that cutting height did not affect edible DM yield. Similarly, in Venezuela there was no yield difference after cutting at 50 or 70 cm (Lugo-Soto et al. 2009). In contrast, Lobo and Acuña (2004) found in Costa Rica that harvesting at 90 cm height led to higher DM yields in comparison with 30 and 60 cm, and in Nicaragua DM production was higher after cutting at 60 cm in comparison with 20 and 40 cm (Pasquier Flores and Rojas Vallecillo 2006). Again, environmental conditions affecting plant growth and production are suggested to be responsible for reported variations.

Appropriate management might be different if the objective is to maximize dry season production, when forage availability is generally limited. Based on their research in Goiás and Tocantins, Sobrinho and Nunes (1996) suggested that cutting during the 4–5-month dry season of the central Brazilian *Cerrado* stimulates regrowth of plants and leads to green leaves persisting until the start of the subsequent rainy season. For the Puntarenas province, Costa Rica, Lobo and Acuña (2004) recommend a standardization cut at the end of the rainy season to optimize dry season forage production.

Based on observations in cratylia's habitats (Figures 2C and 2D) and under managed conditions (Figure 3), cutting well established plants as close as possible to the ground will activate growing points at the soil surface level that will lead to an increased number of basal regrowth branches during the dry season. To the best of our knowledge, research in this regard has not been conducted, although several researchers have reported the number of sprouting branches in response to cutting (Maass 1996; Rodríguez and Guevara 2002; Lobo and Acuña 2004; Andersson et al. 2006).

In the Andean piedmont of the Colombian eastern plains, Plazas and Lascano (2005) found that in those cases where plants are not cut but browsed, a standardization cut should be performed after browsing to optimize forage production for the next use. Regrowth of edible leaf DM was only 29% of the whole plant as compared with 54% when plants were subjected to a standardization cut at 20 cm height.

Dry matter production

There is a considerable range of DM production reported in the literature (Table 2). This reflects the diversity of environmental conditions and trial arrangements, particularly planting density, at the study sites. In conclusion, DM yields of 10–20 t/ha/year can be obtained, with up to 40% of dry season yield. In the only trial where several Yapacaní morphotype accessions were tested, its productivity was much lower than that of the shrub morphotypes (Peters et al. 2009).

Seed production and seed quality

Daylength reduction is involved in the induction of flowering of cratylia (Andersson et al. 2006), as well as reduced water availability, since some authors report that flowering starts at the end of the rainy/onset of the dry season (Rincón Castillo et al. 2007; Matrangolo et al. 2018a; Pardo-Barbosa et al. 2021). As is characteristic of undomesticated species, flowering and seed setting are asynchronous and despite a previous standardization cut extend over several months after the end of the rainy season (Argel et al. 2001). Consequently, seed (pod) harvesting is a continuing manual operation during part of the dry season. First-year seed production is reported to be lower than in subsequent years (Matrangolo et al. 2018a; Pardo-Barbosa et al. 2021). Mesén Villalobos and Sánchez Ledezma (2008) found that seed yields

Table 1. Overview of cutting frequency of *Cratylia argentea* for maximization of dry matter production for selected countries and regions.

Country, region/site	Study	Results, observations	Reference
Colombia, Antioquia (Bajo Cauca)	Optimum frequency (and 3 cutting heights)	90 days better than 45 or 60 days	Santana and Medina (2005)
Costa Rica, Puntarenas (Esparza)	Optimum frequency (and 3 cutting heights)	90 days better than 60 days (but somewhat lower quality)	Lobo and Acuña (2004)
Costa Rica, San José (Upala)	Optimum frequency in rainy and dry season	75 days better than 60 days; no season effect	López-Herrera and Briceño-Arguedas (2016)
Honduras, Comayagua	Optimum frequency	80 days better than 40 or 60 days	Dicta (2002)
Mexico, Veracruz (Isla)	Optimum frequency	120 days better than 60 or 90 days	Enríquez Quiroz et al. (2003)
Mexico, Veracruz (Tlapacoyan)	Optimum frequency in in 3 seasons (wet, winter and dry; 4 accessions)	6, 9, 12 and 15 weeks tested; overall no statistical differences	Valles-de la Mora et al. (2014)
Nicaragua, Managua	Optimum frequency (and 3 cutting heights)	16 weeks better than 8 or 12 weeks	Reyes Sánchez et al. (2007)
Peru, Ucayali (Pucallpa)	Optimum regrowth age in rainy and dry season	30 days better than 10, 20 or 40 days; no difference between rainy and dry season	Medina Dávila (2021)
Venezuela, Barinas (Pedraza)	Optimum frequency (and 2 cutting heights)	90 days better than 30 or 60 days	Lugo-Soto et al. (2009)

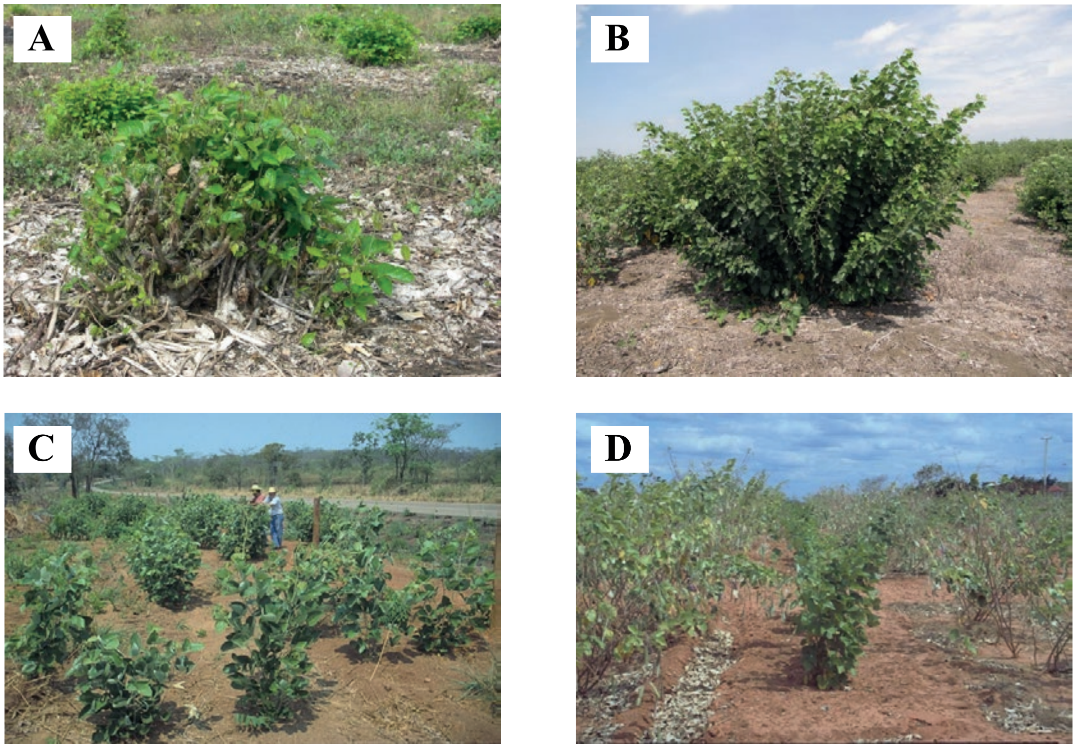

Figure 3. Management of *Cratylia argentea*. (A) Initial regrowth from basal buds after cutting of 7-yr old plants, CIAT-Quilichao, Colombia (Photograph: R. Schultze-Kraft); (B) Approx. 9-mo regrowth from basal buds, CIAT-Quilichao, Colombia (Photograph: A. Ciprián, CIAT); (C) Dry-season regrowth of shrub morphotype from below-ground buds after vegetation cutting and soil surface scraping by a bulldozer in Mato Grosso, Brazil (Photograph: R. Schultze-Kraft); (D) Dry season performance of 20-mo old plants in Anzoátegui, Venezuela: lateral rows are uncut, but still retaining leaves; central row is 4-mo old dry season regrowth. (Photograph: R. Schultze-Kraft)

(kg/ha) increased from 120 in year 1 to a peak of 2,450 in year 4 and then dropped to 830 in year 7 during a 7-yr on-farm study in San José Province, Costa Rica, showing the dynamics of seed production and the high yields that can be obtained.

The seed production potential of cratylia is high (Table 3), but yields are influenced by environment, planting density and management. Two guideline publications with a focus on agronomy, phenology, crop management and harvest to post-harvest management in Colombia offer comprehensive information and recommendations for artisanal seed production (Argel et al. 2003; Pardo-Barbosa et al. 2021), while overviews of seed production aspects in Brazil were provided by Ramos et al. (2003) and Matrangolo et al. (2018a).

When seed production of forage plants is difficult, vegetative propagation is often seen as an alternative. Pizarro et al. (1996) reported that for cratylia only 1% of vegetative-propagation trials using cuttings were successful, whereas experiences of Matrangolo et al. (2018a) with cuttings and tissue culture were positive. Tissue culture of cratylia was also successful in China (Li Zhiying et al. 2007).

Declining seed viability of cratylia is a major issue for dissemination. If seed longevity is to be ensured in the tropics, seeds must be stored under low temperature and low relative humidity (Table 4). In Cochabamba city, Bolivia (2,560 masl elevation and 16 °C mean temperature), storage under ambient conditions did not affect seed quality, while in the humid tropical lowlands of Cochabamba department, seed viability declined within <1 year (Gutiérrez 2010). Ramos et al. (2003) considered cratylia seeds to be orthodox, i.e., their desiccation does not affect their viability. However, Montoya Bárcenas et al. (2009) found that a seed moisture content <8% reduces germination, suggesting some recalcitrant behavior.

Biotic constraints

To date, no serious biotic constraints have been reported for cratylia. Among pests, leaf cutting ants, mainly *Atta* species, were registered in Brazil (Sobrinho and Nunes

Table 2. Overview of selected dry matter yields of *Cratylia argentea* reported for different countries and locations within countries.

Country, region/site	Study objective	Yield mean/range[1,2]	Observations	Reference
Bolivia, Cochabamba (humid low-land tropics)	Forage production potential at 3 locations (farms)	10.7	Veranera; mean of 3 locations; 7 mo after sowing; 10,000 plants/ha; leaf:stem (L/S) ratio: 2.34	CIF (2009)
Brazil, Minas Gerais (Zona da Mata)	Forage production potential	14.3	Accession CNPGL-119; 6-mo regrowth; 13,000 plants/ha	Xavier et al. (1990)
Brazil, Federal District	Forage production potential of 11 accessions	0.5–2.1	12-mo regrowth; L/S ratio: 1.4–3.1; 2,500 plants/ha	Pizarro et al. (1996)
Brazil, Minas Gerais (Central)	Phytomass production potential	Green matter: 72.5	Cumulative yield of 14 months (4 cuts with 3–4-mo interval); 73% leaf; 20,000 plants/ha	Matrangolo et al. (2013)
Brazil, Minas Gerais (Central)	General information on cratylia based on regional research experiences	39 (leaf DM)	Cumulative yield of 18 cuts in a total of 56 months; 6,300–7,500 plants/ha	Matrangolo et al. (2018a)
Colombia, Cauca (CIAT-Quilichao)	Forage production potential within the early cratylia collection	85–272 g DM/plant	Single-row evaluations; range of 11 accessions; means of two 3-mo regrowth cuts	Maass (1996)
Colombia, Antioquia (Bajo Cauca)	Forage production as influenced by cutting management	2.6 (digestible DM)	9-mo cumulative yield; mean of best cutting management; 10,000 pl/ha	Santana and Medina (2005)
Colombia, Meta (Andean piedmont)	On-farm evaluation of forage potential in wet and dry season	Wet: 3.34 Dry: 0.59	Veranera; 1-yr yield, means of 10 farms; 10,000 plants/ha; L/S ratio wet season: 1.9; dry season: 1.1	Plazas and Lascano (2005)
Colombia, Cauca (CIAT-Quilichao)	Forage production of a 38-accession collection in wet and dry season	g DM/plant Wet: 190–382 Dry: 124–262	Single rows; accession ranges, means of 2 cuts each in wet and dry season; 8-week regrowth	Andersson et al. (2006)
Colombia, Caquetá (Amazon piedmont)	Forage production potential in 2 topographies, rolling hills (R) and flat (F)	g DM/plant R: 3,078 F: 883	Total of four 3-month yields; L/S ratio: 1.8 (R) and 1.4 (F)	Suárez et al. (2008)
Colombia, Cauca (CIAT-Quilichao)	Forage production of 11 Yapacaní and 6 shrub morphotype accessions in wet and dry season	g DM/plant Yapacaní Wet: 99; Dry: 75 Shrub Wet: 246; Dry: 284	Means of accessions and three 8-week regrowth cuts in each season	Peters et al. (2009)
Colombia, Meta (Andean piedmont)	Forage production of 5 selected accessions	14.6	80-day yields; mean of accessions; 64% leaf; 10,000 plants/ha	Corpoica (2017)
Colombia, Casanare (Yopal)	Forage production on degraded soil	7.86	Total of five 45-day interval cuts; mean L/S ratio 2.91; 10,000 plants/ha	Navas Panadero et al. (2020)

Continue

Country, region/site	Study objective	Yield mean/range[1,2]	Observations	Reference
Costa Rica, Alajuela (Atenas)	Forage production of an 11-accession collection in wet and dry season	Edible DM (g/plant) Wet: 110–190	Edible DM (leaf and thin stems); single rows; accession ranges, means of five 8-wk and four 12-wk cuts in wet and dry season, respectively	Argel (1996)
Costa Rica, Alajuela (Atenas)	Forage production of CIAT 18516 as affected by planting density	3.7	Yield per cut; 8-week regrowth rainy season, 12-week regrowth dry season; 20,000 plants/ha	Argel et al. (2001)
Costa Rica, Puntarenas (Esparza)	Forage production of Veraniega as influenced by cutting management	7.4	Mean of eight 90-d regrowth cuts at 90 cm height; 28% of total yield in dry season; 20,000 plants/ha	Lobo and Acuña (2004)
Costa Rica, San José (Upala)	Forage production of Veraniega as influenced by season and regrowth age	g DM/plant Wet: 272 Dry: 241	90-day cutting interval	López-Herrera and Briceño-Arguedas (2016)
Mexico, Veracruz (Isla)	Forage production as influenced by cutting management	11.3	Yield per year (three 120-d regrowth cuts); 61% leaf; 20,000 plants/ha	Enríquez Quiroz et al. (2003)
Mexico, Veracruz (Tlapacoyan)	Forage production of 4 accessions as influenced by cutting frequency and season	8.0	Mean of accessions and cutting frequencies; yield per year; seasonal contribution: wet, 33%; winter, 22%; dry, 45%; 10,000 plants/ha	Valles-de la Mora et al. (2014)
Nicaragua, Managua	Forage production of accession CIAT 18668 as influenced by planting density and cutting height	18.1	Yield per year; 33% of total yield in dry season; 60 cm cutting height; 40,000 plants/ha	Pasquier Flores and Rojas Vallecillo (2006)
Nicaragua, Managua	Forage production of Veranera as influenced by planting density and cutting interval	18.2	Yield per year; 69% edible forage; 25–35% of total yield in dry season; 16-wk cutting interval; 40,000 plants/ha	Reyes Sánchez et al. (2007)
Peru, San Martín (Tarapoto)	Forage production of accession CIAT 18516 in wet and dry season	Wet: 5.6 Dry: 4.7	Yield of 12-week regrowth; planting density not provided	Rojas Reátegui (2002)
Venezuela. Anzoátegui (El Tigre)	Forage production of a 10-accession collection in wet and dry season	Wet: 1.94 Dry: 0.76	Yields per cut; leaf only; collection mean of 2 (wet season) and 1 (dry season) 8-wk regrowth cuts/ year (2 years); 20,000 plants/ha	Rodríguez and Guevara (2002)
Venezuela, Barinas (Pedraza)	Forage production as influenced by cutting management	g DM/plant 107.3	90-day yield; mean of 2 cutting heights; 5,102 plants/ha	Lugo-Soto et al. (2009)

[1]All yield data are in t DM/ha if not indicated otherwise; [2]Calculation of per-hectare yields based on per-plant measurements (if planting density data were available).

Table 3. Overview of seed production of *Cratylia argentea* reported for different countries and locations within countries.

Country, region/site	Variety/accession	Plant density (plants /ha)	Mean/range (kg/ha)[1]	Observations	Reference
Costa Rica, Alajuela (Atenas)	Veraniega	10,000	500–700	Plants 3 years old; harvests during 2–3 months	Argel et al. (2001)
Colombia, Cauca (CIAT-Quilichao)	CIAT 18516 CIAT 18668	1,600	596	Mean of 2 accessions: 2 harvests in 1 year	Maass (1996)
Colombia, Meta (Andean piedmont)	Veranera	6,666	313	Mean of 7 farms	Plazas and Lascano (2005)
Colombia, Meta (Andean piedmont)	Veranera	2,500	250	Plants >2 years old	Rincón Castillo et al. (2007)
Colombia, Cauca (CIAT-Quilichao)	CIAT 18516 CIAT 18668	1,600	372	Mean of 2 accessions: 2 harvests in 1 year	Lascano et al. (2002)
Colombia, Cauca (CIAT-Quilichao)	Collection of 38 accessions		g/plant Mean: 179 Range: 13–757	1 harvest period; 14 months old plants in single-row plots	Andersson et al. (2006)
Colombia, Meta (Altillanura and Andean piedmont)	3 accessions	5,000	623–816	Mean yields at 3 sites; 1 harvest period	Corpoica (2017)
Brazil, Minas Gerais (Central)	Unidentified accession	12,000	1,409	1 year old plants; harvest during 1 month (October)	Miranda et al. (2011)
Brazil, Minas Gerais (Central)	Unidentified accession		g/plant Mean: 530 Range: 20–2,460	12 plants >3-yr old; harvest during 1 month (October)	Matrangolo et al. (2018a)
Costa Rica, San José	Veraniega	10,000	Year 1: 120 Year 2: 600 Year 3: 2,020 Year 4: 2,450 Year 5: 1,890 Year 6: 1,360 Year 7: 830	7-yr study; daily seed harvests during 2 months	Mesén Villalobos and Sánchez Ledezma (2008)
Honduras, Comayagua	Unidentified accession	10,000	800		Dicta (2002)

[1]Calculation of per-hectare yields based on per-plant measurements (if planting density data were available).

Table 4. Overview of germination of *Cratylia argentea* seeds following storage under ambient (A) and controlled (C) storage conditions.

Country, region	Germination at harvest	Germination after storage		Observations	Reference
		A	C		
Costa Rica, Alajuela (Atenas)	80%	50%		24 months storage; A: 24 °C, 70% RH[1]	Argel et al. (2001)
Brazil, Federal District	90%	33%	91%	Mean of 2 accessions (CIAT 18516 and CIAT 18668); 24 months storage; C: 5–10 °C, 5–10% RH	Ramos et al. (2003)
Brazil, Minas Gerais (Central)	84%	50% and <10%	84%	16 and 18–26 months storage, respectively; C: refrigerator	Matrangolo et al. (2018a)

[1]RH – relative humidity.

1996; Matrangolo et al. 2018b), Colombia (Lascano et al. 2002) and Venezuela (Navarro Díaz et al. 2004); plants, however, recover readily. In Colombia, establishment can be affected by beetle larvae of the Melolonthidae family (Maass 1996). In seed production plots in Brazil, the wasp, *Podagrion* sp. (Hymenoptera: Torymidae) and bruchids have been reported as insect pests (Matrangolo et al. 2018a) and in Colombia the bean pod borer, *Maruca testulalis* (Pardo-Barbosa et al. 2021). At the experimental station level, Andersson et al. (2006) recorded a nematode problem at CIAT-Quilichao, considering it of minor, site-specific importance.

Regarding diseases, Mesén Villalobos and Sánchez Ledezma (2008) registered 3% plant loss in the fifth year in a 7-yr experiment in Costa Rica due to stem diseases, possibly caused by fungi of the genera *Nectria*, *Phytophthora* and *Graphium*; they also observed *Penicillium* and *Aspergillus* species on cratylia seeds possibly related to poor storage conditions. In Colombia, the fungi *Phoma* and *Cladosporium* have been associated with the occasional occurrence of empty pods (Pardo-Barbosa et al. 2021).

Multipurpose uses

Several authors have suggested that cratylia, being an N-fixing legume, has potentially other uses in addition to providing forage for livestock, i.e., particularly for reclamation of degraded soils, as mulch and green manure in mixed production systems, and/or providing fuel wood (Xavier et al. 1995; Matrangolo et al. 2013, 2018a).

Soil improvement

In Colombia, Parra and Gómez-Carabalí (2000) reported from a medium-elevation site (Corpopalo, Santander de Quilichao, Cauca; 1,075 masl) that, after 16 weeks, cratylia presented a faster litter degradation and N release than *Codariocalyx* and flemingia. In contrast, Cobo et al. (2002) found at higher elevation (Pescador, Cauca department; 1,500 masl) that decomposition and nutrient release of 6-months old cratylia foliage were slow. Also, in Colombia (Casanare department), Navas Panadero et al. (2020) showed that, after 14 months of a cratylia protein bank established on an Entisol soil (considered "degraded" after 2 years of intensive experimental applications of pesticides), soil organic matter (SOM), soil organic carbon and soil macrofauna had increased. In the Central Pacific region of Costa Rica, Lobo and Acuña (2004) observed that SOM under a pure stand of cratylia increased in 3 years from 3.1% to 4.1%.

In the *Central* region of Minas Gerais, Marques et al. (2014) concluded from a soil restoration study that cratylia has potential for revegetating gully-eroded sites. In revegetation pot studies using soil contaminated with toxic iron ore sludge after the 2015 Mariana dam disaster in Minas Gerais, outstanding performance of cratylia, along with *Sophora tomentosa*, was reported among the 5 legume species tested (Costa et al. 2018).

Integrated production systems

The potential of cratylia for integrated crop/tree-livestock production systems has been suggested by several authors (Navarro Díaz et al. 2004; Matrangolo et al. 2016; Valles-de la Mora et al. 2014) and documented from studies conducted in Brazil and Colombia. For the *Central* region of Minas Gerais, Miranda et al. (2011) and Gomes et al. (2015) showed the potential of cratylia as green manure in alley-cropping systems. From the same region, Matrangolo et al. (2018a) reported that in a total of 18 cuts in 56 months, cratylia leaf biomass applied as green manure to the soil contributed (kg/ha): 1,337 N; 97.7 P; 715.4 K; 672.4 Ca; 134.9 Mg; and 84 S. From a 2.5-year agro-silvo-pastoral trial conducted in Mato Grosso do Sul, Gama et al. (2014) concluded that cratylia was less suitable than leucaena for a silvopastoral system in association with Massai grass (*Megathyrsus maximus*, formerly *Panicum maximum*). In the Andean piedmont region of Colombia, farmers established cratylia protein banks via intercropping with maize or vegetables to reduce the weeding costs for planting the legume (Plazas and Lascano 2005).

Ecological aspects

From a several-year survey of the fauna visiting native cratylia in central Minas Gerais, Matrangolo et al. (2018b) concluded that, mainly due to the large number of potentially beneficial arthropods, cratylia should be considered a "biodiversity island" in the region. The study emphasized arthropods diversity on cratylia, where bees accounted for 15.5%, biological control agents for 24%, and phytophagous insects feeding on green plants for 60.5% of the arthropods present. The potential agroecological implications of these observations were discussed by Matrangolo et al. (2018a, 2019).

Strengths and weaknesses

Strengths and weaknesses of cratylia based on the review of the literature cited are:

Strengths

- Adaptation to acid, infertile soils with high levels of aluminum
- Adaptation to low-phosphorus soils but responsive to fertilizer application
- Rhizobium promiscuity
- Tolerance of drought
- Tolerance of fire
- Absence of major biotic constraints
- Vigorous regrowth after cutting
- High DM yield potential
- High seed production potential
- Multi-use potential (forage, soil improvement, fuel wood)
- Suitability for integrated production systems

Weaknesses

- Labor requirements for establishment and forage harvest
- Slow establishment
- Rapidly declining seed quality
- Need of manual seed harvest over an extended period

Research suggestions

The proceedings of the Cratylia workshop held in July 1995 in Brasília concluded with research recommendations on (1) taxonomy, biogeography and genetic resources and (2) agronomic evaluation (Pizarro and Coradin 1996). Many of the suggested studies were carried out during the past 30 years, but some recommendations remain, and new research needs were identified in the meantime. Among the range of topics that result from this review and require research actions, we consider the following as priority:

Genetic resources. A consolidated inventory of germplasm accessions along with their passport data and information on actual availability of viable seed is required as a basis for further collecting. Available genetic diversity of cratylia needs to be increased by collecting germplasm in areas so far neglected (such as Peru and Bolivia) as well as in areas of higher elevations and higher latitudes (for exploration of potential adaptation to low temperatures).

Genetics. Studies are needed to clarify the self-incompatibility of cratylia and possible environmental influences on the breeding system, as well as to determine possible genetic shift within an accession as a consequence of repeated multiplication cycles. Such studies are important to optimize seed multiplication protocols in genebanks where the original genetic purity of an accession is conserved or for consideration of bulking seeds of mixed accessions for use.

Adaptation. Research in Sub-Saharan Africa and Southeast Asia in locations with low fertility soils and well-defined dry seasons to clarify why cratylia performed poorly in those few cases where the species was included in evaluation trials. Multilocational trials for cut and carry systems using high-quality seed could be considered once agro-ecological niches have been identified.

Agronomy. While overcoming the drawback of slow establishment should receive the highest research attention though screening the whole range of available genetic resources for speed of early plant growth, including Yapacaní morphotype accessions, which could lead to subsequent breeding opportunities for this trait, other areas include:

- Rhizobiological research to quantify the N fixation potential of cratylia with cowpea rhizobia and continue the search for more effective *Rhizobium*/*Bradyrhizobium* strains.

- Studies to further clarify the need for liming of this acid soil-adapted legume as well as its responsiveness to fertilizer.

- Cutting management studies to activate regrowth meristems at soil surface level for optimizing dry season regrowth and production.

Utilization. Studies on the use of cratylia for purposes other than the provision of forage are scarce and merit research attention, including its potential for soil improvement and role in production systems where forage/livestock is integrated with crops and/or trees (agropastoral, silvopastoral systems).

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(Note of the editors: All hyperlinks were verified 16 May 2024).

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