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Revaluation of the *Samaropsis mendesii* Rigby, 1972 from Paraná Basin lower Permian

Reavaliação de Samaropsis mendesii Rigby, 1972 do Permiano inferior da Bacia do Paraná

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Abstract

This paper suggests an emendation to the diagnosis of *Samaropsis mendesii* Rigby, 1972 (Rio Bonito Formation, Santa Catarina State, Paraná Basin) on the basis of which the *Samaropsis gigas* Marques-de-Souza et Iannuzzi 2007 comes to be considered a junior synonym of this species. Adding the specimens previously considered as *S. gigas* from the Rio Grande do Sul State, the stratigraphic range of *S. mendesii* is extended to the uppermost portion of the Itararé Group. Also, we provide a comparative analysis with the closest Indian species *Otofeista milleri* (Feistmantel) Pant et al. (1985) (Karharbari beds). The comparison of the *S. mendesii* with the Indian material pointed to a strong morphometric correspondence between both, highlighting the potentiality of the use of this seed form in stratigraphic correlations due to the peculiarity of the morphology and the abundance of these seeds in Cisuralian (Sakmarian-Artinskian) strata of Gondwana.

Keywords: Gondwanan seeds; Synonymy; *Samaropsis mendesii*; *Samaropsis gigas*; *Otofeista milleri*; Lower Permian.

Resumo

Este artigo sugere uma emenda à diagnose de *Samaropsis mendesii* (1972) (Formação Rio Bonito, Estado de Santa Catarina, Bacia do Paraná) e como resultado *Samaropsis gigas* Marques-de-Souza and Iannuzzi 2007 torna-se um sinônimo junior dessa espécie. Ao incluir espécimes previamente considerados como *S. gigas* provenientes do Rio Grande do Sul, a amplitude estratigráfica de *S. mendesii* passa a ser estendida até a porção mais superior do Grupo Itararé. Além disso, realiza-se uma análise comparativa com a espécie indiana de morfologia próxima, i.é *Otofeista milleri* (Feistmantel) Pant et al. (1985) (Camadas Karharbari). A comparação de *S. mendesii* com a espécie indiana apontou uma forte correspondência morfométrica entre elas, destacando o potencial de uso desse tipo de semente em correlações estratigráficas, devido à peculiar morfologia e a abundância do registro dessas em estratos do Cisuraliano (Sakmariano-Artinskiano) no Gondwana.

Palavras-chave: Sementes gondvânicas; Sinonímia; *Samaropsis mendesii*; *Samaropsis gigas*; *Otofeista milleri*; Permiano Inferior.

INTRODUCTION

Paleobotanical studies since the late nineteenth century and more intensely the early twentieth century have resulted in increased recognition of the diversity of Gondwanan seed shapes and sizes in fossil beds from countries like India (Zeiller, 1902; Surange and Lele, 1956; Pant and Nautiyal, 1960; Lele, 1962; Maithy, 1965; Lele, 1968; Pant et al., 1985), Australia (Walkom, 1921; Walkom, 1935), Argentina (Feruglio, 1946; Archangelsky and Cúneo, 1987; Gutierrez et al., 1992; Archangelsky, 1995; Archangelsky, 2000), Africa (Seward, 1917; Hoeg and Bose, 1960), and Brazil (White, 1908; Millan, 1965; Rigby, 1972; Millan, 1977; Millan, 1994; Bernardes-de-Oliveira et al., 2007; Marques-de-Souza and Iannuzzi, 2007; Marques-de-Souza and Iannuzzi, 2009). Among the pioneering works with seeds from Gondwana there are those developed by Feistmantel (1879, 1881, 1882) and Zeiller (1902) with species in India, by Seward (1917) about African seeds, and White (1908) referring to Brazilian species. However, we observe that many species erected until the first half of the twentieth century are not based on detailed descriptions and / or unique specimens, hindering their comparison with new occurrences and consequently in establishing links between species already described. In this sense, the revaluation of the species becomes an absolute necessity to ensure the appropriate comparison of the seeds to the existing species through new prospects and analyses. Hence, their diagnostic features need to be widely known, facilitating and giving more reliability to the comparative studies.

Therefore, this paper presents a comparative analysis of two species from different localities in the Paraná Basin (Lower Permian), viz. *Samaropsis mendesii* (Rigby, 1972 and *Samaropsis gigas* Marques-de-Souza and Iannuzzi, 2007). Later this material is compared with the Indian species *Otofeista milleri* (Feistmantel) Pant et al. (1985). This study analyzes the potential use of this species in stratigraphic studies given the peculiarity of the morphology of these Permian seeds.

MATERIAL AND METHODS

The type material of *Samaropsis gigas* and *S. mendesii* was reexamined, whereas for *Otofeista milleri*, a revision was made based on the information available in the original literature where this species was erected (i.e., Pant et al., 1985).

The single specimen of *Samaropsis mendesii* is preserved as an impression and is derived from the Joaquim Branco horizon (Horizon I of Mendes, 1952), in municipality of Lauro Muller, Santa Catarina State, southern Brazil. It was collected in the Irapuá bed, upper portion of the Siderópolis Member in the Rio Bonito Formation, Paraná Basin (Rigby, 1972). The holotype is deposited in the Palaeobotany Collection of the Environmental and Sedimentary Geology Department (GSA), University of São Paulo (USP), and identified by the acronym DGP 7.

Specimens of *Samaropsis gigas* are preserved as impressions and are recovered from the Morro do Papaléo outcrop, in municipality of Mariana Pimentel, Rio Grande do Sul State, southern Brazil. Stratigraphically, they occur in levels ranging from the uppermost portion of the Itararé Group to the third upper portion of the Rio Bonito Formation (Marques-de-Souza and Iannuzzi, 2007). The type material of *S. gigas* is deposited in the Palaeobotany Collection of the Museum of Paleontology, Department of Paleontology and Stratigraphy (DPE) of the Federal University of Rio Grande do Sul (UFRGS), and identified by the acronym MP-Pb.

The *Otofeista milleri* material is preserved as impressions / compressions and corresponds to a new combination proposed by Pant et al. (1985) for *Samaropsis milleri* (Feist.) Seward, 1917 based on new collections and the inclusion of morphological and anatomical features (i.e. cuticles features) in its diagnosis. The type material was recovered from Dhamni, southeast of Khaira, in the Karharbari beds of South Rewa Basin, India. Later, *S. milleri* had been recorded in Kuttung Series, Werrie Basin, Australia, by Walkom (1935), and in Congo, by Hoeg and Bose (1960). These last occurrences were considered as a "possible" synonyms of *Otofeista milleri* by Pant et al. (1985) and will be discussed later herein.

This study considered the following diagnostic features for comparative morphologic (= morphographic) analysis: i) the differentiation of the testa in endotesta, sclerotesta and sarcotesta; ii) the shape of the apical and basal regions of the seeds, reinterpreted based on the categories established for modern plants by Gonçalves and Lorenzi (2007) and Ferri et al. (2005); iii) the shape and surface of the nucellus (if smooth or striated); iv) the ratio between the widths of the testa and the nucellus; v) the presence or absence of a median ridge along the nucellus; vi) the presence or absence of sinus at one or both extremities of the seed. The material was observed and the measurements were taken using the stereomicroscope and the photos.

RESULTS AND DISCUSSIONS

GYMNOSPERMAE
Semina Incertae Sedis
Samaropsis mendesii Rigby, 1972 emend.
Figure 1

Synonymy

1948- *Samaropsis* sp. in Dolianiti, Bol. nº. 123, p. 35, Est. B.
1967- *Samaropsis milleri* (Feistm.) Seward, 1917, in Millan, p. 4-5, Est. 1.

1969- *Samaropsis milleri* (Feistm.) Seward, 1917, in Millan, p. 111, Est. 1, fig. 4
1972- *Samaropsis mendesii* Rigby, 1972, p. 284-286, Est. 4, fig. 30.
1977- *Samaropsis mendesii* Rigby, 1972, in Bernardes-de-Oliveira, p. 234-235.
2007- *Samaropsis gigas* Marques-de-Souza and Iannuzzi, p. 98-100, fig. 4.

Holotype: DGP 7/ 1189.
Paratypes: MP-Pb 3992, MP-Pb 3423, MP-Pb3662, MP-Pb3994, MP-Pb 3022, MP-Pb 3032, MP-Pb 3045, MP-Pb 3230, MP-Pb 3420, MP-Pb 3429, MP-Pb 3656, MP-Pb 3660A/B, MP-Pb 3691A, MP-Pb 3742, MP-Pb3957, MP-Pb 3965, MP-Pb 3986, MP-Pb 3991, MP-Pb 3992B, MP-Pb 3993A, MP-Pb 3995, MP-Pb 3996.

Type locality: Lauro Müller, Santa Catarina State (uppermost Rio Bonito Formation, Paraná Basin).

Original Diagnosis: *Seed with broadly ovate sclerotesta, cordate base and broadly emarginated apex, surrounded with continuous wing or sarcotesta, very broad at base with width approximately half the width of seed, becoming narrow along sides, broadening towards apex. Apical split in sclerotesta, median ridge absent, micropyle not seen, apparent elliptical hilum within angle of cordate base* (Rigby, 1972, p. 284).

Emended diagnosis: *Seed ovate, platyspermic, nucellus smooth, with a prominent median ridge, emarginated apex and cordate to rounded base, surrounded by a testa characterized by three distinct layers: the inner and fibrous endotesta; the middle and smooth sclerotesta with well-developed base and the same shape of the nucellus; the outer well-developed asymmetrical sarcotesta, very broad at base, becoming narrow along sides, broadening towards apex. Sarcotesta may have a basal narrow elliptical scar, possibly the insertion point of the seed in the mother plant. Micropyle emarginated and sometimes opened in the form of "V".*

Discussion and comparison: Access to the type material of *Samaropsis mendesii* allowed the precise comparison of this morphospecies from Santa Catarina State with *Samaropsis gigas*, erected by Marques-de-Souza and Iannuzzi 2007 based on specimens from the Morro do Papaléo outcrop, Rio Grande do Sul State. New measurements showed that *S. mendesii* and *S. gigas* are morphometrically similar (Table 1). Marques-de-Souza and Iannuzzi (2007) noted on a comparative basis with the description of the material available in the literature that mainly four aspects differentiated these two species.

First and foremost, the morphospecies *S. mendesii*, according to the original description, lacked a medial ridge in nucellus. Figure 1C shows, however, that the holotype of *S. mendesii* has a median ridge, even if not very well preserved, which goes from the micropyle region towards the central portion of the nucellus, where it is interrupted. The same feature is common in the specimens of Rio Grande do Sul (Figures 1A-B, D-E) although in this case it is much better delineated.

Second, the possible presence of a small slit in the apical portion of the sarcotesta, forming an *emarginated apex*, noticed in *S. mendesii* but absent in *S. gigas*. The revaluation of material showed that this minor incision could also be seen in some specimens of *S. gigas* (MP-Pub 3423; Figure 1B). It may be related to a possible micropilar opening, as sarcotesta of *S. gigas* that was interpreted by Marques-de-Souza and Iannuzzi (2012) as a voluminous structure, fleshy consistency (not papyraceous) that covered the entire surface of the seed. Since this slit is not apparent in all specimens it is possible to be present only in a certain stage of the seed maturation.

The third feature used to separate *Samaropsis gigas* from *S. mendesii* by Marques-de-Souza and Iannuzzi (2007) was the cordate base of sarcotesta in *S. mendesii*. It was noticed, after examining the type material of both species, that this basal contour is cordate only if the specimen has the seed insertion stalk scar still preserved (MP-Pb 3992; Figure 1A). In cases where this structure is not preserved, the basal outline of the sarcotesta is rounded (MP-Pb 3990 and MP-Pb 3662; Figure 1E). Clearly, this variation results from a preservation feature that probably depends on the face and / or on the angle that the seed impression is showing in the matrix.

Fourth and final aspect, although *S. mendesii* does not show the presence of endotesta in the holotype, this absence

Table 1. Morphometric comparison of the three analyzed species taking into account the main diagnostic characters.

Species	Visible testa	Apex Shape	Base Shape	Medial ridge	Cuticular / anatomical characters	Total length x width (mm)	Nucellus length x width (mm)
Samaropsis mendesii Rigby (1972)	Sclerotesta; Sarcotesta.	Emarginate	Cordated	present	absent	52 x 42	35.8 x 30.3
Samaropsis gigas Marques-de-Souza and Iannuzzi (2007)	Endotesta; Sclerotesta; Sarcotesta.	Rounded / cordated / emarginated	Rounded / Cordated	present	absent	49-54 x 28-38	21-33 x 18-28
Otofeista milleri (Feist.) Pant et al. (1985)	Sclerotesta; Sarcotesta	Rounded	Rounded / cordated	present	present	18-48 x 15-35	23-32 x 15-25

The data provided to *Otofeista milleri* were obtained from the literature. The data of *Samaropsis mendesii* and *S. gigas* were obtained by observation of the type materials.

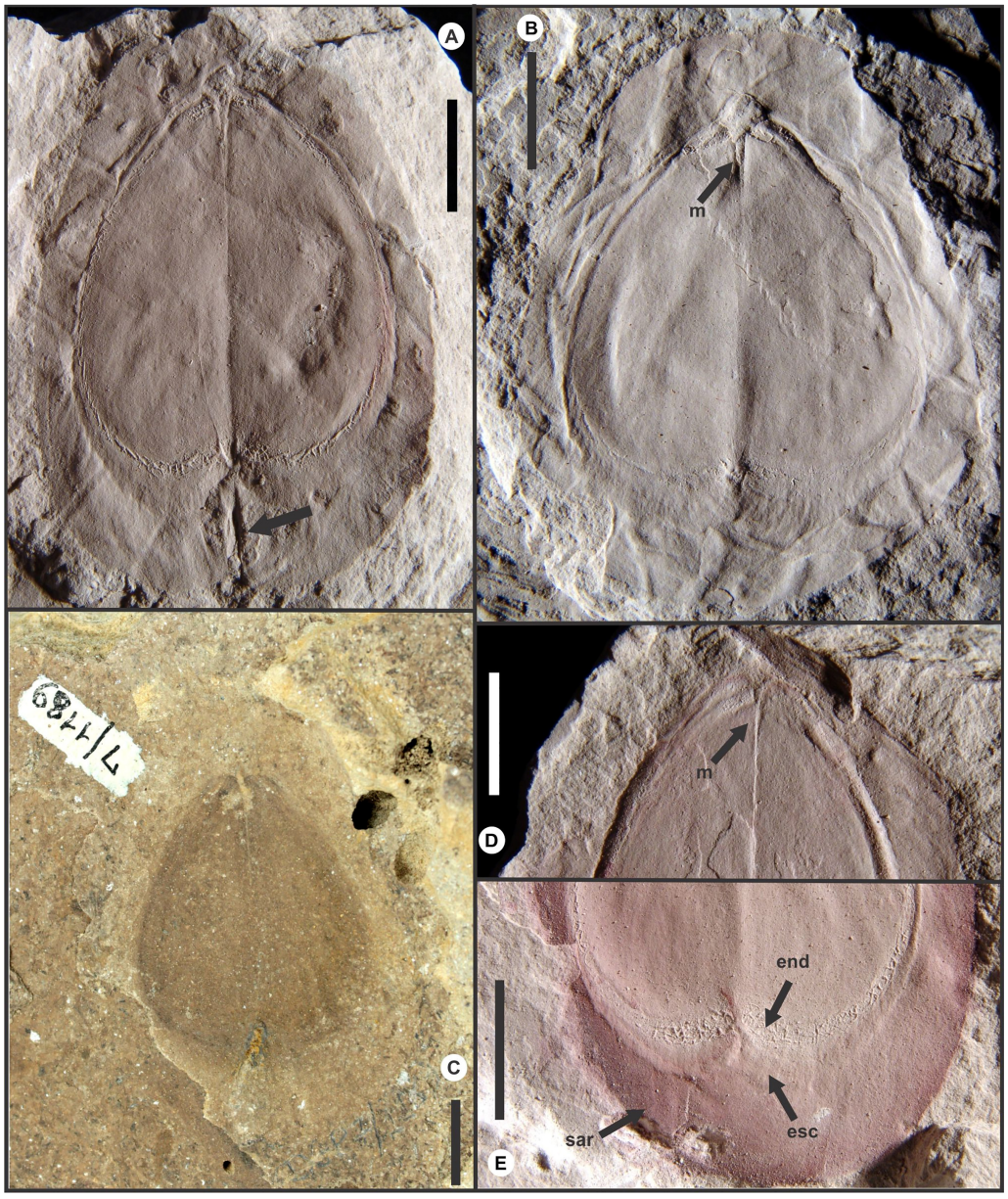

Figure 1. *Samaropsis mendesii* Rigby, 1972 emend. A - MP-Pb 3992 paratype. More complete specimen where the arrow indicates the presence of seed insertion stem; B - MP-Pb 3423 paratype; showing the emarginated micropyle, opening in a "V" and apical region of sarcotesta with its rounded contour; C- DGP 7/1189 holotype; showing the outline of the nucellus, the sclerotesta and sarcotesta; D-3994 MP-Pb paratype; showing the apical region in detail with the micropyle (m) emarginated; E - MP-Pb 3662 paratype, detail of the basal region that has preserved the three testa (end, esc, sar). Note that specimens figured in A, B, D, and E, were previously classified as *Samaropsis gigas* Marques-de-Souza and Iannuzzi (2007). Abbreviations: m, micropyle; end, endotesta; esc, sclerotesta; sar, sarcotesta. Scale bars: 1 cm.

can be attributed to poor preservation of the specimen. Bearing in mind that it is a very thin layer, positioned between the nucellus and sclerotesta, the endotesta is not commonly seen even in many of the analyzed specimens of *S. gigas* and / or other species of seeds. In addition, the material from the Rio Grande do Sul State is regularly preserved in a pure mudstone, in which the fine grained matrix allowed exceptional preservation of the seeds as impressions. The type material of *S. mendesii* from the Santa Catarina State, in turn, is preserved in fine sandstone, preventing the most delicate structures to be preserved as impressions.

Considering that *Samaropsis mendesii* was designated on the basis of a single specimen it became difficult to verify the morphological variations and the effect of preservation

features, since there were no other specimens for comparison that could allow the separation of the features inherent to the *taxon* (intra specific variations) from those of taphonomic origin. Thus, the concomitant analysis of the type materials of the Brazilian species *S. mendesii* and *S. gigas* allowed to visualize that both have close morphometric and morphographic resemblances endorsing to group them in the same species. To ensure that the morphological features seen in the abundant material originally described as *S. gigas* will be considered in future studies, the diagnosis of *S. mendesii* is emended.

Stratigraphic and geographic distribution

The holotype of *Samaropsis mendesii* Rigby, 1972 emend. was recovered from the Irapuá bed, uppermost Rio Bonito Formation, in Lauro Müller, Santa Catarina State. To erect *S. mendesii*, Rigby (1972) placed in synonymy the specimen previously collected in Irapuá bed, but in Bainha outcrop, municipality of Criciúma, also in Santa Catarina, and classified as *Samaropsis milleri* by Millan (1967). Later, Bernardes-de-Oliveira (1977) pointed out the occurrence of *S. mendesii* in the other exposure of Irapuá bed, at Bairro 20 outcrop, also located in Criciúma. The specimens from the Morro do Papaléo outcrop, Rio Grande do Sul State, previously included in *S. gigas*, extend from now the stratigraphic distribution of *S. mendesii* to the uppermost portion of the Itararé Group since once been recovered from the N4 level, in addition to those listed in N7 and N8 levels which correspond to the middle to upper portion of Rio Bonito Formation (Marques-de-Souza and Iannuzzi, 2007; Iannuzzi, 2010).

Comparison with other Gondwanan similar species

The morphometric analysis provided in Table 1 gives a clear picture that there is little variation in diagnostic features provided by the three large sized species that are more or less similar to each other and characteristic of the Cisuralian from Gondwana.

Although Pant et al. (1985) have proposed a new combination for *Samaropsis milleri* as *Otofeista milleri*, the historical understanding of this morphospecies is important to the progress in comparative studies. *Samaropsis milleri* was first described by Feistmantel (1882) as *Carpolithes milleri* because the author did not initially identify its sarcotesta. The sarcotesta even partially preserved was only recognized in the type material many years later by Seward (1917). Even without a fully defined contour, many authors included later new occurrences of similar large sized seeds, recovered in different parts of Gondwana, into the species *S. milleri* (Walkom, 1935; Hoeg and Bose, 1960; Maithy, 1965; Millan, 1967).

The material identified by Walkom (1935) as *Samaropsis milleri* comes from the late Paleozoic (i.e., Gzelian-Sakmarian interval) coal deposits of Upper Kuttung Series (= Currabubula Formation), Werrie Basin (= New England Orogen), eastern Australia, and does not show sarcotesta preserved. The author based on the dimensions of the central body of the seed to establish the correspondence with Indian material, suggesting that the absence of sarcotesta occurred due to preservation problems.

Hoeg and Bose (1960) recognized the presence of *Samaropsis milleri* in the Carrière M3, above the coal seams in Luena, Congo. The dimensions of the material correspond to the smallest specimens of this seed form and, according to the authors the specimens collected were incomplete without preservation of apical and basal portions of the seeds.

The material identified by Maithy (1965) as *Samaropsis milleri*, from Central Pit and Srirampur quarries, and from the Karharbari beds, in the coal region of Giridih, Bihar, India, "is not in a good state of preservation" (Maithy, op. cit. p.48), and so the evident diagnostic features are poorly preserved and consequently weakly defined.

As mentioned before, the single Brazilian specimen identified by Millan (1967) as *Samaropsis milleri* was placed in synonymy with *S. mendesii* by Rigby (1972). Thus, the occurrence of this Indian species in Brazil was ruled out.

In Pant et al. (1985) after analyzing about 70 specimens from the type locality of *Samaropsis milleri*, proposed the new combination for this species, i.e. *Otofeista milleri*, based on the inclusion of morphoanatomical characters, i.e. cuticular features. Therefore, the authors included as "possible" synonyms of *O. milleri* not only the type material of *Samaropsis milleri* but also all other specimens included in this species described through the Gondwana and discussed above (Seward and Sahni, 1920; Maithy, 1965; Walkom, 1935; Hoeg and Bose, 1960).

It is evident the necessity of review on the occurrence of *S. milleri* in Australia and Congo as well as the Indian record made by Maithy (1965) since all these materials are scarce, incomplete and poorly preserved, as indicated by the authors previously mentioned. In turn, Rigby (1972) suggested that these occurrences could probably correspond to three distinct species.

Moreover it is considered difficult to point out the degree of similarity of those materials only on the basis of few remaining morphographic features, excluding the general outline of the seed. Other Gondwanan species that are similar to *S. milleri* or *O. milleri* in their nucellus and sclerotesta outline differ, however, in their general outlines of the sarcotesta, as in the case of *S. leslii* (Zeiller) Seward 1917. In addition, all other specimens of *S. milleri* regarded as possibly synonymous with *O. milleri* by Pant et al. (1985) do not have any anatomical cuticular information that would allow a comparison with the organization and cell morphologies. These aspects possibly contributed to the

synonymy were indicated by those authors as a possibility but have not been singled out conclusively.

However, by comparing the Brazilian material to the Indian, one realizes that the morphological similarities between *S. mendesii* and *O. milleri* are quite evident. It is further strengthened when considering the specimens previously assigned to *S. gigas*. It should be note that the abundance of specimens permits the comparison of not only morphometric data (Table 1) but also of features such as the outlines of the sarcotesta, sclerotesta, and central body and V-shaped micropilar opening (Pant et al., 1985; Marques-de-Souza and Iannuzzi, 2007). On the other hand, the absence of anatomical features in Brazilian specimens make difficult to propose a formal synonymy with Indian species. At last, it should be emphasized that these occurrences spread over a wide paleogeographic region through the Gondwana supercontinent, which increases the chances that this fossil seed form do not necessarily match a unique natural species.

The use of seeds in stratigraphic correlations

From the point of view of biostratigraphy, the contributions using the Paleozoic seeds from Gondwana are still incipient. The authors who have taken efforts in organizing the stratigraphic comparisons of the described seed species include Millan (1969, 1974) and Archangelsky (1999). In the studies carried out by Millan (1969, 1974), all the Gondwanan species of seeds were taken into consideration, but most part of them were examined only from the literature. Still, the author worked with the "taphoflorule" concept, which he defined as local populations derived from each deposit. The precise stratigraphic levels of the seeds were not a concern in these studies.

Archangelsky (1999), on the other hand, was dedicated to the stratigraphic distribution of the Argentinean species preserved in Carboniferous-Permian interval from distinct basins, and pointed out that only those species defined by complete specimens recovered from different outcrops would be useful for the purpose of correlation. For Archangelsky (1999), seeds with very simple morphology (e.g. many of the species listed in the genus *Cordaicarpus*) would not be good biostratigraphic guides since they occur over the entire sedimentary sequences and can be easily confused with each other. These forms are not easily distinguishable due to the absence of good diagnostic characters, especially when they are poorly preserved, and may come from different parent plants (Archangelsky, 1999). Moreover, the most common genera, such as *Samaropsis* and *Cordaicarpus*, are produced by different plant groups during the late Paleozoic (Pant et al., 1985) and consequently, they have some stratigraphic importance only when considered in specific level (Archangelsky, 1999).

Combining the aspects discussed herein with the assertions of Archangelsky (1999), it is possible to consider that if *Otofeista milleri* and *Samaropsis mendesii* (= *S. gigas*) are the same species they could be, amongst the known seeds an important fossil index for stratigraphic studies in Gondwanan deposits since their occurrences are restricted to Cisuralian, probably to the Sakmarian-Artinskian interval. Finally, stands out that these species have good number of well-defined diagnostic features which are considered useful for biostratigraphy (Archangelsky, 1999) and are not commonly found in most seeds preserved as impressions/ compressions.

FINAL CONSIDERATIONS

Samaropsis gigas Marques-de-Souza and Iannuzzi 2007 was considered a synonym of *Samaropsis mendesii* Rigby (1972). This taxonomic change extended downwards the stratigraphic range of *S. mendesii*, previously restricted to the Rio Bonito Formation up to the uppermost Itararé Group, establishing a Sakmarian-Artinskian interval of occurrence. The incorporation of dozens of specimens previously attributed to *S. gigas* into *S. mendesii* allowed a clear view of the morphological variations of this species, facilitating their comparison with the Indian species *Otofeista milleri* Pant et al. (1985). The comparison performed indicated the strong morphometric resemblance between these two species. However, *O. milleri* was erected not only based on morphological (= morphographic) characters, but also on anatomical cuticular features, making it difficult and / or preventing the synonymization of these two species. However, if considered that this is the same morphotype species, the use of these seed forms in an intra-Gondwanan stratigraphic correlation seems plausible to Cisuralian epoch.

Finally, the occurrence of *Samaropsis milleri*-type seeds in Australia (Walkom, 1935), Congo (Hoeg and Bose, 1960), and other locations in India (Maithy, 1965), should be reviewed and if possible, expanded through the recovery of more specimens, ensuring the verification of wide distribution in the Gondwana and / or equivalence of this seed form with *O. milleri*, as suggested by Pant et al. (1985).

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