Secondary metabolites of Bagassa guianensis Aubl. wood: A study of the chemotaxonomy of the Moraceae family

Mariana Royer, Gaëtan Herbette, Véronique Eparvier, Jacques Beauchêne, Bernard Thibaut, Didier Stien

Secondary metabolites of *Bagassa guianensis* Aubl. wood, a study of the chemotaxonomy of the Moraceae family.

Mariana Royer[1]; Gaëtan Herbette[2]; Véronique Eparvier[1]; Jacques Beauchêne[3]; Bernard Thibaut[1]; Didier Stien[1,*]

Affiliations

[1] CNRS, UMR Ecofog, Université des Antilles et de la Guyane, Cayenne, France

[2] Spectropole, FR 1739 – Université d'Aix-Marseille, Faculté de Saint-Jérôme, service 511, Avenue Escadrille Normandie Niémen, 13397 Marseille cedex 20, France

[3] Cirad, UMR Ecofog, BP 709, F-97387 Kourou, France

Corresponding authors

Dr. Didier Stien, CNRS, UMR Ecofog, Institut d'Enseignement Supérieur de la Guyane, BP 792, 97337 Cayenne cedex, France. E-mail: didier.stien@guyane.cnrs.fr Phone: +594 594 29 75 17 Fax: +594 594 28 47 86.

Abstract

In effort to explain wood durability of Moraceae plants family, a phytochemical study was undertaken on *Bagassa guianensis*. The phytochemical investigation of the ethyl acetate extract obtained from the heartwood led to the isolation of 18 secondary metabolites, including 6 moracins [the new 6-*O*-methyl-moracin M (**3**), 6- *O*-methyl-moracin N (**4**) and moracin Z (**5**); the known moracin M (**1**), moracin N (**2**) and moracin P (**6**)], 8 phenolic derivatives [the new (-)-epialboctalol (**12**), arachidin 4 (**10**) and the known alboctalol (**11**), *trans*-resveratrol (**7**), arachidin 2 (**9**), *trans*-oxyresveratrol (**8**) and artogomezianol (**13**)], the 3 known flavonoids steppogenin (**14**), katuranin (**15**), dihydromorin (**16**), the β-sitosterol (**17**) and the resorcinol (**18**). Comparison with literature data indicates that stilbenoids are presumably responsible for the natural durability of the wood. In addition, chemical composition points out that *B. guianensis* is closely related to *Morus* sp. in the phylogeny and should be placed within the Moreae s. s. tribe in the Moraceae family.

Keywords: *Bagassa guianensis*, Moraceae, secondary metabolites, stilbenes, moracins, flavonoids, natural durability

1. Introduction

Wood as a material is used extensively in construction and other applications where it can be degraded by many different organisms, mainly fungi and insects. However, some trees have specialized considerably long-lasting heartwoods. It has been demonstrated in the past that wood natural durability can be ascribed to the presence of extractives (Smith et al., 1989; Wang et al., 2005; Hsu et al., 2007), although structural components of the cell wall may also contribute to its resistance to biodegradation (Silva et al., 2007). Heartwood natural durability can also result from synergetic or additive effects of compounds with various modes of action (toxic, hydrophobic, free radical scavengers and so on) (Suttie and Orsler, 1996; Okitani et al., 1999; Schultz and Nicholas, 2000; Schultz et al. 2007; Binbuga et al., 2008). Future processes to preserve wood constructions may involve returning to mankind's historical use of naturally durable heartwood as well as discovering eco-friendly wood protection agents inspired from long-lasting woods (Schultz et al., 2007).

Bagassa guianensis Aubl. (Moraceae) commercially known as tatajuba is a large rather infrequent unbuttressed canopy tree naturally occurring in French Guiana. *Bagassa guianensis* is a member of Moraceae family, which is divided in 5 unequal tribes when comparing the number of species in these tribes (Mabberley, 2002). *Bagassa guianensis* (the only member of its genus) was originally classified in the Artocarpeae tribe, but Weiblen genoma-based classifications have suggested recently that this species would better be included in Moreae tribe (Datweyler and Weiblen, 2004; Zerega et al, 2005).

Species in the Moraceae family have important economic and medicinal value. They are widely acknowledged as a rich source of bioactive secondary metabolites such as flavonoids,

stilbenes, triterpenoids and xanthones (Lee et al., 2009; Ngadjui et al., 2005; Han et al., 2006; Jayasinghe et al., 2008). Also, some of them like *Maclura pomifera* and *B. guianensis* are capable of specializing very long-lasting woods (Scheffer and Morrell, 1998; Schultz et al., 1995), although in the latter case, the substances responsible for this high durability were unknown. We therefore embarked upon identifying secondary metabolites of tatajuba wood that may responsible for its natural durability. In addition, our secondary goal here was to confirm (or refute) botanical classification of the *Bagassa* genus by chemotaxonomy.

2. Results and Discussion

The dried heartwood of *Bagassa guianensis* was extracted with ethyl acetate. This extract was fractionated by silicagel column chromatography to give 9 fractions. Subsequent preparative HPLC purifications of these fractions allowed us to isolate compounds **1**-**18** (figure 1).

Figure 1 Compounds **1-18** isolated from *Bagassa guianensis* (Moraceae). (a) New compounds; (b) New names.

Compounds **1** to **6** shared several common spectral characteristics. The ^{1}H and ^{13}C NMR spectral data (Table 1) indicate the presence of two independent aromatic systems with a 3,5-dihydroxyphenyl and a substituted benzofuran. For example, **3** exhibited the 3,5-dihydroxyphenyl with characteristic ^{1}H spectrum composed of one doublet at δ 6.78 for H-2'/H-6' and a triplet at δ 6.25 for H-4'. These protons are coupled to each other with a ^{4}J coupling of 2.1 Hz. In addition, ^{13}C spectrum indicates the presence of two equivalent aryl hydroxyl groups at δ 159.7. The 3,5-dihydroxyphenyl moiety was linked to C-2 by the observation of a long range ^{1}H-^{13}C correlation between H-2'/H-6' and C-2 at δ 156.5. The second aromatic system appeared characteristic of a 6-monosubstituted benzofuran with

signals of protons H-4, H-5 and H-7 being a broad doublet at δ 7.43 (J = 8.5 Hz), a doublet of doublet at δ 6.85 (J = 8.5 and 2.0 Hz) and a doublet at δ 7.09 (J = 2.0 Hz), respectively. On the furan ring H-3 gives a doublet at δ 6.95 (J = 0.6 Hz) due to a long range ^{5}J coupling with H-7 (confirmed by the presence of crosspeak between H-3 and H-7 on COSY NMR spectrum). When compared to moracin M (**1**), it became obvious from signal at δ 3.85 (3H, s) and the presence of crosspeak at δ 56.2 in the ^{1}H-^{13}C HSQC spectra that compound **3** was a moracin M methyl ether. The ^{1}H-^{13}C long-range HMBC spectra gave a crosspeak with C-6 at δ 159.6 unambiguously placing the methoxy group on C-6. HREIMS of **3** allowed us to ascertain molecular formula $C_{15}H_{12}O_4$ further confirming that we had isolated the new 6-*O*-methyl-moracin M (**3**).

Table 1 ^{1}H and ^{13}C NMR spectroscopic data for moracins **3**-**5** in CD_3OD

Compound **4** was isolated as yellowish amorphous powder. The HREIMS indicated a molecular formula $C_{20}H_{20}O_4$ deduced from the ion peack at m/z 325.1437 $[M + H]^+$ (calcd 325.1434). The ^{1}H and ^{13}C NMR spectral data of **4** were closely related to those of moracin N (**2**) (Lee et al., 2001) except for the replacement of hydroxyl group by a methoxy group as described for the above compound **3**. Indeed, the ^{1}H NMR data of **4** (Table 1) demonstrated the presence a methoxy group on C-6 in the benzofuran ring, with a signal at δ 3.88 (3H, s), a crosspeak at δ 56.2 in the ^{1}H-^{13}C HSQC experiment and a crosspeak with C-6 at δ 157.4 in the ^{1}H-^{13}C long-range HMBC spectra. This novel molecule was named 6-*O*-methyl-moracin N.

Compound **5** was isolated as an amorphous brown powder. The molecular formula $C_{20}H_{22}O_5$ was deduced from the HREIMS at *m*/*z* 343.1542 $[M + H]^+$ (calcd 343.1540). The ^1H- and ^{13}C-NMR spectral data of **5** were closely related to those of 6-*O*-methyl-moracin N (**4**) (Table 1). The main difference was observed in the prenyl moiety at C-5. The double bond is absent in **5** and it was unambiguously established that side chain at C-5 is hydrated and is therefore a 3-hydroxy-3-methylbutyl group, with the upfield shifts of methylene group H-1'' from δ 3.34 to δ 2.73 and the apparition of a methylene H-2'' at δ 1.74 in place of the vinyl proton at δ 5.52; in addition, the two methyl groups H-4'' and H-5'' became equivalent at δ 1.27 (Table 1). The ^1H-^{13}C long-range HMBC spectra exhibited a crosspeak between the methylene group H-1'' and H-2'' with C-5 at δ 128.6 proving the linkage C-1''/C-5 between the 3-hydroxy-3-methylbutyl moiety and the benzofuran ring. This molecule is a hydrate of 6-*O*-methyl-moracin N and was named moracin Z.

Spectral data along with HREIMS of **1**, **2** and **6** allowed us to determine and ascertain by comparison with literature data that we had also isolated moracin M (**1**) (Basnet et al. 1993, Zhou et al., 1999), moracin N (**2**) (Lee et al. 2001) and moracin P (**6**) (Dat et al., 2009).

Stilbenoids *trans*-resveratrol (**7**) (Lee et al. 2001; Su et al., 2002), *trans*-oxyresveratrol (**8**) (Likhitwitayawuid and Sritularak, 2001; Lee et al., 2001; Su et al., 2002; Li et al., 2007), arachidin 2 (**9**) (Orsini et al., 2004) and artogomezianol (**13**) (Likhitwitayawuid and Sritularak, 2001) were identified by comparison of the respective spectral and chemical data with those described in the literature (Figure 1).

Compound **10** was a colorless syrup with molecular formula $C_{19}H_{22}O_4$ as deduced from the HREIMS at *m*/*z* 315.1592 $[M + H]^+$ (calcd 395.1591). The ^1H spectral data of **10** were closely

related to those of arachidin 2 (**9**) (Table 2) and suggested a stilbenoid compound with a *para*-disubstituted aromatic ring A, a *trans* double bond between the aromatic rings, and a 1',3',4',5'-tetrasubstituted aromatic ring B. Ring A is symmetrical, with 2 doublets at δ 7.32 (*J* = 8.7 Hz, H-2/H-6) and δ 6.75 (*J* = 8.7 Hz, H-3/H-5). The *trans* configuration of the double bond can be ascertained by the very large coupling constant between the two protons at δ 6.90 (*J* = 16.5 Hz, H-α) and δ 6.74 (*J* = 16.5 Hz, H-β), and the B ring is symmetrical as well and was characterized by a singlet at δ 6.46 (H-2'/H-6'). In the same way as we identified a hydrated side chain in the moracins series, the main difference here between **9** and **10** is in the side chain in position 4', the double bond of which is also hydrated. This has been established by the observation of methylene group H-1'' at δ 2.66 instead of δ 3.28 and the apparition of a second methylene H-2'' at δ 1.68. In addition, the two methyl groups H-4'' and H-5'' became equivalent at δ 1.25. The chromatography collected quantities was too low to observe heteronuclear ^{1}H-^{13}C HSQC / HMBC correlations and direct ^{13}C chemicals shifts by ^{13}C/DEPTQ sequence. However, the above-described data in comparison with those of arachidin 2 are sufficient to ascertain identification of compound **10** as *trans*-4'-(3-hydroxy-3-methylbutyl)-oxyresveratrol. We named this new compound arachidin 4.

Table 2 ^{1}H and ^{13}C NMR spectroscopic data for stilbenes **9** and **10** in CD_3OD

Compounds **11** and **12** both isolated as brownish syrups presented the ion peak at *m/z* 489.1540 $[M + H]^+$ in HREIMS indicating that they are isomers with molecular formulas $C_{28}H_{24}O_8$ (calcd 489.1544). The ^{1}H-NMR allowed us to identify a 3,5-dihydroxyphenyl group and two distinct 2,4-dihydroxyphenyl groups in both compounds. By comparison of the respective spectral and chemical data with those described in the literature, compound **11** was

identified as alboctalol (Bates et al., 1997). Compound **12** has an $[\alpha]_D^{20}$ value of -7.4° (c 0.004, CH_3OH). It was clear that **12** was a diastereoisomer of **11** with equivalent H-18/H-22 protons at δ 6.01 (Table 3). In **11**, H-18/H-22 pair gives a doublet at a strong upfield shift of δ 5.77 typical of the π-stacking effect of the neighboring 2,4-dihydroxyphenyl groups. In addition, on this aliphatic ring, the main differences with **11** are on methylene H-5 and methines H-6, H-7 and H-8. H-5_{ax} at δ 3.19 exhibited a broad triplet with large couplings (J = 13.7 Hz) with the gem H-5_{eq} and the vicinal H-6 suggesting that the 6-aryl group should be equatorial and proton H-6 axial. This observation was corroborated by the multiplicity of H-5_{eq} signal at δ 2.72. This signal is a doublet of doublet with a large coupling constant J = 15.6 Hz with H-5_{ax} and a small coupling constant J = 3.0 Hz with H-6_{ax}. Signal of H-6_{ax} at δ 3.51 is a broad triplet of doublet with two larges coupling constants J = 11.6 Hz with H-5_{ax} and H-7 and a small coupling constant J = 2.1 Hz with H-5_{eq}. This pattern indicates that the 7-aryl group is equatorial and H-7 axial. H-7_{ax} at δ 3.41 exhibited one doublet of doublet with one large coupling constant (J = 11.3 Hz) with H-6_{ax} and a second rather large coupling constant (J = 8.2 Hz) with H-8 indicating that the 8-aryl group might be equatorial and proton H-8 axial. These assumptions were confirmed by NOESY experiment with cross peaks observed between H-5_{eq} and H-6_{ax}, H-6_{ax} and H-8_{ax}, H-6_{ax} and H-18, H-8_{ax} and H-22 and between H-5_{ax} and H-16, H-7_{ax} and H-16, H-7_{ax} and H-28 (Figure 2). All data permitted to confirm that we had isolated a new epimer of alboctalol (**11**) therefore named (–)-epialboctalol (**12**).

Table 3 ^{1}H and ^{13}C NMR spectroscopic data for distilbenes **11** and **12** in CD_3OD

Figure 2 Pertinent NOE interactions observed for (–)-epialboctalol (**12**) from NOESY experiment

189

190 In addition to these moracins and stilbenoids, we isolated flavanones steppogenin (**14**) (Lee et
191 al., 2001), katuranin (**15**) (Lee et al., 2001) and dihydromorin (**16**) (Su et al., 2002), together
192 with β-sitosterol (**17**) (Basnet et al., 2003, Aldrich Library of 13C and 1H FT NMR spectra,
193 1992) and resorcinol (**18**) (Aldrich Library of 13C and 1H FT NMR spectra, 1992). These
194 known compounds were identified by comparison of the respective spectral and chemical data
195 with those described in the literature.

196

197 Essentially three classes of compounds were isolated in this study: moracins, stilbenes and
198 flavanones. Only resorcinol **18** and β-sitosterol **17** do not belong to these classes. These two
199 compounds are widely distributed in nature and cannot be viewed as chemotaxonomic
200 markers.

201

202 Moracin N, M and P have been isolated before from *Morus alba*. In general, it was found
203 from the literature that *Morus* genus is purveyor of moracins (Tagasuki et al., 1979; Hirakura
204 et al., 1986; Basnet et al., 1993; Nguyen et al., 2009). The only one exception is the isolation
205 of moracin M from *Artocarpus dadah* (Su et al., 2002).

206

207 Among stilbenes, *trans*-oxyresveratrol was isolated from various plants including *Morus* sp.
208 and *Artocarpus* sp. (Hirakura et al, 1986; Su et al, 2002; Shimizu et al., 1998; Song et al,
209 2009). *Trans*-resveratrol was isolated from many sources including the Moraceae *Cudrania*
210 *javanensis* classified today as *Maclura cochinchinensis* (Murti et al., 1972, Chapman & Hall,
211 2006). The distylbene artogomezianol **13** is a constituent of *Artocarpus gomezianus* roots and
212 albolactol **11** was isolated from heartwood of *Morus alba* (Likhitwitayawuid and Sritularak
213 2001, Ferlinahayati et al., 2008).

Regarding flavonoids, it has been described that many Moraceae can produce steppogenin (El-Sohly et al, 1999; Su et al, 2002; Sheu et al., 2005). Katuranin was also isolated from various biological sources in *Morus* and *Maclura* genera (El-sohly et al., 1999, Lee at al., 2009) and dihydromorin was isolated from *Morus, Artocarpus*, and *Maclura* genera (Shimizy et al., 1998, El-Sohly et al, 1999, Su et al., 2002).

It has been hypothesized before that stilbenes are the major types of compounds isolated from Moraceae and may be useful chemotaxonomic markers (Rowe and Conner, 1979). Also, Schultz has shown that stilbenoids play an important role in the high natural durability of *Maclura pomifera* wood (Schultz et al., 1990). Stilbenes are known as fungicide, termicides and bactericide (Hart and Shrimpton, 1979; Likhitwitayawui and Sritularak, 2001; Javasinghe et al., 2004), and may also exhibit antioxidant properties (Dani et al., 2008; Iacopini et al., 2008; Luo et al., 2005). If it is reasonable to believe that stilbenes are responsible for *Bagassa guianensis* heartwood natural durability based on literature precedents, stilbenes can be considered as a secondary chemotaxonomic marker here indicating that *Bagassa* is related to *Morus*, *Artocarpus*, and *Maclura* genera. In Weiblen classification, *Artocarpus* belongs to the Artocarpeae tribe and *Maclura* belongs to the Moreae sensu largo tribe, and both Moreae and Artocarpeae tribes are rather closely related genetically.

The peculiarity of *B. guianensis* in comparison with other Moraceae is the very high proportion of moracins. In this matter, it can be hypothesized that *Bagassa* genus is closely related to *Morus* and that moracins are specific to these two genera. These findings are in agreement with Weiblen genetic-based classification where both *Bagassa* and *Morus* belong to the Moreae sensu stricto tribe. It should be mentioned that the *Sorocea* genus, which also belongs to the Moreae s. s. tribe, has been investigated before in the literature and apparently

239 does not contain moracins (see for example Ferrari et al., 2003; Ross et al., 2008). This
240 observation speaks in favor of a very close relationship between *Bagassa* and *Morus*.
241
242 ## 3. Concluding remarks
243 Studies of defensive wood chemicals in *Bagassa guianensis* allowed us to identify large
244 amount of diversely functionalized stilbenes presumably responsible for wood natural
245 durability. In addition, it was found based on the presence of moracins that *Bagassa* is very
246 closely related to Morus genus, therefore corroborating Weiblen phylogenetic classification
247 where *B. guianensis* belongs to the Moreae s. s. tribe rather than to the Artocarpeae tribe.
248
249 ## 4. Experimental
250 ### *4.1 General experimental procedure*
251 The ^{1}H and ^{13}C-NMR spectra were recorded on a Bruker Avance DRX500 spectrometer (^{1}H-
252 500.13 MHz) equipped with a 5 mm triple resonance inverse Cryoprobe TXI (^{1}H-^{13}C-^{15}N),
253 with z gradient. Spectra were recorded with 1.7 mm NMR capillary tube in 40 µL of 99.99%
254 CD_3OD solvent (δ_{1H} 3.31 ppm - δ_{13C} 49.00 ppm) at 300 K. The ^{1}H (500 MHz) and ^{13}C NMR
255 (125 MHz) data are reported in ppm downfield from tetramethylsilane. Coupling constants are
256 in Hz and s stands for singlet, d for doublet, t for triplet, q for quartet, m for multiplet and br
257 for broad. Hydrogen connectivity (C, CH, CH_2, CH_3) information was obtained from edited
258 HSQC and/or DEPTQ-135 experiments. Proton and carbon peak assignments were based on
259 2D NMR analyses (COSY, NOESY, HSQC and HMBC). HREI-MS were performed using a
260 QStar Elite mass spectrometer (Applied Biosystems SCIEX, Concord, ON, Canada) equipped
261 with an ESI source operated in the positive ion mode. The capillary voltage was set at 5,500
262 V, the cone voltage at 20 V and air was used as the nebulizing gas (20 psi). In this hybrid
263 instrument, ions were measured using an orthogonal acceleration time-of-flight (oa-TOF)

mass analyzer. Analyst software version 2.1 was used for instrument control, data acquisition and data processing. The accurate mass measurements were performed in triplicate with two internal calibrations. Direct sample introduction was performed at a 5 µL/min flow rate using a syringe pump. The UV spectra were recorded on a Perkin-Elmer Lambda 5 spectrophotometer . Optical rotations were measured with a Perkin-Elmer 241 polarimeter equipped with a sodium lamp (589 nm) and a 1 dm cell. The HPLC separations were performed on a Supelco Discovery® HS PEG column (250 × 21.1 mm, 5 µm) using a Waters system equipped with a W600 pump and a W2996 photodiode array absorbance detector. The samples were injected manually through a Rheodyne injector and the flow rate was 15 $mL.min^{-1}$. Silica gel 60 (35-70 µm) and analytical TLC plates (Si gel 60 F 254) were purchased from SDS (France). All other chemicals and solvents were analytical grade and purchased from SDS (France).

4.2 Plant Material

Bagassa guianensis was collected in Régina, French Guiana. A voucher specimen is kept at the herbarium of Cayenne (CAY-RA13), French Guiana.

4.3 Extraction and isolation

The dried powdered heartwood of *Bagassa guianensis* (140 g) was extracted with ethyl acetate (3 × 500 mL) at room temperature to give a crude extract which was fractionated first on a silica gel column chromatography with polarity gradient of hexane/ethyl acetate mixtures: 80/20; 50/50; 20/80; 0/100. 9 fractions numbered F1 to F9 were obtained. Fractions F1 to F5 were purified on HPLC with a linear gradient of hexane/isopropanol, by the following method: 70:30 changing over 2 min to 60:40, then to 40:60 at 10 min and pure isopropanol at 15 min and remaining as is for 5 min. The fractions F6 and F9 were analyzed and purified with an isocratic method: 30:70 hexane/isopropanol. These methods allowed us to isolate moracin M **1** (6.2 mg; w/w 0.019%), moracin N **2** (6.7 mg; w/w 0.020%), 6-*O*-

289 methyl-moracin M **3** (3.3 mg; w/w 0.010%), 6-*O*-methyl-moracin-N **4** (9.1 mg; w/w 0.027%),
290 moracin Z **5** (5.2 mg; w/w 0.016%), moracin P **6** (1.2 mg; w/w 0.003), *trans*-resveratrol **7**
291 (12.6 mg; w/w 0.038%), *trans*-oxyresveratrol **8** (112.3 mg; w/w 0.343%), arachidin 2 **9** (5.1
292 mg; w/w 0.015%), arachidin 4 **10** (0.4 mg; w/w 0.001%), alboctalol **11** (0.5 mg; w/w
293 0.001%), (–)-epialboctalol **12** (5.4 mg; w/w 0.016%), artogomezianol **13** (12.7 mg; w/w
294 0.038%), steppogenin **14** (11.5 mg; w/w 0.035%), katuranin **15** (1.5 mg; w/w 0.004%),
295 dihydromorin **16** (20.4 mg; w/w 0.062%), the β-sitosterol **17** (8.4 mg; w/w 0.025%) and the
296 resorcinol **18** (1.8 mg; w/w 0.005%). Compounds 1-6, 9-10 and 17-18 were obtained from
297 the purification of the fractions F1-F5 while compounds 7-8 and 11-16 were isolated from the
298 fractions F6-F9.

299 *4.3.1* 6-*O*-Methyl-moracin M (**3)**

300 Yellowish amorphous powder; HR-EIMS $[M + H]^+$ *m/z* 257.0805 $[M + H]^+$ (calcd 257.0808);
301 ^1H and ^{13}C NMR (500 MHz; CD_3OD) see table 1.

302 *4.3.2* 6-*O*-Methyl-moracin N (**4**)

303 Yellowish amorphous powder; HR-EIMS $[M + H]^+$ *m/z* 325.1437 $[M + H]^+$ (calcd 325.1434);
304 ^1H and ^{13}C NMR (500 MHz; CD_3OD) see table 1.

305 *4.3.3* Moracin Z (**5**)

306 Yellowish amorphous powder; HR-EIMS $[M + H]^+$ *m/z* 343.1542 $[M + H]^+$ (calcd 343.1540);
307 ^1H and ^{13}C NMR (500 MHz; CD_3OD) see table 1.

308 *4.3.4* Arachidin 4 (**10**)

309 Colorless syrup; HR-EIMS $[M + H]^+$ *m/z* 315.1592 $[M + H]^+$ (calcd 315.1591); ^1H and ^{13}C
310 NMR (500 MHz; CD_3OD) see table 2.

311 *4.3.5* (–)-Epialboctalol (**12**)

312 Brownish syrup; $[\alpha]_D^{20}$ –7.4° (c 0.004, CH_3OH); HR-EIMS $[M + H]^+$ *m/z* 489.1540 $[M + H]^+$
313 (calcd 489.1544); ^1H and ^{13}C NMR (500 MHz; CD_3OD) see table 3.

The 3 known moracins M (**1**), N (**2**) and P (**6**) and the other known compounds 7-**9**, **11**, and **13-18** were identified by comparison of their physical and spectral data with those reported in the literature.

Role of the funding source

The authors gratefully acknowledge the *Programme Amazonie du CNRS* for financial support, as well as the CNRS and the Région Guyane, France, for the research fellowship attributed to MR.

References

Aldrich Library of 13C and 1H FT NMR Spectra, 1992, 2, 207A; 243A (nmr).

Basnet P., Kadota S., Terashima S., Shimizu M., Namba T., 1993. Two new 2-arylbenzofuran derivatives from hypoglycemic activity-bearing fractions of *Morus insignis.* Chemical and Pharmaceutical Bulletin 41, 1238–1243.

Bates R.B., Caldera S., Deshpande V.H., Malik B.L., Paknikar S.K., 1997. Revised structure of alboctalol. Journal of Natural Products 60, 1041–1042.

Binbuga N., Ruhs C., Hasty J.K., Henry W.P., Schultz T.P., 2008. Developing environmentally benign and effective organic wood preservatives by understanding the biocidal and non-biocidal properties of extractives in naturally durable heartwood. Holzforschung 62, 264–269.

Chapman E., Hall W., 2006. Dictionary of Natural Products , CRC, Version 14:2.

Dani C., Bonnato D., Salvador M., Pereira M.D., Henriques J.A.P., Eleutherio E., 2008. Antioxidant protection of resveratrol and catechin in *Saccharomyces cerevisiae*. Journal of Agricultural and Food Chemistry 56, 4268–4272.

Dat N.T., Jin X., Lee K., Hong Y.-S., Kim Y.H., Lee J.J., 2009. Hypoxia-Inducible Factor-1 Inhibitory Benzofurans and Chalcone-Derived Diels-Alder Adducts from *Morus* Species. Journal of Natural Products 72, 39–43.

Datwyler S.L., Weiblen G.D., 2004. On the origin of the fig: phylogenetic relationships of Moraceae from ndhF sequence. American Journal of Botany 91, 767–777.

El-Sohly H.N., Joshi A., Li X-C., Ross S.A., 1999. Flavonoids from *Maclura tinctoria*. Phytochemistry 52, 141–145.

Ferlinahayati S.Y.M., Juliawaty L.D., Achmad S.A., Hakim E.H., Takayama H., Said I.M., Latip J., 2008. Phenolic constituents from the wood of *Morus australis* with cytotoxic activity. Zeitschrift fur Naturforschung – Section C. Journal of Biosciences 63, 35–39.

Ferrari F., Cechinel Filho V., Cabras T., Messana I., 2003. Sorocein L and sorocein M: two Diels-Alder type adducts from *Sorocea ilicifolia*. Journal of Natural Products 66, 581–582.

Han A-R., Kang Y-J., Windono T., Lee S.K., Seo E-K., 2006. Prenylated flavonoids from heartwood of *Artocarpus communis* with inhibitory activity on lipopolysaccharide-induced nitric oxide production. Journal of Natural Products 69, 719–721.

Hart J.H., Shrimpton D.M., 1979. Role of stilbenes in resistance of wood to decay. Phytopathology 69, 1138–1143.

Hirakura K., Fujimoto Y., Fukai T., Nomura T., 1986. Two phenolic glycosides from the root bark of the cultivated mulberry tree (*Morus lhou*). Journal of Natural Products 49, 218-224

Hsu, F.-L., Chang H.-T., Chang S.T., 2007. Evaluation of antifungal properties of octyl gallate and its synergy with cinnamaldehyde. Bioresource Technology 98, 734–738.

361 Iacopini P., Baldi M., Storchi P., Sebastiani L., 2008. Catechin, epicatechin, quercetin, rutin
362 and resveratrol in red grape: content, *in vitro* antioxidant activity and interactions.
363 Journal of Food Composition and Analysis 21, 589–598.
364 Jahasinghe U.L.B., Samarakoon T.B., Kumarihamy B.M.M., Hara N., Fujimoto Y., 2008.
365 Four new prenylated flavonoids and xanthones from the root bark of *Artocarpus*
366 *nobilis*. Fitoterapia 79, 37–41.
367 Jayasinghe U.L.B., Puvanendran S., Hara N., Fujimoto Y., 2004. Stilbene derivatives with
368 antifungal and radical scavenging properties from the stem bark of *Artocarpus nobilis*.
369 Natural Products Research 18, 571–574.
370 Lee D., Bhat K.P.L., Fong H.H.S., Farnsworth N.R., Pezzuto J.M., Kinghorn A.D., 2001.
371 Aromatase Inhibitors from *Broussonetia papyrifera.* Journal of Natural Products 64,
372 1286–1293.
373 Lee Y.J., Kim S., Lee S.J., Ham I., Whang W.K., 2009. Antioxydant activities of new
374 flavonoids from *Cudrania tricuspidata* root bark. Archives of Pharmacal Research 32,
375 195–200.
376 Li H., Cheng K.W., Cho C.H., He Z., Wang M., 2007. Oxyresveratrol as an antibrowning
377 agent for cloudy apple juices and fresh-cut apples. Journal of Agricultural and Food
378 Chemistry 55, 2604–2610.
379 Likhitwitayawuid K., Sritularak B., 2001. A new dimeric stilbene with tyrosinase inhibitiory
380 activity from *Artocarpus gomezianus.* Journal of Natural Products 64, 1457–1459.
381 Luo M., Liang X.Q., Dang P., Holbrook C.C., Bausher M.G., Lee R.D., Guo B.Z., 2005.
382 Microarray-based screening of differentially expressed genes in peanut in response to
383 *Aspergillus parasiticus* infection and drought stress. Plant Science 169, 695–703.
384 Mabberley D.J. (2002) The Plant Book, second Ed, Cambride University Press, 858 p.

385 Murti V.V.S., Seshadri T.R., Sivakumaran S., 1972. Cudriniaxanthon and butyrospermol
386 acetate from the roots of *Cudrania javanensis*. Phytochemistry 11, 2089–2092.
387 Ngadjui B.T., Watchueng J., Keumedjio F., Nagmeni B., Simo I.K., Abegaz B.M., 2005.
388 Prenylated chalcones, flavones and other constituents of the twigs of *Dorsteronia*
389 *angusticornis* and *Dorsteronia barteri* var. *subtriangularis*. Phytochemistry 66, 687–
390 692.
391 Nguyen T.D., Jin X., Lee K., Hog Y-S., Young H.K., Jung J.L., 2009. Hypoxia-inducible
392 factor-1 inhibitory benzofurans and chalcone-derived Diels-Alder adducts from *Morus*
393 species. Journal of Natural Products 72, 39–43.
394 Okitani T., Takabe K., Takahashi M., 1999. The role of extractives involved in the natural
395 durability of domestic softwood. Wood Research 86, 51–52.
396 Orsini F., Verotta L., Lecchi M., Restano R., Curia G., Redaelli E., Wanke E., 2004.
397 Resveratrol derivatives and their role as potassium channels modulators. Journal of
398 Natural Products 67, 412–426.
399 Ross S.A., Rodríguez-Guzmán R., Radwan M.M., Jacob M., Ding Y., Li X.-C., Ferreira D.,
400 Manly S.P., 2008. Sorocenols G and H, anti-MRSA oxygen heterocyclic Diels-Alder-
401 type adducts from *Sorocea muriculata* roots. Journal of Natural Products 71, 1764–
402 1767.
403 Rowe J.W., Conner A.H., 1979. Extractives in Eastern Hardwood. A review. USDA Forest
404 Service General Technical Report FPL 18. Forest Products Laboratory, Madison, WI,
405 66 pp.
406 Scheffer T.C., Morell J.J., 1998. Natural durability of wood: A worldwide checklist of
407 species. Forest Research Laboratory, Oregon State university; College of Forestry,
408 Research Contribution 22, 45 pp.

409 Schultz P., Hubbard J.T.F., Jin L., Fisher T.H., Nicholas D.D., 1990. Role of stilbenes in the
410 natural durability of wood: Fungicidal structure-activity relationships.
411 Phytochemistry 29, 1501–1507.
412 Schultz T.P., Harms W.B., Fischer T.H., McMurtrey K.D., Minn J., Nicholas D.D., 1995.
413 Durabiliy of angiosperm heartwood: the importance of extractives. Holzforschung 49,
414 29–34.
415 Schultz P., Nicholas D., 2000. Naturally durable heartwood: evidence for a proposed dual
416 defensive function of the extractives. Phytochemistry 5, 47–52.
417 Schultz P., Nicholas D., Preston A.F., 2007. A brief review of the past, present and future of
418 wood preservation. Pest Management Science 63, 784–788.
419 Sheu Y-W., Chiang L-C., Chen I-C., Tsai I-L., 2005. Cytotoxic flavonoids and new
420 chromenes from *Ficus formosana* f. *formosana*. Planta Medica 71, 1165–1167.
421 Shimizu K., Kondo R., Sakai K., Lee S-H., Sato H., 1998. The inhibitory component from
422 *Artocarpus incisus* on melanin biosynthesis. Planta Medica 64, 408–412.
423 Silva C.A., Monteiro B.B., Brazolin S., Lopez A.C.G., Richter A., Braga M.R., 2007.
424 Biodeterioration of brazilwood *Caesalpinia echinata* Lam. (Leguminosae-
425 Caesalpinioideae) by rot fungi and termites. International Biodeterioration and
426 Biodegradation 60, 285–292.
427 Smith A.L., Campbell C.L., Diwakar M.P., Hanover J.W., Miller R.O., 1989. Extracts from
428 black locust as wood preservatives: A comparison of the methanol extract with
429 pentachlorophenol and chromated copper arsenate. Holzforschung 43, 293–296.
430 Song W., Wang H-H., Bucheli P., Zhang P-F., Wei D-Z., Lu Y-H., 2009. Phytochemical
431 profiles of different mulberry (*Morus* sp.) species from China. Journal of Agricultural
432 and Food Chemistry 57, 9133–9140.

Su B.N., Cuendet M., Hawthorne M.E., Kardono L.B.S., Riswan S.F., Harry H.S., Mehta R.G., Pezzuto J.M., Kinghorn A.D., 2002. Constituents of the bark and twigs of *Artocarpus dadah* with cyclooxygenase inhibitory activity. Journal of Natural Products 65, 163–169.

Suttie E.D., Orsler R.J., 1996. The influence of the natural extractives of Opepe (*Nauclea diderrichii*) and African Padauk (*Pterocarpus soyauxii*) timbers on their durability. IRG/WP N° 96-30098, 1–15.

Takasugi M., Nagao S., Masamune T., 1979. Structure of moracins E, F, G and H, new phytoalexins from diseased mulberry. Tetrahedron Letters 48, 4675–4678.

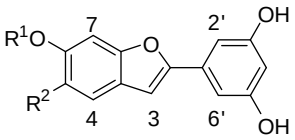
Wang S.Y., Chen P.F., Chang S.T., 2005. Antifungal activities of essential oils and their constituents from indigenous cinnamon (*Cinnamomum osmophloeum*) leaves against wood decay fungi. Bioresource Technology 96, 813–818.

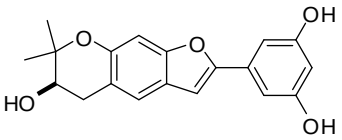
Zerega N.J.C., Clement W.L., Datwyler S.L., Weiblen G.D., 2005. Biogeography and divergence times in the mulberry family (Moraceae). Molecular Phylogenetics and Evolution 37, 402–416.

Zhou C.X., Tanaka J., Cheng C.H.K., Higa T., Tan R.X., 1999. Steroidal alkaloids and stilbenoids from *Veratrum taliense*. Planta Medica 65, 480–482.

Figures and legends

Moracins

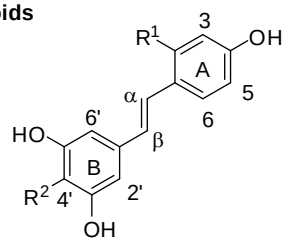


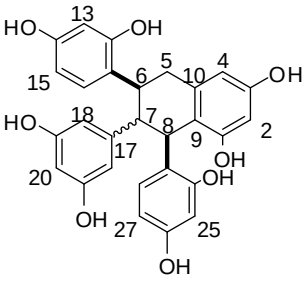


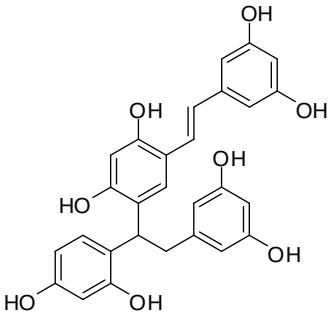
	R^1	R^2	
1	H	H	Moracin M
2	H	Prenyl	Moracin N
3[a]	Me	H	6-*O*-Methyl-moracin M
4[a]	Me	Prenyl	6-*O*-Methyl-moracin N
5[a]	Me	3-Hydroxy-3-methylbutyl	Moracin Z[b]

6 Moracin P

Stilbenoids







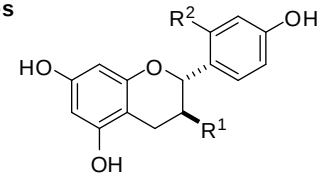
	R^1	R^2	
7	H	H	*trans*-Resveratrol
8	OH	H	*trans*-Oxyresveratrol
9	H	Prenyl	Arachidin 2
10[a]	H	3-Hydroxy-3-methylbutyl	Arachidin 4[b]

11 C_{17} C_7 Alboctalol

12[a] C_{17} C_7 (-)-Epialboctalol[b]

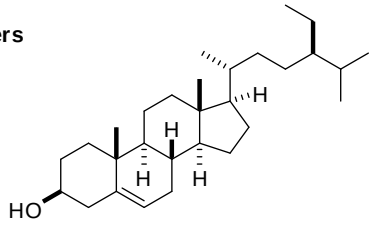
13 Artogomezianol

Flavanones

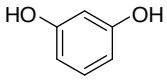


	R^1	R^2	
14	H	OH	Steppogenin
15	OH	H	Katuranin
16	OH	OH	Dihydromorin

Others

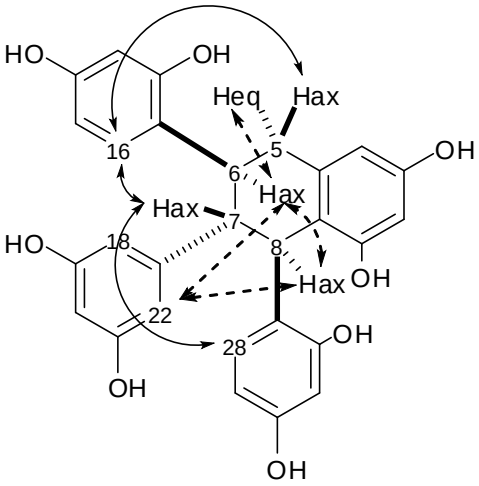


17 β-Sitosterol



18 Resorcinol

Figure 1 Compounds **1-18** isolated from *Bagassa guianensis* (Moraceae). (a) New compounds; (b) New names.



457
458

459 **Figure 2** Pertinent NOE interactions observed for (–)-epialboctalol (**12**) from NOESY

460 experiment

461

Tables

Table 1 ^{1}H and ^{13}C NMR spectroscopic data for moracins **3-5** in CD_3OD

Atom	**3**		**4**		**5**	
	δ_C	δ_H (*J* in Hz)	δ_C	δ_H (*J* in Hz)	δ_C	δ_H (*J* in Hz)
2	156.5	-	156.2	-	156.2	-
3	96.5	6.95, d (0.6)	102.1	6.90, s	102.0	6.91, d (0.6)
4	121.9	7.43, d (8.5)	121.3	7.25, s	121.6	7.30,s
5	112.9	6.85, dd (8.5, 2.1)	127.5	-	128.6	-
6	159.6	-	157.4	-	157.5	-
7	102.0	7.09, brd (2.0)	94.7	7.09, s	94.7	7.09, s
8	157.0	-	155.7	-	155.8	-
9	123.7	-	123.0	-	123.1	-
1’	133.6	-	133.9	-	133.6	-
2’/6’	104.0	6.78, d (2.1)	103.9	6.77, d (2.1)	103.5	6.77, d (2.1)
3’/5’	159.7	-	159.9	-	160.0	-
4’	103.5	6.25, t (2.1)	103.5	6.24, t (2.1)	103.4	6.25, t (2.1)
1’’	-	-	29.7	3.34, brd (7.3)	26.7	2.73, m
2’’	-	-	124.3	5.32, tm (7.3)	45.5	1.74, m
3’’	-	-	132.7	-	71.5	-
4’’	-	-	17.8	1.73 brs	28.9	1.27, s
5’’	-	-	26.0	1.74 brs	28.9	1.27, s
MeO	56.0	3.85, s	56.2	3.88 s	56.0	3.89, s

Table 2 ^{1}H and ^{13}C NMR spectroscopic data for stilbenes **9** and **10** in CD_3OD

Atom	**9**		**10**
	δ_C	δ_H (*J* in Hz)	δ_H (*J* in Hz)
1	130.6	-	-
2	128.6	7.31, d (8.6)	7.32, d (8.7)
3	116.5	6.75, d (8.6)	6.75, d (8.7)
4	158.1	-	-
5	116.5	6.75, d (8.6)	6.75, d (8.7)
6	128.6	7.31, d (8.6)	7.32, d (8.7)
α	128.3	6.88, d (16.3)	6.90, d (16.5)
β	127.2	6.74, d (16.3)	6.74, d (16.5)
1’	137.6	-	-
2’	105.7	6.46, s	6.46, s
3’	157.2	-	-
4’	116.0	-	-
5’	157.2	-	-
6’	105.7	6.46, s	6.46, s
1’’	23.3	3.28, d (7.1)	2.66, m
2’’	124.6	5.23, tm (7.1)	1.68, m
3’’	131.4	-	-
4’’	26.0	1.62, brs	1.25, s
5’’	18.0	1.75, brs	1.25, s

Table 3 ^{1}H and ^{13}C NMR spectroscopic data for distilbenes **11** and **12** in CD_3OD

Atom	**12**		**11**
	δ_C	δ_H (*J* in Hz)	δ_H (*J* in Hz)
1	156.7	-	-
2	101.8	6.10, d (2.2)	6.32, d (2.2)
3	156.2	-	-
4	107.3	6.19, d (2.2)	6.32, d (2.2)
5_{ax}	40.1	3.19, brt (13.7)	2.98, dd (16, 14)
5_{eq}		2.72, dd (15.6, 3.0)	2.53, dd (16.3, 4.3)
6_{ax}	40.3	3.51, brtd (11.6, 2.1)	3.75, dt (14, 3.7)
7_{ax}	56.2	3.41, dd (11.3, 8.2)	-
7_{eq}	-	-	3.28, d (3.3)
8_{ax}	44.1	4.42, d (8.2)	4.67, brs
9	119.6	-	-
10	142.2	-	-
11	123.7	-	-
12	156.4	-	-
13	103.3	6.16, d (2.2)	?
14	156.4	6.12, dd (8.4, 2.3)	6.13, dd (8.4, 2.3)
15	107.3	-	-
16	129.7	6.82, d (8.2)	6.44, d (8.2)
17	149.2	-	-
18	108.4	6.01, d (1.9)	5.77, d (1.9)
19	157.9	-	-
20	100.8	5.93, t (2.2)	6.02, t (2.2)
21	157.9	-	-
22	108.4	6.01, d (1.9)	5.77, d (1.9)
23	125.2	-	-
24	156.1	6.76, d (8.2)	6.25, d (8.2)
25	103.2	6.23, dd (8.2, 2.5)	6.04, dd (8.2, 2.5)
26	156.7	-	-
27	108.1	6.19, d (2.2)	6.25, d (2.2)
28	131.2	-	-