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Theobroma: CONSERVATION STATUS OF A THREATENED GENUS

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Theobroma species occur in Amazon rainforest areas, threatened by devastation and overexploitation. From the 22 species described, only half is collected and deposited in germplasm banks, some with few accessions. Brazil and Colombia are the main centers of diversity, with a great number of endemic species. Brazil presents species from all sections excepting the *Andropetalum* ones, which presents only one species, *T. mammosum*, endemic to Central America. There is no precise information about the conservation status of the genus. Recently, important crops have received breeding contribution from wild species. Genes related to disease and insect resistance, and to biochemical compounds have been introgressed from wild to cultivated species. The restriction of the natural occurrence of the *Theobroma* species to the Amazon region, the occurrence of strong incompatibility barriers for interspecific hybridization and the neglect of breeders in collecting and studying wild species make the *Theobroma* a threatened genus. In addition to that, *T. cirmolinae* have been cited as under extinction risk in the IUCN (International Union for Conservation of Nature) red list. It is necessary to develop and disseminate up-to-date information about threatened and endangered species of the genus *Theobroma*. This kind of information is essential for the management of these important natural and genetic resources. The objective of this work is to review the conservation status of the genus *Theobroma*. Here we present a partial list of *Theobroma* genetic resources and an empirical extinction risk rank. Most species were classified as threatened indicating that *Theobroma* is really a genus in great risk.

Key words: *Theobroma*, ecology, conservation, extinction, genetic resources

***Theobroma*: Status da conservação de um gênero ameaçado.** Espécies de *Theobroma* ocorrem em áreas de Floresta Amazônica ameaçadas por devastação e exploração excessiva. Das 22 espécies descritas, só metade está reunida e depositada em bancos de germoplasma, algumas com pequeno número de acessos. O Brasil e a Colômbia são os principais centros de diversidade, com um grande número de espécies endêmicas. O Brasil apresenta espécies de todas as seções com exceção da *Andropetalum* que apresenta só uma espécie, *T. mammosum*, endêmica à América Central. Não há nenhuma informação precisa sobre o estado de conservação do gênero. Recentemente, importantes espécies cultivadas receberam contribuição de espécies selvagens. Genes relacionados à resistência a doenças e insetos e para componentes bioquímicos foram introgredidos de espécies silvestres em espécies cultivadas. A restrição da ocorrência natural das espécies de *Theobroma* à Região Amazônica, a ocorrência de fortes barreiras de incompatibilidade para hibridação interespecífica e a dificuldade dos melhoristas em coletar e estudar espécies silvestres faz do *Theobroma* um gênero ameaçado. Além disso, *T. cirmolinae* tem sido citada como em risco de extinção na lista vermelha da IUCN (International Union for Conservation of Nature). É necessário desenvolver e disseminar informações atualizadas sobre espécies ameaçadas e em extinção do gênero *Theobroma*. Este tipo de informação é essencial para o manejo destes importantes recursos naturais e genéticos. O objetivo deste trabalho foi revisar o estado de conservação do gênero *Theobroma*. Aqui é apresentada uma lista parcial de recursos genéticos de *Theobroma* e um ranking empírico de risco de extinção. A maioria das espécies foi classificada como ameaçada, indicando que *Theobroma* é realmente um gênero em grande risco.

Palavras-chave: *Theobroma*, conservação, ecologia, extinção, recursos genéticos.

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Introduction

The Amazon region has suffered a series of anthropogenic impacts that have resulted in great loss of biodiversity (Vieira et al., 2008). Many researchers have cited an extinction crisis as a result of alterations in natural habitats reaching alarming proportions (Rodrigues, 2006), and an accelerated biodiversity deterioration is expected in the future. There are two reasons for the world to be concerned about this looming, irreversible loss. The first is instrumental: bio-diversity conservation provides specific economic services or avoids specific risks. The second is intrinsic: the people attach aesthetic and spiritual values to it, or because their values demand it (Kozlowski et al., 2009).

Theobroma is a genus for which the conservation concerns did not arrive to non-explored species. Accessions of wild species have not been collected and introduced in germplasm collections for a long time and the extent of genetic diversity within wild species is not well known, simply because those accessions available have not been studied. As a consequence, none wild species was chosen as a potential target to introgressive hybridization based on knowledge of its agronomic potential.

The reduction of the *Theobroma* gene pool appears to be irreversible, since its natural occurrence is restricted to tropical rain forests, which are threatened by many anthropogenic causes (Vieira et al., 2008). According to Prance (1991), genetic implications of the loss of tropical rainforests lead to the loss of wild relatives of many species of proven economic value such as rubber, coffee and cacao upon which the future of the crop may depend and species which have not yet been used but which certainly have economic potential as medicine (Shanley and Luz, 2003), foods (Shanley et al., 2010), fibers (Oliveira et al., 1991) and other useful products.

The main goal of our work is highlight the current conservation status of the genus *Theobroma*, which is suitable for such an evaluation, because no study has focused on this aspect. Most of the published studies only emphasize cultivated species, *T. cacao* and *T. grandiflorum*, in spite of the recognized importance of the wild species in the genetic improvement of cultivated species. Here we present an empirical extinction risk, for all species, as suggested in Kotiaho et al. (2005), based on literature data and personal information and a classification of the species as for the extinction risk.

Methods

We used the Directorio de Colecciones de Germoplasma em América Latina y el Caribe catalog (Knudsen 2000), contact by e-mail and publications to elaborate a partial list of the genetic wild resources of the *Theobroma* genus collected and conserved at germplasm collections at some countries from Latin America (Table 1).

Based on the IUCN Red List criteria and Kotiaho's approach (Kotiaho et al 2005), with some adaptations, we classified *Theobroma* species as threatened, those which could be assigned as vulnerable (VU), endangered (EN), or critically endangered (CR), and as non-threatened (NT) all other ones. From that we created an adapted red list classification (ARLC).

We also developed an Ecological Extinction Risk Rank (EERR), as obtained by Kotiaho et al (2005), adopting four criteria: a) dispersion of the species (ecological component); b) fruit and seed production (botanical component); c) collected and deposited germplasm (genetic component), and d) pdf citation online (information component). Based on that we can define which species are most threatened by extinction risk, which of them need to be included in a conservation priority list and which can be done for its conservation. Based on EERR we considered as NT species, those whose EERR was equal to or less than 0.2, VU those with EERR from 0.21 to 0.49; EN those with EERR from 0.50 to 0.69 and CR those with EERR higher than 0.70 and classified them based on Red List *strictu sensu* concepts (Kotiaho et al 2005).

Results and Discussion

Botanical features

The most comprehensive taxonomic treatment of the genus was conducted by Cuatrecasas (1964). Within the genus six sections are recognized: *Andropetalum*, *Glossopetallum*, *Oreanthes*, *Rhitydocarpus*, *Telmatocarpus* and *Theobroma*, that comprise 22 species of which only two (*T. cacao* and *T. grandiflorum*), are economically exploited. Recently,

T. cacao was reintroduced at the *Malvaceae* family based on molecular analysis (Alverson et al., 1999). The genus is centered in South America Amazonian region and is spread through the South of Mexico. Few endemic species are cited, including *T. canumanense* to Brazil, *T. mammosum* to Costa Rica and *T. cirmolinae* and *T. chocoense* to Colombia. This botanical classification has been confirmed by phylogeny based on molecular data (Figueira et al., 1994; Silva and Figueira, 2005; Whitlock and Baum, 1999; Borrone et al., 2007). The genus presents great diversity in morphological traits in most of its external features (Santos et al., 2011). Wild relatives of cacao are perennial species that share growth pattern from small trees with small canopy, as *T. speciosum*, to tall trees with large canopy, as *T. bicolor*. The species of *Theobroma* are all rather episodic in their distribution and rarely become dominant of the local vegetation. The majority of these species are found in humid forests growing only in the presence of shade and none is found in dry forest regions.

Conservation status

Brazil is the only cocoa producing country which possesses two catalogued and published list of *Theobroma* collections with many accessions of wild *Theobroma* and *Herrania* species. Both are located in Belém, Pará, Brazil, the first nominated as Basil George David Bartley collection (CEPLAC) and the second as George O'Neil Addison Collection (EMBRAPA). Historically few accessions of wild species have been introduced in those collections, compared to *T. cacao*, as occur with germplasm collection of other genera, like *Trifolium* (Morris and Greene 2001), *Dioscorea* (Malaurie et al., 1993), *Sorghum* (Eberhart et al., 1997), and many others.

The conservation of the *Theobroma* genetic resources in germplasm collections is concentrated,

Table 1. Number of individuals of wild species from the *Theobroma* genus in germplasm collections

Section	Species	Brazil	C. Rica	Ecuador	Honduras	Trinidad	Africa
Andropetalum	*T. mammosum*	none	10	>10	none	none	NI
Glossopetalum	*T. angustifollium*	none	9	>10	none	none	NI
Glossopetalum	*T. canumanense*	none	none	none	none	none	NI
Glossopetalum	*T. chocoense*	none	none	none	none	none	NI
Glossopetalum	*T. cirmolinae*	none	none	none	none	none	NI
Glossopetalum	*T. grandiflorum*	>1000	NI	none	none	1	NI
Glossopetalum	*T. hylaeum*	none	none	none	none	none	NI
Glossopetalum	*T. nemorale*	none	none	none	none	6	NI
Glossopetalum	*T. obovatum*	>100	none	none	none	none	NI
Glossopetalum	*T. simiarum*	none	10	none	none	none	NI
Glossopetalum	*T.sinuosum*	none	none	none	none	none	NI
Glossopetalum	*T. stipulatum*	none	none	none	none	none	NI
Glossopetalum	*T. subincanum*	>100	5	none	none	none	NI
Oreanthes	*T.bernouilli*	none	none	none	none	none	NI
Oreanthes	*T. glaucum*	3	none	none	none	none	NI
Oreanthes	*T. speciosum*	>200	16	none	none	27	NI
Oreanthes	*T. sylvestre*	15	none	none	none	none	NI
Oreanthes	*T. velutinum*	none	none	none	none	none	NI
Rhytidocarpus	*T. bicolor*	>200	1	>10	>10	none	NI
Telmatocarpus	*T. gileri*	none	1	none	none	none	NI
Telmatocarpus	*T. microcarpum*	20	7	none	none	12	NI
Theobroma	*T. cacao*	>1000	>1000	none	none	>1000	>1000

Source: Knudsen 2000, Silva et al 2004 and personal informations; NI=no information

mainly in Brazil, Costa Rica and Trinidad and few introductions have been done in Africa (Knight and Rogers, 1955; Aikpokpodion, 2003). These countries harbor the greatest number of genetic accessions deposited at germplasm banks. None of those collections have accessions of all *Theobroma* species and most species are not represented in any collection. The negligence of the countless botanical expeditions with wild species is outstanding which represents a great risk to the conservation within the genus. Data showed here present great gaps of information, which can be replaced with future collaborative efforts, but this work can serve as a start to the development of a global *Theobroma* germplasm databank.

Reduction of genetic vulnerability

To reduce the genetic vulnerability it is necessary to know about many features of a taxon like its reproductive biology, risk and threats of extinction, distribution, local abundance or rarity, history and age of the population and environmental features. Kozlowski (2008), pointed out the conservation paradox which can be summarized as should we conserve more threatened species or the ones that can be explored.

The data in Table 2 show that most non-threatened species are those with great number of accessions deposited at germplasm collections. *T. cacao* and *T. grandiflorum* present the smallest EERR (0.20 and 0.28, respectively), which can be explained by the greatest number of preserved accessions and the dispersion of cultivated areas around the world. *T. bicolor*, although not worldwide cultivated, is a widely dispersed species and is often used for juice and beverage production. *T. sylvestre* and *T. canumanense* are the only species of restricted occurrence to Brazil (Cuatrecasas, 1964) and the last is also the only one

Table 2. List of species, extinction risk rank (ERR), domestication status (DS), the adapted red list classification (ARLC), in increasing order of the extinction risk and red list classification *strictu sensu* (RL)

Section	Species	DS	ERR	ARLC[b]	RL
Theobroma	*T. cacao*	cultivated	0.20	NT	NT
Glossopetalum	*T. grandiflorum*	Semi-cultivated	0.28	NT	VU
Rhytidocarpus	*T. bicolor*	Wild	0.28	NT	VU
Glossopetalum	*T. subincanum*	Wild	0.44	NT	VU
Glossopetalum	*T. obovatum*	Wild	0.52	NT	EN
Oreanthes	*T. speciosum*	Wild	0.52	NT	EN
Oreanthes	*T. sylvestre*	Wild	0.60	NT	EN
Telmatocarpus	*T. microcarpum*	Wild	0.60	NT	EN
Glossopetalum	*T. angustifollium*	Wild	0.68	T	EN
Glossopetalum	*T. chocoense*	Wild	0.68	T	EN
Glossopetalum	*T. stipulatum*	Wild	0.68	T	EN
Glossopetalum	*T. simiarum*	Wild	0.72	T	CR
Oreanthes	*T.bernouilli*	Wild	0.72	T	CR
Oreanthes	*T. glaucum*	Wild	0.72	T	CR
Telmatocarpus	*T. gileri*	Wild	0.72	T	CR
Andropetalum	*T. mammosum*	Wild	0.76	T	CR
Glossopetalum	*T. cirmolinae*	Wild	0.76	T	CR
Glossopetalum	*T. nemorale*	Wild	0.76	T	CR
Glossopetalum	*T.sinuosum*	Wild	0.76	T	CR
Oreanthes	*T. velutinum*	Wild	0.76	T	CR
Glossopetalum	*T. canumanense*	Wild	0.80	T	CR
Glossopetalum	*T. hylaeum*	Wild	0.80	T	CR

[b]NT= non-threatened, T= threatened;

without any accession introduced in germplasm collections. For some species like *T. sylvestre* and *T. angustifollium*, the EERR is likely overestimated, because of the lack of information about the distribution of them in some germplasm collections, like the one from Trinidad. According to the Red List concepts, 11 out of the 14 species considered theatened were classified as critically endangered, including *T. glaucum* and *T. canumanense*, two Brazilian species. According to the criteria assumed here only *T. cacao* is totally out of extinction risk.

The rank certainly is over or underestimated to some species and the main cause for that is the lack of information. But the results are consistent with real situation of the *Theobroma* genetic resources, especially for wild species, and allow us to plan management strategies and conservation efforts. The cacao research community needs to be alert about the risks of erosion on genetic resources available in the genus *Theobroma*. The environmental impacts of the Amazonia occupation are determinant to the great loss of biodiversity which includes wild *Theobroma* species that are not preserved at germplasm collections.

In the tropics, where extinction rates of species are high because of land-use changes, setting conservation priorities is critical (Kjaer et al., 2004). One critical strategy is to identify biodiversity hotspots where exceptional concentrations of endemic species are undergoing exceptional loss of habitat, which can help the definition of conservation efforts. Nowadays, as many as 44% of all species of vascular plants and 35% of all species in four vertebrate groups are confined to 25 hotspots comprising only 1.4% of the land surface of the Earth (Myers et al., 2000).

Potentiality of genetic resources

Few reports have demonstrated the existence of divergent traits into wild species that do not exist in *T. cacao*. Disease resistance was assessed to few species and accessions, as for *Ceratocystis* wilt (Delgado and Echandi, 1965) and witches' broom disease (Nunes et al., 2002). Biochemical evaluations have showed outstanding differences between *T. cacao* and wild relatives regarding to fat content and composition (Carpenter et al., 1994), seed polyhenols (Griffiths, 1960) and seed lipid-protein synthesis capacity (Martini et al., 2008). Some species like *T. obovatum* and *T. subincanum* presents a great potential as a fruitful crop due to small size, beauty of the fruit and its very sweet pulp. *T. grandiflorum* cultivation have increased in traditional Brazilian cocoa growing regions due the high value of its pulp, which have a strong and distinct flavor, used for juice and a suite of other semi-transformed and industrialized products.

Wild species can harbor important genes which can be transferred to cultivated *Theobroma* species, but this important genetic resource have been neglected by researchers, specially because the difficult in obtain interspecific hybrids by conventional methods. The development of new techniques like genetic engineering, *in vitro* pollination and somatic hybridization can be used to overcome the strong interspecific incompatibilities barriers. According to Janick (1999), the exploitation of wild species as new crops presents many advantages like production diversification, improvement of diet and helps enhance development in rural areas by creating local, rural-based industries. However, these can not be done without government support and leadership.

Concluding Remarks

Wild *Theobroma* species need to be evaluated in its occurrence sites regarding to frequency, density, dominance, richness of species and population sizes to have enough data to develop and implement efficient conservation strategies. We also need to study geographic distribution to confirm if the dispersion mapped by Cuatrecasas (1964) remains.

Also, it is necessary that ecological and conservational aspects of the genus *Theobroma* become a priority to researchers in a way to minimize the potential risks of genetic erosion in the genus. Extinction of wild relatives of cultivated crops has been reported for a long time, increasing losses of genetic diversity and pointing out the necessity of conservation policies. Some gaps of information about species can be filled out starting from this work.

The conservation status of the *Theobroma* genus presented here is only an approximation and needs more information to be complete. The gaps must be filled out with researchers participation from all countries where wild germplasm is preserved. Although those gaps are relevant, we can observe that *Theobroma* is

really a threatened genus and efforts need to be done to collect, introduce, evaluate and use new wild species accessions. A global strategy to conserve *Theobroma* genetic resources also needs to be defined.

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