BOSQUE 36(1): 105-112, 2015 DOI: 10.4067/S0717-92002015000100011

Mozambique’s charcoals: anatomy of nine native species

Carbones de Mozambique: anatomía de nueve especies nativas

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SUMMARY

Most of the charcoal commercially produced in Mozambique is from natural forests, including high value species. This production often negatively affects the environment and one of the main reasons is the lack of sustainable forest management techniques. To facilitate forest control, we characterize the anatomy properties of charcoal made from *Afzelia quanzensis, Amblygonocarpus andongensis, Combretum imberbe, Dalbergia melanoxylon, Guibourtia conjugata, Khaya nyasica*, *Millettia stuhlmannii, Pterocarpus angolensis* and *Swartzia madagascariensis*. All these species possess high commercial value. The samples were carbonized at 450 °C for 1 h. Some shrinkage-related ruptures were present in charcoals, but the structure kept good definition of the cells features and did not influence the distinction of the species. The propagation of this knowledge would relieve pressure on valuable species and may also help with control of the charcoal supply chain.

Key words: carbonization, anatomical characteristics, commercial wood, wood anatomy.

RESUMEN

La mayor parte del carbón producido en el comercio en Mozambique es de bosques naturales, incluyendo las especies de alto valor comercial. Esta producción afecta negativamente el medio ambiente y una de las principales razones es la falta de técnicas de manejo forestal sostenible. Para facilitar el control del uso de los bosques, se caracterizan las propiedades de anatomía de carbón vegetal a base de *Afzelia quanzensis, Amblygonocarpus andongensis, Combretum imberbe, Dalbergia melanoxylon, Guibourtia conjugata, Khaya nyasica*, *Millettia stuhlmannii, Pterocarpus angolensis* y *Swartzia madagascariensis*. Todas estas especies tienen un alto valor comercial. Las muestras fueron carbonizadas a 450 °C durante 1 h. Algunas rupturas relacionadas con las pérdidas estuvieron presentes en los carbones, pero la estructura mantuvo buena definición de las características anatómicas de las células y no influyeron en la distinción de las especies. La difusión de este conocimiento podría aliviar la presión sobre las especies valiosas y también puede ayudar con el control de la cadena de suministro de carbón.

Palabras clave: carbonización, características anatómicas, maderas comerciales, anatomía de la madera.

INTRODUCTION

Mozambique has a great diversity of natural forests, and forestry biomass has an important role due to its environmental, social and economic dimensions (Vasco and Costa 2009). Biomass energy in the form of charcoal or firewood is used by over 85 % of urban households in Mozambique. Charcoal commerce covers an extensive value chain, from those at the production sites to those transporting and retailing it in the cities. Despite the dimension of this sector, it is a largely informal activity with limited recorded information (Vasco and Costa 2009, Cuvilas *et al.* 2010). Practically all the charcoal comes from natural forests. The production is characterized by a lack of sustainable forest management techniques; thus threatening natural resources (Bila 2005).

The estimated allowable cutting of trees in Mozambique is about two million cubic meters per year (Marzoli 2007). Regarding its commercial and scientific value, rarity, utility, resistance and quality, species which produce wood are classified into precious, first class, second class, third class and fourth class (Ministério da Agricultura). Some authors commented by Ali *et al.* (2008) explain that there are 118 wood species listed in the National Forestry Rules Guidelines classified in accordance with their value and some, classified as precious and first class, such as *Berchemia zeyheri* (Sond.) Grubov (pau-rosa), *Spirostachys africana* Sond. (sandalo), *Swartzia madagascariensis* Desv. (pau-ferro), *Afzelia quanzensis* Welw. (chanfuta), *Milletia stuhlmannii* Taub. (jambirre), *Pterocarpus angolensis* DC. (umbila), *Androstachys johnsonii* Prain. (mecrusse) and *Combretum imberbe* Wawra (monzo) are in declining availability in the Mozambican forests.

For energy purposes it is not allowed the use of wood from precious, first, second and third class, as well as those species that are scarce, protected or with historic and cultural value (Ministério da Agricultura 2002). Nevertheless, in Mozambique this is widely disobeyed by charcoal producers, because the choice of species for production depends on its availability and local culture (Bila 2005). In 2010 the use of firewood to produce charcoal was more than eleven million cubic meters (Steierer 2011). In African countries, the use of firewood and charcoal has been increasing as a consequence of urbanization and economic growth. This situation concerns environmentalists and those responsible for the management of forestry resources (Girard 2002, Clancy 2008).

Several studies have demonstrated that the anatomical structure of wood is maintained after carbonization (Kim and Hanna 2006, Gonçalves *et al.* 2012, Muñiz *et al.* 2013, Nisgoski *et al.* 2014). These authors have shown it is possible to identify species by examining charcoal samples. There are no scientific papers focusing on the features of charcoal made from species native to Mozambique. Along with this, literature on the anatomical features of arboreal species is not widely known in Mozambique, which contributes to the weak forestry control.

The present study characterizes the charcoal anatomy of nine species from Mozambique. All the species are prohibited for energetic purposes. We aim at contributing to the knowledge of these species and at helping to improve the forestry control.

METHODS

The samples were obtained from trees without a defined age growing in natural forests in Cabo Delgado (E39°17´01.70´´ S12°09´17.82) and Sofala (E34°50´34.79´´, S17°30´21.19´´), provinces of Mozambique with annual average precipitation varying from 800 to 1,200 mm and predominant tropical and humid climate (INDE 2009). All the species chosen are native and possess high commercial value (table 1). For each species, three trees were randomly chosen for felling. The samples were taken as discs at breast height. The thickness of the discs was 5 cm with diameterof 18-35 cm outside the bark. All samples were free from defects. For the analyses, the samples were cut into blocks measuring 2.5 x 2.5 x 5 cm.

The samples were wrapped in aluminum foil and carbonized in an electric muffle furnace at 450 °C for 1 hour, with a heating rate of 7.5 °C per minute. After carbonization, the samples were cooled and weighed.

For anatomical analyses, the charcoal was broken by hand following the three structural planes of the wood and analyzed under a Zeiss Discovery v12 stereo microscope. The anatomical description was done based on the procedures of the Iawa Committee (1989). The images of charcoal were obtained by scanning electron microscopy with a tabletop microscope (Hitachi TM-1000). No metallic-sputter-coating was needed. The determination of qualitative anatomical features was based on 25 measurements of tangential vessel diameter (μm), vessel frequency (vessels mm^{-2}), ray frequency (rays mm^{-1}), ray width (μm) and ray height (μm).

RESULTS

The anatomical characteristics of the charcoal samples are summarized in quantitative (table 2) and qualitative (table 3) features, and illustrated in figures 1 - 3.

Table 1. List of species studied.
Lista de las especies estudiadas.

Scientific name	Commercial name	Family	Commercial class
Afzelia quanzensis Welw.	Chanfuta	Caesalpiniaceae	First
Combretum imberbe Wawra	Mondzo	Combretaceae	First
Khaya nyasica Stapf ex Baker F.	Umbaua	Meliaceae	First
Millettia stuhlmannii Taub.	Jambire	Fabaceae	First
Pterocarpus angolensis DC.	Umbila	Fabaceae	First
Swartzia madagascariensis Desv.	Pau-ferro	Caesalpiniaceae	First
Dalbergia melanoxylon Guill. *et* Perr.	Pau-preto	Fabaceae	Precious
Guibourtia conjugata (Bolle) J. Léonard	Chacate-preto	Caesalpiniaceae	Precious
Amblygonocarpus andongensis (Welw. Ex Oliv.) Exell *et* Torre	Mutiria	Mimosaceae	Second

Source: Ministério da Agricultura (2002).

Table 2. Mean values and standard deviations of quantitative anatomical features of charcoal from nine Mozambique species.
Valores medios y error estándar de las características anatómicas cuantitativas del carbón de nueve Mozambique especies.

Species	Vessel mm^{-2}	Vessel diameter (µm)	Ray mm^{-1}	Ray width (µm)	Ray height (µm)
Afzelia quanzensis	6 (1.8)	166 (25)	6 (1.7)	48 (8)	223 (39)
Amblygonocarpus andongensis	23 (3.4)	116 (32)	6 (1.1)	39 (5)	221 (45)
Combretum imberbe	5 (1.4)	142 (31)	9 (2.2)	30 (5)	161 (38)
Dalbergia melanoxylon	11 (1.9)	114 (33)	9 (1.8)	29 (8)	156 (47)
Guibourtia conjugata	30 (4.8)	80 (18)	7 (1.5)	38 (7)	303 (76)
Khaya nyasica	20 (3.0)	127 (40)	4 (2.4)	83 (21)	426 (106)
Millettia stuhlmannii	11 (1.7)	202 (72)	6 (2.4)	42 (10)	199 (25)
Pterocarpus angolensis	9 (1.1)	182 (39)	10 (3.2)	38 (7)	106 (16)
Swartzia madagascariensis	20 (3.9)	70 (20)	9 (2.0)	28 (5)	124 (15)

Table 3. Summary of qualitative anatomical features of charcoal from nine species.
Resumen de las características anatómicas cualitativas del carbón de nueve especies.

Species	GR	OD	PP	IP	Axial parenchyma	RW	RCC	SS	MI
Afzelia quanzensis	√	√	Simple	Alternate	Lozenge-aliform, confluent, and marginal	2-3	A	Absent	√
Amblygonocarpus andogensis	√	√	Simple	Alternate	Aliform, confluent and marginal	1-2	A	Absent	√
Combretum imberbe	√	√	Simple	Alternate	Vasicentric, aliform, confluent and in bands	1-2	D	Absent	√
Dalbergia melanoxylon	√	√	Simple	Alternate	Vasicentric and diffuse-in-aggregates, aliform, confluent, marginal	1-2	A	Rays, axial parenchyma, vessels	√
Guibourtia conjugata	√	√	Simple	Alternate	Vasicentric, aliform, confluent, marginal	3	A	Absent	√
Khaya nyasica	√	√	Simple	Alternate	Vasicentric and scanty	2-5	C	Absent	√
Millettia stuhlmannii	–	√	Simple	Alternate	Confluent and bands	1-3	A	Rays, axial parenchyma, vessels	√
Pterocarpus angolensis	√	√	Simple	Alternate	Aliform,confluent and bands	1-2	A	Rays, axial parenchyma, vessels	√
Swartzia madagascariensis	√	√	Simple	Alternate	Aliform, confluent and bands	1-2	A	Rays, axial parenchyma, vessels	√

Legend: GR – growth ring; OD– other deposits; PP– perforation plates; IP– intervessel pits; RW – ray width; RCC – rays: cellularcomposition; Rays: cellular composition: A – all ray cells procumbent; B – body ray cells procumbent with one row of upright and/or square marginal cells; C – body ray cells procumbent with mostly 2 to 4 rows of upright and/or square marginal cells; D – rays with procumbent, square and upright cells mixed throughout the ray; SS – storied structure; MI – mineral inclusions.

Shrinkage-related ruptures (figure 4) were observed in samples of *Afzelia quanzensis*, *Amblygonocarpus andongensis*, *Dalbergia melanoxylon*, *Guibourtia conjugata*, *Khaya nyasica*, *Pterocarpus angolensis* and *Swartzia madagascariensis*. *Dalbergia melanoxylon* presented ruptures in a parallel direction and perpendicular to the rays and *P. angolensis* only ruptures perpendicular to the rays. The other species only presented ruptures oriented in the direction of the rays.

DISCUSSION

The qualitative anatomical structures of charcoal are the same as those observed in the description of the wood from these species analyzed in other studies. The database of Inside Wood (2012) contains the anatomical description of the hardwood species *Afzelia quanzensis*, *Amblygonocarpus andongensis*, *Combretum imberbe*, *Dalbergia me-*

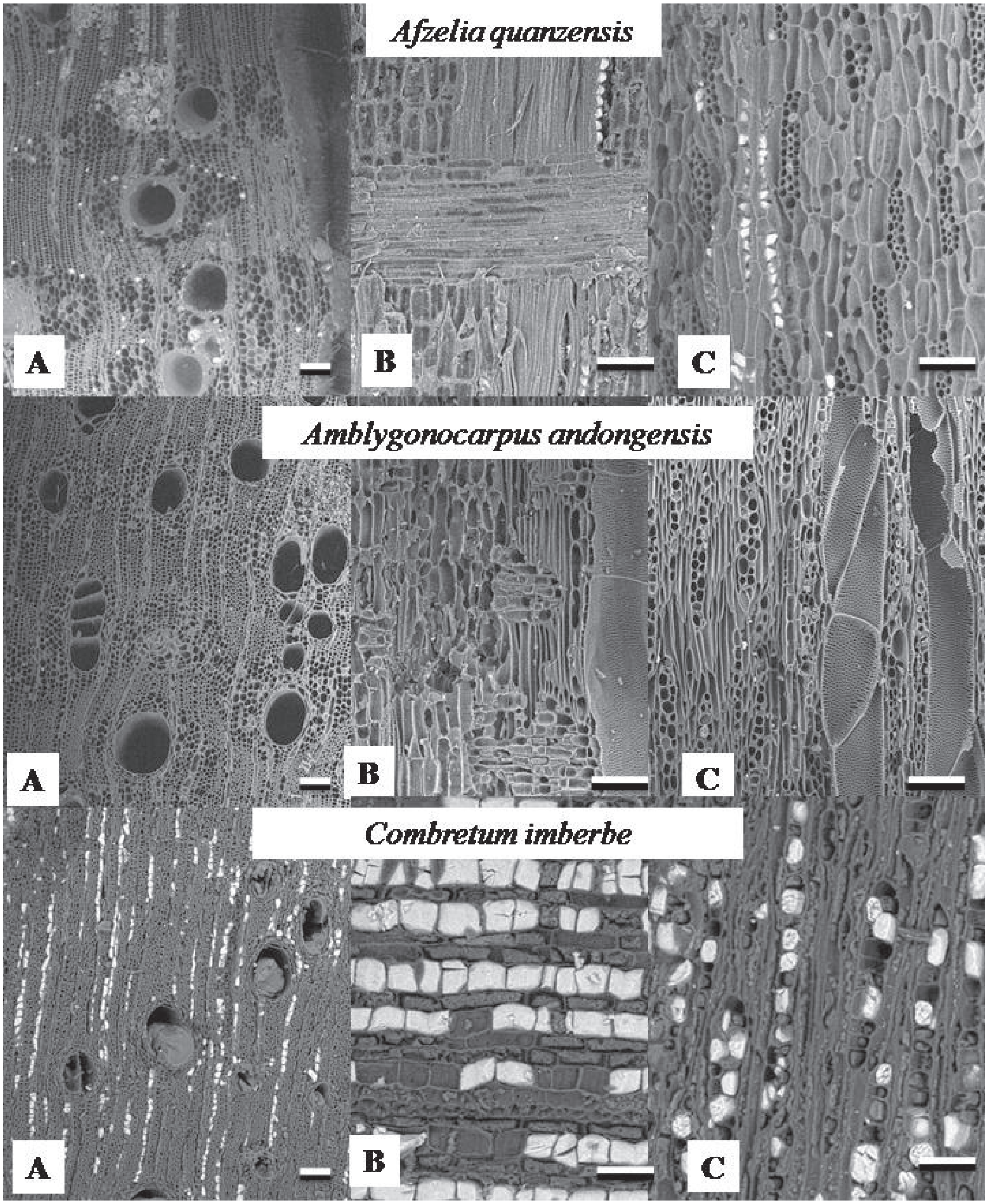

Figure 1. Scanning electron microscopy: images of transversal (A), radial (B) and tangential (C) section of charcoal. Scale bar = 100 µm.
Microscopía electrónica de barrido: imágenes de la sección transversal (A), radial (B) y tangencial (C) del carbón. Escala = 100 µm.

lanoxylon, Millettia stuhlmannii, Pterocarpus angolensis, Swartzia madagascariensis; Richter and Dallwitz (2000) described the hardwood of *A. quanzensis, D. melanoxylon, Guibourtia conjugata, Khaya nyasica, M. stuhlmannii, P. angolensis, S. madagascariensis*; and Ali *et al.* (2008) reviewed the anatomical characteristics of the hardwood of *A. quanzensis, K. nyasica, P. angolensis, M. stuhlmannii.*

The carbonization at 450 ºC and 7.5 °C per minute of heating rate preserved well the structure of charcoal with good definitions of the cells features. Other works reported similar behaviors at different temperatures and/or heating rate, *e.g:* (i) *Dichrostachys cinerea* (L.) Wight *et* Arn. (Leguminosae) and *Salix subserrata* Willd. (Salicaceae) carbonized at 400 ºC and 6.67 ºC per minute (Prior and

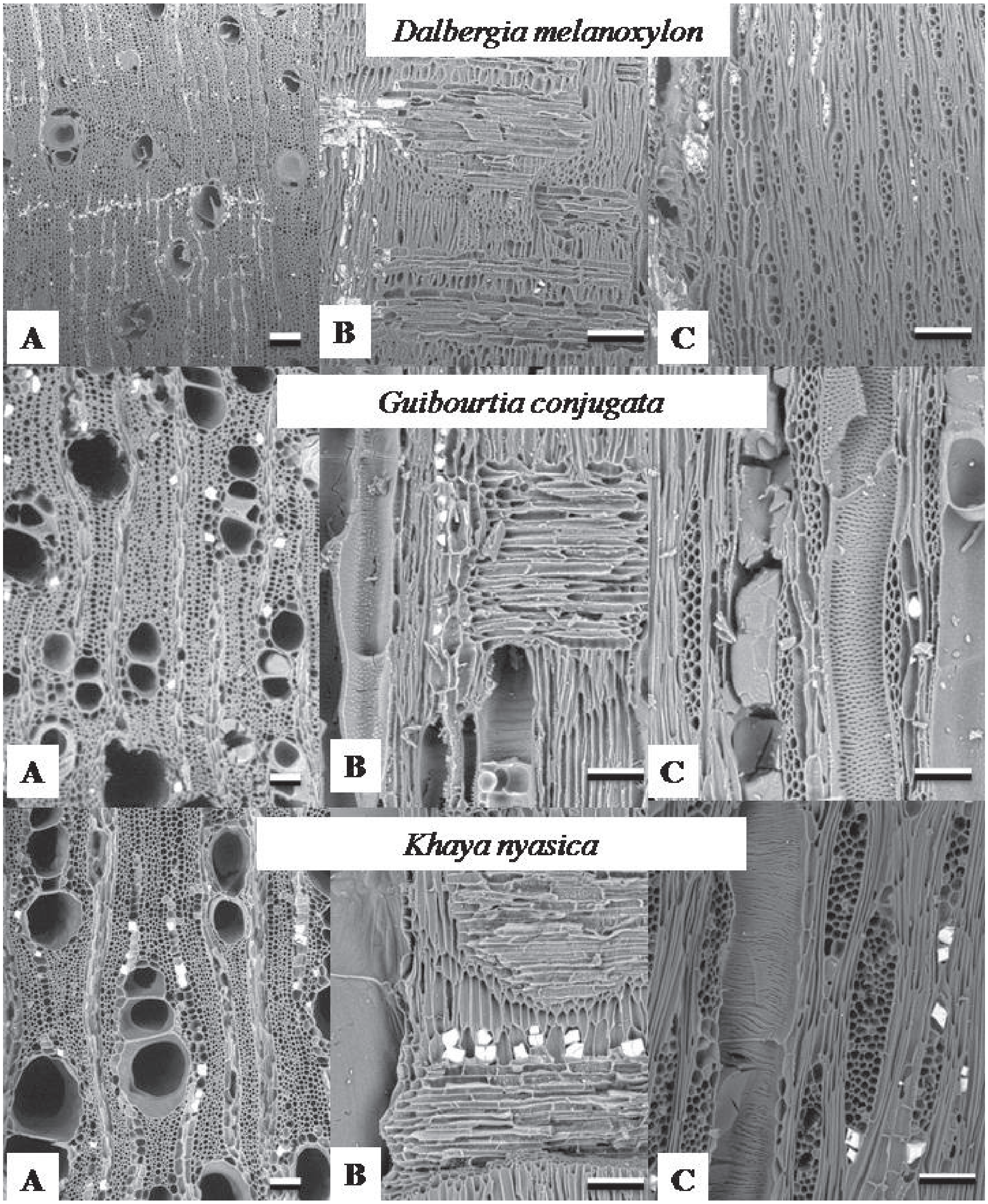

Figure 2. Scanning electron microscopy: images of transversal (A), radial (B) and tangential (C) section of charcoal. Scale bar = 100 µm.

Microscopía electrónica de barrido: imágenes de la sección transversal (A), radial (B) y tangencial (C) del carbón. Escala = 100 µm.

Alvin 1983); (ii) *Quercus variabilis* Bl. at 450 °C and 5 °C per minute (Kwon *et al.* (2009) (iii) *Corymbia* spp. and *Eucalyptus* spp. carbonized at 450 °C and 1.66 °C per minute (Gonçalves *et al.* 2014), (iv) *Ocotea porosa* (Ness *et* Mart.) Barroso carbonized at temperatures varying from 350-650 °C and heating rate from 1.04-1.24 °C per minute (Nisgoski *et al.* 2014). Kim and Hanna (2006), studying *Quercus variabilis* BL. observed destroyed fiber walls, explaining that this effect is due to the tensions created by the effect of temperatures over 400 °C. Prior and Alvin (1983) evaluated the anatomical changes as being due to the increase of temperature in the woods of *Dichrostachys cinerea* and *Salix subserrata*. They found that over 300 °C, the cell walls begin to acquire amorphous features in the

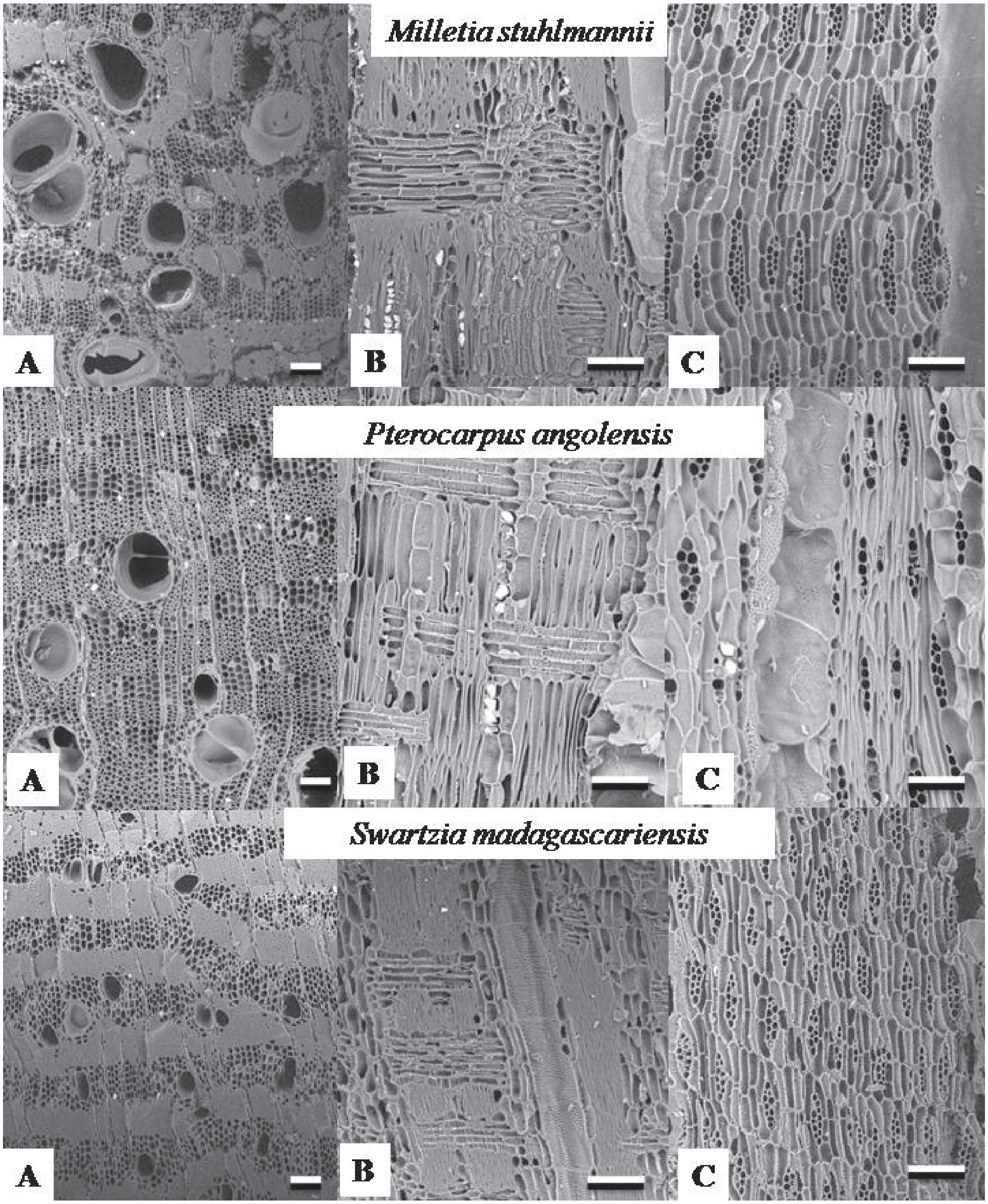

Figure 3. Scanning electron microscopy: images of transversal (A), radial (B) and tangential (C) section of charcoal. Scale bar = 100 µm.

Microscopía electrónica de barrido: imágenes de la sección transversal (A), radial (B) y tangencial (C) del carbón. Escala = 100 µm.

charcoal, although the medium line of the lamella and primary wall could still be distinguished. Kwon *et al.* (2009) studied *Q. variabilis* and found that over 350 °C it was impossible to observe the fiber walls.

Ruptures are also observed in other works in: (i) rays - C*orymbia citriodora* (Hook.) K.D.Hill *et* L.A.S. Johnson, *C. maculata* (Hook.) K.D.Hill *et* L.A.S. Johnson, *Eucalyptus dunnii* Maiden, *E. tereticornis* Sm. and *E. viminalis* Labill. (Gonçalves *et al.* 2014), *Quercus variabilis*, *Q. robur* L. (Kim and Hanna 2006) and *Q. alba* L. (McGinnes *et al.* 1971); (ii) axial parenchyma cells - *E. dunnii* (Gonçalves *et al.* 2014); (iii) fibers - *Mimosa tenuiflora* (Willd.) Poiret and *M. ophthalmocentra* Martius (Dias Leme *et al.* 2010). As the causes of ruptures are not yet explained, our results

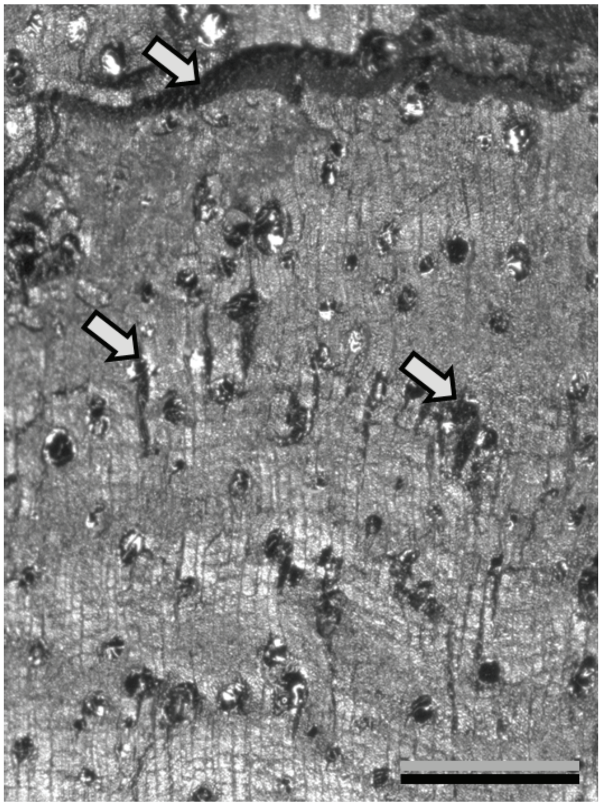

Figure 4. Ruptures in *Dalbergia melanoxylon* charcoal. Scale bar = 100 µm.

Rupturas en *Dalbergia melanoxylon* carbon. Escala = 100 µm.

were expected and did not compromise the identification of the anatomical features. Moreover, ruptures apparently did not influence charcoal quality.

The charcoal of species studied presented prismatic crystals in the cells of axial parenchyma of *Afzelia quanzensis*, *Amblygonocarpus andongensis, Dalbergia melanoxylon*, *Guibourtia conjugata*, *Millettia stuhlmannii*, *Pterocarpus angolensis* and *Swartzia madagascariensis*. In the case of *Combretum imberbe* and *Khaya nyasica*, these were only observed in the ray cells.

CONCLUSIONS

Anatomical changes due to carbonization do not influence the distinction of species. The knowledge of charcoal anatomy can help in the control of the species in the charcoal supply chain. We hope this kind of study can be multiplied in order to contribute with nature conservancy in Mozambique.

ACKNOWLEDGEMENTS

We thank the Ford Foundation and Federal University of Paraná (UFPR), Brazil, for support and the opportunity provided to conduct this research.

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Recibido: 11.06.14
Aceptado: 20.01.15