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1 **Improvement of thermophysical quality of biomass pellets produced from rice husks**

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18 husks.

19

20 **Abstract** This work was initiated to improve the thermophysical quality of biomass pellets
21 produced from rice husks using arabic gum. Dried and crushed arabic gum was solubilized in
22 a 1:2, 1:3 and 1:4 m/v binder/water ratios. In addition, the rice husks and pellets were
23 physiochemically characterized. The formulation of the mixture was carried out by mixing
24 rice husks of diameter less than or equal to 0.5 mm with arabic gum. It emerges from this
25 work that the rice husks from the SEMRY (Yagoua Rice Expansion and Modernization

26 Company) from Yagoua in the Far North Region of Cameroon, had 94.736, 17.046, 67.454,
27 and 15.5% dry matter, ash, organic matter and fixed carbon respectively. Their Lower Heating
28 Value (LHV) and electrical conductivity were 1178 J/g and 0.756 mS/cm respectively. The
29 solid biofuel (pellets) obtained show a water content varying between 7.97 and 9.794%. Their
30 shock resistance, friability index and Lower Heating Value (LHV) depend on the
31 concentration of the binder used. The thermophysical characteristics of biomass pellets were
32 proportional to the volume of binder and compaction. The 1:2 binder/water ratio showed the
33 best thermophysical characteristics.

34

35 **Keywords:** Rice husks, arabic gum, pellet, resistance profile

36

37 **1. Introduction**

38 Consumption of fossil fuels worldwide has increased tremendously in last few decades,
39 which leads to several environmental issues, including greenhouse gas emissions and
40 deteriorating air quality caused by pollutants such as SO_x, NO_x and fine particulate matter.
41 Moreover, the fluctuation of fossil fuel prices and the depletion of fossil resources have
42 shadowed the global economy. The production of carbon-neutral and low-emission fuels
43 from renewable resources, such as biomass, is of growing importance in the gradual
44 substitution of conventional fossils. For this purpose, cooking energy is essential for all
45 population around the world. Therefore, the population's access to butane gas, wood,
46 charcoal or other cooking fuels must be ensured in order to guarantee food, health,
47 economic and social security in the country [1]. In this international context of tensions over
48 fossil fuels and awareness of climate risks, interest in renewable energies appears to be an
49 essential alternative that contributes to meeting the challenges posed by the environment,
50 climate change or even energy needs without stops more important. It is important to note

51 that most renewable energies are made up of both dispersed resources, more or less
52 available at all times. In addition, two billion people around the world depend on wood
53 energy from deforestation for their household energy needs [2]. In Africa more particularly,
54 this resource represents 89% of energy sources. This recourse to unsustainable wood is a
55 major cause of deforestation, which poses a serious ecological problem. This deforestation
56 accentuates drought, desertification as well as climate change.

57 Beyond the fight against poverty, the conservation of biodiversity and the mobilization
58 against climate change, the exclusive use of wood as a household fuel has many other major
59 drawbacks [3].

60 However, resources are becoming scarce, it is increasingly difficult for a household to
61 have access to fossil fuels. Now, Lignocellulosic biomass is an alternative energy resource.
62 The use of lignocellulosic biomass as an energy source has drawbacks such as high
63 humidity, high hygroscopicity, low energy density as well as difficulties in handling and
64 storage. Densification into pellets is one of available strategy to solve these problems.
65 Essentially, pellets production is mainly based on sawdust from several sources, such as
66 sawmills, carpentry, and other waste material. Biomass use in form of pellets generates a
67 biofuel that is more cost-effective than the direct use of non-modified biomass residues for
68 energy production. In addition, pellet production from non-woody biomass is increasing in
69 importance. This situation can be alleviated by enhancing the value of plant residues such as
70 those from harvesting from agriculture like rice husking. Thus, several studies [4, 5, 6]
71 show that the rice husks obtained from husking can be used as lignocellulosic biomass
72 capable of serving the production of solid biofuels such as pellets. Moreover, in recent
73 years, several studies have focused on improving the pellet quality, in particular regarding
74 durability and bulk density, through the use of organic components, for example, sewage
75 sludge and inorganic binders. In addition, in the Far North region of Cameroon more

76 precisely in Yagoua, there is a large company (*SEMRY, Yagoua Rice Expansion and*
77 *Modernization Company*) which produces around 100,000 tonnes of paddy rice and
78 generates around 20,000 tonnes of rice husks each year [7,8], since about 22 wt% of paddy
79 is rice husk, which is normally disposed of by open burning. These purely energetic residues
80 are intended for abandonment and sometimes destroyed [7, 9]. However, they could be used
81 as an energy source after compaction to give solid biofuel. However, the latter resulting
82 from compaction poses a problem of friability [10, 11]. This reduces its interest during
83 transport, handling and storage, in short during its use.

84 Certainly, work has been carried out with the aim of reducing this phenomenon
85 (friability), in particular when clay is used as a binder [12]. Binders are organic or inorganic
86 substances that can be added, generally in a lower quantity, to feedstock for pelletization, in
87 order to improve the mechanical characteristics of the pellet. In addition, binders can reduce
88 the energy required for palletization. However, lignocellulosic biomass should be converted
89 to a more hydrophobic, homogenized, energy dense fuel, with better handling characteristics
90 from its raw conditions [13]. On the other hand, there is no work on the use of arabic gum
91 as a binder for the production of pellets from rice husks [14, 15]. Therefore, the objective of
92 this work is to produce solid biofuel from rice husks using gum arabic as a binder in order
93 to reduce its friability and improve its handling.

94

95 **2. Materials and methods**

96 ***2.1. Preparation of samples***

97 Rice husks samples of NERICA variety were obtained from SEMRY (Yagoua Rice Expansion
98 and Modernization Company) from Yagoua in the Far North Region of Cameroon. Rice
99 husks samples were sorted by screening on metallic sieve in order to retain samples with
100 diameter ≤ 0.5 mm.

101 Arabic gum was harvested, for its quality like binder, from Mindif in the Far North Region of
102 Cameroon. It was dried and crushed before being sieved to retain samples with diameter \leq
103 0.5 mm.

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111 ***Figure 1. Rice husks from SEMRY***

Figure 2. Arabic gum from Mindif

112 ***2.2. Production of pellets***

113 The crushed arabic gum compound was mixed with water for solubilization. This operation
114 was done using a defined quantity of gum (50 g) for three volumes of water (100, 150 and
115 200 mL) according on the work of Ouattara [6]. During this process, three different
116 formulation intakes were used, notably, 1:2, 1:3 and 1:3 m/v binder/water ratio. After adding
117 the adequate amount of water using a 250 mL graduated cylinder, the solution was stirred in
118 order to homogenize it well. The 250 and 500 mL Erlenmeyer flasks were used for mixing
119 arabic gum with water. For each solution formulated, the time was noted. Following the
120 preparation of the binder, it was poured into a box which contained 100 g of the rice husk
121 while mixing to compact into balls. Each time the behavior of the mixture changes, the
122 amount of binder poured was noted. Thus, for each operation a pellet was obtained and
123 exposed for sun drying.

124 ***2.3. Physicochemical and biochemical analysis***

125 Biochemical and chemical analysis were done according to UICPA method [16] for dry

126 matter, ash and minerals contents; protein, crude fiber, extractible compounds, cellulose,
127 lignin, hemicellulose and lipid contents was carried out by standard methods of AFNOR [17],
128 total energy by the method of Edem et al. [18]. LHV and electrical conductivity were
129 determined by AOAC method [19]. LHV of pellet has been determined as follow: samples
130 have been wheighed using a precision balanced (*Balance de précision Sartorius Practum*
131 *224-1S, Paris, France*). This sample is introduced in a bomb calorimeter (*DDS - CAL2K*), the
132 lid is locked and the initial temperature noted. The reaction is allowed to run to completion
133 and the calorific value is recorded as seen on the bomb Calorimeter in cal/g. This value is then
134 converted to J/g for easy calculations from which the lower calorific value is then obtained by
135 dividing the calorific value by 1.06.

136 Friability index and toughness were determined according to ISO standards [20]. Friability
137 index test consisted in subjecting 10 pellets to a regular fall force for a given time in order to
138 to appreciate the loss of mass of these pellets. Toughness or Shock resistance has been
139 determined by estimating the hardness of a pellets by measuring the intensity of the force that
140 is diametrically applied to cause its rupture by crushing.

141 **2.4. Combustion tests**

142 Combustion tests were carried out in the laboratory for each sample, in batch condition in a
143 circular furnace electrically heated at 500°C (PYROX VK65/500) in which, the burning time,
144 the ash rate and the amount of smoke have been determined. For this purpose, 500 g of pellets
145 were introduced at t_0 into the preheated oven and after 15 minutes, the combustion process
146 was stopped.

147 **3. Results and discussion**

148 **3.1. Physicochemical characterization**

149 The results from the characterization of the rice husk are presented in the table 1. The dry
150 matter content was 94.736%. The results obtained show that this variety of rice husk has a

151 same water content compared to that studied by Delot [21] and Akintayo et al. [22], whose
 152 values were 6.41 and 7.04% respectively. The analysis carried out by Adamon et al. [23]
 153 showed that the average moisture of the rice husk was 10%. This difference in the data
 154 obtained may be due to the ambient temperature and the relative humidity of the study areas.
 155 Water plays both the role of binding agent and lubricant. For forest biomass, humidity
 156 between 5 and 10% (wet basis) seems to be optimal for obtaining pellets of good durability.
 157 This range seems to be in general slightly more high for agricultural herbaceous plants,
 158 between 10 and 20% (wet basis).

159 The ash content obtained was 17.046% compared to that resulting from the work of Adamon
 160 et al. [23] which was 18.3%. On the other hand, this value is high in view of the one noted by
 161 Delot [21], which was 13.91%. Delot [21] gave an interval of 17 to 26% of the ash content for
 162 the rice husk. This difference was explained by the quality of each variety of the rice husk. It
 163 can also be the cause of the heating temperature to obtain the ash.

164 Results in table 1 show that the organic matter content is very high. At the end of the
 165 analysis carried out it was 67.454%. Adamon et al. [23] obtained a higher value of 70.6%.
 166 Work carried out by Edouard [4] showed that it varied from 70 to 80%. Delot [21]
 167 demonstrated that this value was 83.8%. These inequalities can be related to the dry matter
 168 content of the rice husks varieties. They can also come from the heating temperature. The
 169 fixed carbon content was deduced from the organic matter at 15.5%.

170 **Table 1.** *Physicochemical characteristics of rice husks*

Physicochemical parameters	Values
Dry matters (%)	94.736
Ashs (%)	17.046
Oganic matters (%)	67.454

Fixed Carbon (%)	15.5
Extractible matters (%)	16.864
Lignin (%)	25.266
Cellulose (%)	35.466
Hemicellulose (%)	34.667
Particles ratio (%)	61.2
LHV (J/g)	1178
Electrical Conductivity (mS/cm)	0.756

171

172 The average lignin content was 25.266 %. Delot [21] obtained 15.04 % during his studies.
 173 This difference could be due to the characteristics of the rice varieties used. The
 174 holocellulose content from this study is very high. Its value is 70.133 %. This shows that the
 175 rice husk studied consists mainly of a high content of polysaccharide (cellulose and
 176 hemicellulose).

177 Table 2 show that minerals content varies between 20 ppm (Mn) to 11680 ppm (SiO₂).
 178 Cereal husks appear to contain significant amounts of silica. Rice, however, clearly stands out
 179 from the rest cereals, with a silica composition in its straws more than three times greater
 180 other cereals. Mn value content is low and it is within the critical level range of 51 to 350
 181 ppm. The high concentration of silica content of the rice husk is an obstacle to the transfer of
 182 moisture from the surrounding air to the rice husk. This is an asset for the conditioning of this
 183 biomass, which is not likely to absorb a significant amount of moisture. These characteristics
 184 are benefit for pellet production. A fairly large concentration of Mg (690.00 ppm) is also
 185 found for the rice husk.

186 Low water content and higher mineral content show that rice husks have great hability for

187 its storage. Delot [24] conducted same studies on maximum humidity level that a material
188 must contain for its storage. This study revealed that to prevent decomposition, humidity level
189 should not be above 15%.

190

191

Table 2. Mineral composition of rice husks

Minerals	Values (ppm)
Fe	67.98
Ca	294.00
Mg	690.00
K	120.25
Na	50.62
Zn	36.19
Al	240.15
Mn	20.00
P	280.00
SiO ₂	11680.00

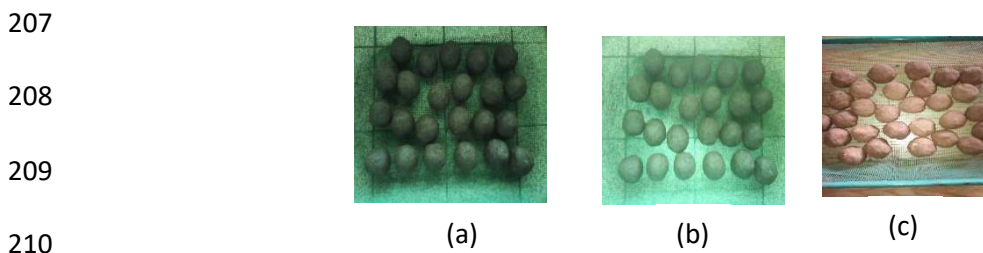
192 Thus, the values obtained meets this criterion. For this purpose, this material can be stored
193 easily without being exposed to rotting due to its decomposition by microorganisms. This
194 shows that its supply does not present any risks. This is an asset for its use in the
195 industrialization of the recovery of plant residues by the production of cooking energy [25,
196 26].

197 **3.2. Pellet formulation and thermophysical characteristics**

198 The pelletization process overcomes certain obstacles posed by biomass; it is thus more and
199 more commonly put in works as a pre-treatment step for the production of energy from
200 biomass, because it has several advantages among which the densification and standardization

201 of the geometry of the fuel [27, 28]. By bringing biomass particles into close contact with the
202 binder, this process appears to elsewhere well suited to implement potential interactions
203 between biomass particles during the reactions that take place during combustion. It is why
204 the pellet form was chosen as material conditioning first [29].

205 The binder mixed with the rice husks gave 3 types of pellets (Fig. 3) which were
206 characterized (Tab 3).



211 **Figure 3.** Pellets produced (a) from the 1:2 ratio ; (b) from 1:3 ratio and (c) from 1:4 ratio

212 Pellets of 20 ± 5 cm were obtained with color depending on the amount of water and binder
213 ratio. The more the binder was poured, the darker the color of the pellets obtained was leading
214 to the conclusion that arabic gum has a coloring character. Figure 3 shows the different colors
215 depending on the volume of the binder in relation to the amount of water. This difference was
216 also observed in the drying time for an average temperature of 33°C which varied from 3 to 7
217 days depending on the type of pellets. This drying time is influenced by the rice husk/binder
218 ratio.

219 The water content of the pellets produced from a 1:2 water ratio was low. The studies carried
220 out show that its average water content was 7.97%. The average water content of pellets made
221 from 1:3 water ratio was higher than those compacted from 1:2 ratio. Its average value was
222 8.88%. For 1:4 this value was 9.94%.

223 It emerges from the analysis that water content is proportional to the volume of water used
224 for the formulation [30]. This can be explained by the fact that the rigidity that the binder
225 confers to these solid biofuels does not allow the light rays to be able to dry the pellets well

226 [31]. This is justified by the hydrophilic nature of arabic gum [32].

227

228

Table 3. Thermophysical characteristics of pellets

Water ratio	Water content (%)	Shock resistance (mPa)	Friability Index	LHV (J/g)
1:2	7.97 ± 0.31^a	199.977 ± 2.523^b	0.44 ± 0.021^a	1879 ± 12.056^b
1:3	8.88 ± 0.47^b	189.988 ± 3.739^a	0.63 ± 0.052^b	1741 ± 22.845^a
1:4	9.94 ± 1.08^{bc}	187.994 ± 5.186^a	0.59 ± 0.042^b	1763 ± 18.743^a

229 The results having the same letters in exponent on the same column are not significantly different (probability threshold $P \leq 0.05$)

230 It appears from Figure 3 and Table 3 that the textural profile and thermophysical
231 characteristics of the pellets varied according to the type of treatment. Water ratio
232 significantly influence ($p < 0.05$) water content which is 7.97 ± 0.31 , 8.88 ± 0.47 and $9.94 \pm$
233 1.08 % respectively for 1:2, 1:3 and 1:4 water ratios. These treatments also had significant
234 effects on the shock resistance, friability index and LHV ($p < 0.01\%$) between 1:2 water ratio
235 and others. As regards the ANOVA ($p < 0.05$), there is no significant difference ($p < 0.05$)
236 between 1:3 and 1:4 water ratio, but a significant difference with 1:2. It can be seen from the
237 table 3 that the friability index of the different pellets varies according to their moisture
238 content which is linked to their ratio. It is clear that the friability index increases as the
239 humidity level increases. This is because the water enhances the effects of the binding agent
240 by helping to generate the Van der Waals forces by increasing the surface area of the particles
241 [33]. These results are in agreement with those of Pereira et al. [34], who state that water
242 plays a binding role in the compaction of wood debris during the production of pellets.

243 In short, it emerges from these results that the shock resistance, friability and LHV of a
244 pellet depends on the amount or concentration of the binder used in its manufacture (water
245 quantities) [35]. Thus, the more this solid biofuel is produced with a high volume of water and

246 low amount of binder, the less resistance shock and LHV will be. These thermophysical
247 characteristics of a pellet are therefore proportional to the concentration of the binder and of
248 its compaction. This shows that the pellets produced can be used easily without crumbling
249 like reported by Racicot [12]. This character has environmental, economic and socio-cultural
250 impacts.

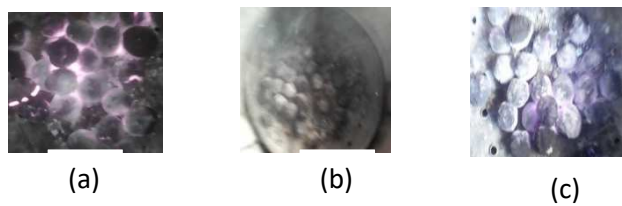
251 The water content of the pellet produced from a 1:2 water ratio was low. The studies carried
252 out show that its average water content was 7.97%. The average water content of pellets made
253 from 1:3 water ratio was higher than those that were compacted from 1:2 ratio. Its average
254 value was 8.88%. For 1:4 this value was 9.94%.

255 It emerges from the analysis that the water content is proportional to the volume of water
256 used for the formulation like demonstrated by Patrick [36]. This can be explained by the fact
257 that the rigidity that the binder confers on these pellets did not allow the light rays to be able
258 to dry the pellets well. This justifies the hydrophilic nature of arabic gum [37, 38]. A
259 compromise should be found between the amount of water to be used and the mass of organic
260 binder to maintain the integrity of the pellet. The 1:2 ratio seems to go in this direction, which
261 is in accordance with the work of Kaliyan and Vance Morey [39].

262 ***3.3. Combustion tests***

263

264 In order to appreciate the different types of pellets produced at different water ratios,
265 combustion tests were carried out. Ignition of pellets made with 1:2 water ratio was easy and
266 solid biofuel ignite easily. The figure 4 shows the quality of the embers that burn without the
267 release of smoke. However, analysis performed show that ignition was difficult for the 1:3
268 water ratio pellet. Pellets have a hard time burning. It emitted fumes. It is the same for the
269 pellets obtained from 1:4 water ratio. They found it difficult to burn. Excessive smoke was
270 given off.



272 **Figure 4.** Combustion tests of pellets produced (a) from the 1:2 ratio ; (b) from 1:3 ratio and
 273 (c) from 1:4 ratio

274 During combustion tests, only the pellets from 1:2 ratio burned were well. After 30 minutes
 275 of ignition, the embers were deactivated; during this test, it was noted that the charcoal
 276 produced can be reused. This is not the case when using clay as a binder [23]. Some authors
 277 have shown that the high concentration of minerals in clay has a negative impact on the
 278 combustion of biofuel [40, 41]. The rice husk being rich in SiO₂ with regard to Table 2 of the
 279 present work, the addition of clay as a binder seems inappropriate for a quality pellet [42, 43].
 280 It is therefore obvious that the use of organic binders have better yields.

281 The combustion test reveals that the excess of water in the final product has a negative
 282 impact on its subsequent use and the nature of the binder seems to play a determining role
 283 [44, 45, 46].

284 **4. Conclusion**

285 During the study focused on the resolution of cooking energy deficits that are present in
 286 areas with fragile ecology where anarchic cutting of trees for firewood was carried out, the
 287 share of biomass to the satisfaction of this livelihood need of the population was addressed.
 288 This work consisted of contributing to the improvement of the quality of the solid biofuel
 289 produced from the husks of the SEMRY rice by using arabic gum from the natural formations
 290 of Mindif in the Far-North region of Cameroon. The physicochemical analyzes carried out
 291 showed that the rice husk from the SEMRY rice NERICA variety consisted of dry matter
 292 content (94.736%). The average lignin content was 25.266 % and holocellulose one was

293 70.133 % showing that the rice husk studied is mainly composed of polysaccharides. It
294 emerges from this work that minerals content varied between 20 ppm (Mn) to 11680 ppm
295 (SiO_2). Mn value content was low and it was within the critical level range of 51 to 350 ppm.
296 The high silica content of the rice husk was an obstacle to the transfer of moisture from the
297 surrounding air to the rice husk. This is an asset for the conditioning of this biomass, which is
298 not likely to absorb a significant amount of moisture. These characteristics were therefor
299 benefit for pellet production.

300 These results showed that the shock resistance, friability and LHV of a pellet depend on the
301 amount or concentration of the binder used in its manufacture (water quantities). Pellets made
302 from rice husks are a source of energy. Its optimal use requires densification, which can be
303 done by means of binders. However, because of its high SiO_2 content, organics binder such as
304 gum arabic which is underutilized offer a better potential for the production of solid biofuels
305 for the poor population.

306 This shows that the pellets produced can be used easily without crumbling. This character
307 has environmental, economic and socio-cultural impacts.

308

309 **Author Contributions:** Conceptualization, D. and H.B.; methodology, D. and H.B.; software,
310 G.C.; validation, D. and M.P.; formal analysis, D. F.A.; Investigation, F.A. and M.N.L.J.;
311 resources, D. and C.G.; data curation, M.N.L.J.; writing—original draft preparation, D. and
312 H.B.; writing—review and editing, D. and G.C.; supervision, M.P. and G.C.; project
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323

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