ASSESSING THE INFLUENCE OF COMPACTATION PRESSURE, MOISTURE AND AVERAGE PARTICLE SIZE ON THE QUALITY OF PELLETS MADE FROM MIXTURES OF INVASIVE ACACIA AND NUTSHELLS

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Abstract. *Finding alternative energy sources to reshape the energy mix is a major concern of all western economies. Reducing the weight of the imported energy bill is becoming an increasingly important factor, an imperative to countries with reduced strategic autonomy and public debt financial difficulties. This preliminary study puts the emphasis on determining the influence on the quality of some manufacturing variables on pellets made of Acacia spp., a species classified as invasive due to its significant spreading capacity and considerably high ability to resist to hostile environment, mixed with nutshells (hazelnuts, almonds and walnuts), a by-product of local agro industries. Compaction pressures resulting from applying 8 and 16 kN forces to a 10 mm internal diameter die, moisture contents of 33 and 23 % (wb) and particle sizes between 850 and 2000 μm were used and the results compared to pellets produced by current industrial manufacturing processes. These several experimental procedures were statistically analyzed using SPSS 17. Data were tested in different comparison tests and the results exhibited some significant differences between the pellets obtained.*

Keywords*: bioenergy, pelletizing, invasive species.*

1 INTRODUCTION

Biomass is one of the oldest source of energy known to men, and is recognized as an important renewable energy (Demirbas, 2009; Jonsson, 2009). Countries with reduced energy autonomy have a strategic interest in limiting their dependence from external/foreign energy suppliers, developing the research for alternative energy sources. Those new energy sources must be reliable and sustainable. The compaction of biomass is a way to obtain a uniform and reliable energy source that is being increasingly perceived as a valid and promising alternative. One way to achieve densification is called pelletization. Pellets are an easy way to store and transport nature's biomass, an alternative energy transfer process from places where the raw material exists to places with stronger energy needs (Panoursou, 2011).

Another important aspect, common to most countries, is the development of new industries, especially if located in areas where jobs are scarce and, therefore, represent an important factor to economic development, and human depopulation combat. If the production of agricultural areas is valued, by means of such densification processes, those regions will have an instrument that will help to maintain people and industry in place and, probably, to enhance the latter.

Pellets production will enable taking the advantage of using a local material, biomass, which is a result of storing solar energy in plants (Champagne, 2008), and developing applications that use it as feedstock for the energy conversion process. That will make it easier to predict the heat input and will facilitate using automated feeding systems (Quaak *et al*., 1999). The pellets usually have a cylindrical shape, with diameters between 6 and 12 mm and 10 to 30 mm long. The most used raw material in the manufacture of pellets is pine and, in order to reduce the costs, in the form of sawdust, since it eliminates the need for grinding. Pellets made with this species are easy to ignite and the ashes and emissions produced are lower than those obtained with other kinds of fuel (Jenkins, 2010).

Nutshell is another kind of fuel. The word 'nut' designates a large number of dried seeds, like nuts, hazelnuts, almonds, walnuts, Brazil nuts, pistachios, etc. They are usually one seed fruits that develop a very hard wall. The edible part is the internal one, the wall being rejected. Nutshells are a by-product of local agro industries, with heating values around 12 MJ/kg. When used alone for the pellet production, they present an important drawback: nutshells tend to break into fine powder, causing serious difficulties during the production, both for the pellet formation itself and concerning the amount of mass that tends to come out of the pelletizing process unused (Mani *et al*., 2006).

There was an expressed interest in using nutshells to make pellets and, to be able to reduce that inconvenient powdering effect, the use of an aggregative wooden material with high lignin content was sought.

An invasive species was envisaged and *Acacia spp.* (*A. dealbata*, *A. longifolia*, *A. melanoxylon*) was chosen due to its wide availability in this region. *Acacia sp.* is a fast growing evergreen tree or shrub that can get up to 20 m tall, well adapted to temperate, arid and semiarid climate and tolerant to cold. In Portugal, it is classified as invasive (DL565, 1999) due to its significant spreading capacity and considerably high ability to resist to hostile environment (Peperkorn *et al*., 2005). There are also some biological attributes that facilitates the invasive characteristics, such as tolerance to changing soil conditions, taking advantage of environmental disturbances, vegetative reproduction and fire tolerance (Lorenzo *et al*., 2010). It has a growth rate of 15 ton ms/ha/year (Freire et al., 2003), resembling the observed to *Pinus pinaster* (May and Attiwill, 2003. This makes it an interesting species in the field of energy crops as no competition appears among different final uses of the plant. Also, the lignin content allows the prospective development of mixtures for the production of pellets. In some countries this species of *Acacia* is called “Mimosa” (Fernandes, 2008).

2 MATERIALS AND METHOD

One of the aims was to choose a substance that could be used as a local source of biomass feedstock, with reduced or even unknown previous useful applications, to find new uses for biomass and biomass wastes. That search was going to include species that were up to then considered either as waste or as invasive species. Furthermore, the area of Viseu has plenty of *Acacia*, and at the same time it is a region seeking increased development and new industrial activities.

The *Acacia spp.* was collected in the area of Viseu. The material was selected according to the predicted growth in two years, in the form of round wood with diameters less than 2 cm (Freire *et al*., 2003). In doing so, harvesting and gathering material from a given location every two years would create a sustainable source of wood material. To produce pellets from this raw material it is necessary to chip the tree. In this case, one single pass through the knife mill was sufficient to obtain the material with the required size for the pressing process. Another single pass through the industrial hammer mill was also made, as it was the usual manufacturing procedure.

The method used to determine the water content consists of weighing a sample of 100 g before and after drying it at 105ºC. The drying process is halted when no weight change can be noticed. This procedure was performed according to ÖNORM G 1074 (ON, 2002). As the manufacturing of pellets requires moisture contents lower than 12% (wb), the original biomass had to be dried out. The process of drying was performed using a lab stove and a solar drier. The latter embraces a ‘less fossil fuel consumption’ concept, bypassing one of the more expensive phases of the processes involved in the pellets production (Ananias et al., 2008).

The nutshells were collected in a local agro industry located in Mangualde, region of Viseu. The shells were considered a waste and were sold to locals at low prices, which use them in conventional heating systems.

Both raw materials, after being chipped and sieved through the hammer’s grates, were passed through a mechanical vibratory grading system (Retsch AS200) to obtain average sizes within the 850 to 2000 μm range,. The *Acacia* particles with less than 850 μm were rejected; there were no particles with sizes greater than 2000 μm. The same was done with the nutshells.

The final sieve grading was made only with the dried material, as the wet one tends to aggregate, making the grading difficult to perform and the average particle size results inaccurate.

Although the sieves separate the material by size, the sizes between 2000 and 850 μm include a small quantity of small powder that adheres to the rest of the larger particles. This small powder will be called “dust particles”.

2.1. Material preparation

Biomass samples were ground using a lab knife mill, for the case of the pure compression pellets, and an industrial hammer mill (AGEM TFS420), for the case of the industrial pellets. The first machine had a screen size of 2.5 mm, the second one a 3.2 mm screen size. The samples did not need wetting as the raw material was collected during winter with average moisture contents of 39% (wb). They were subsequently dried in a lab stove (Venticell 55L) and a solar drier (Paiva and Lopes, 2010), respectively for the pure compression and industrial pellets, until they reached moisture values in the 23 to 33% (wb) range. Once the raw materials had the desired moisture content and size dimension, different mixtures were created, with 40, 60, 80 and 100% *Acacia* (wt.).

2.2. Pressing

The samples with the above mentioned mixtures and moisture contents were used to create pure compression pellets with 8 and 16 kN applied forces, using an INSTRON Universal Testing Machine (Kaliyan and Morey, 2010) coupled to a single-pelleter (plunger-die) and the industrial pellets, using a roller-and-die pelletizing machine (AGI GC-9PK200).

With the Universal Testing Machine, from every mixture, samples with 2 ± 0.01g were prepared and placed inside the cylindrical matrix with 10 mm internal diameter. A pre-pressing was applied to maintain the material in site, to reduce the amount of air between the particles and to shorten the trajectory of the piston (Relova *et al*., 2009). The pressure was applied by a hydraulic press that could exert a force up to 100 kN. For every mixture sample five pellets were made and the corresponding length and weight measured, using a digital caliper and a precision scale, respectively. A sample of the results for 8 and 16 kN applied loads is illustrated in Fig. 1.

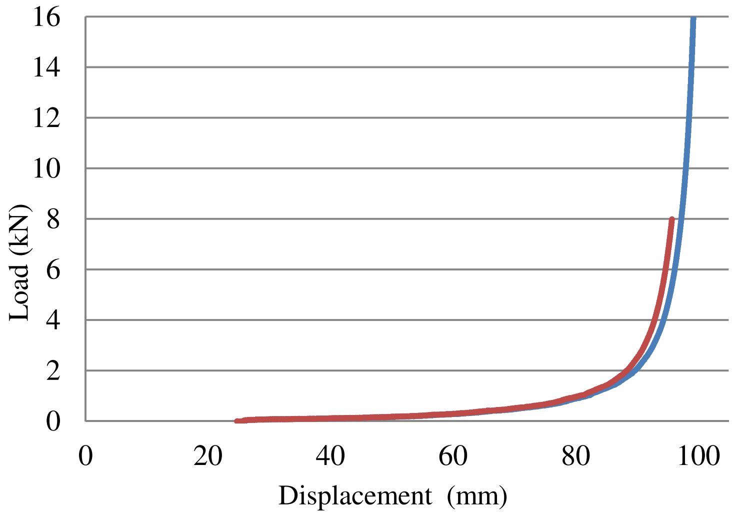

Figure 1. Applied load *vs.* displacement, pure compressions pellets: red line- 8 kN, blue line- 16 kN.

The pellets produced by this method proved to be quite fragile. The lower the pressure, the more fragile the pellets, as can be observed examining the pictures taken immediately after manufacturing them (Fig. 3). Shortly after, the pure compression pellets begun to crumble, especially in the case of the pellets produced with the 33% moisture (wb) material and with lower pressures.

Nonetheless, pure compression pellets demonstrated the same pattern behavior of known wooden materials (Mani *et al.*, 2006) and other invasive local species (Marques *et al.*, 2010), with a change in slope approaching densification values of 70%.

Further increases in density are expected to involve an increase in the fragility of the pellets (Relova *et al.*, 2009). In the case of the industrial pellet machinery, the pellets were produced with the same mixtures.

The pressure applied was not measured nor calculated but, looking at the significant rise in temperature that can be witnessed, its value must be considerably high; the high temperatures attained, beyond 174 ºC (melting point of lignin), lead to the polymerization of the lignin (Fang *et al.*, 2008), promoting the adhesion between the particles of the raw material and thus constituting one major aggregation factor that will be decisive for the quality issues.

2.3. Analysis method

The pure compression pellets revealed to be quite fragile and tend to crumble easily with the application of any or force. The pellets created with the industrial pellet machinery were tested to assess some relevant variables of the final product: dimensions, particle density, bulk density and mechanical durability.

Those variables will be used to perform an evaluation of the correlation coefficient using SPSS Statistics (Statistical Package for the Social Sciences, 2011): a correlation matrix that allows determining the linear relation between the variables and the degree of significance is created; an assessment of the dependent variable variance is also delivered.

2.3.1. Mechanical durability assessment

One of the major features involved in the pellets production is the mechanical durability. As the places where they are produced are most of the times far away from the places where they are burnt, handling and transportation have a severe impact on the final product received by domestic users.

The mechanical durability expresses therefore the ability of the densified biomass to remain undamaged when it is subject to shock or/and friction.

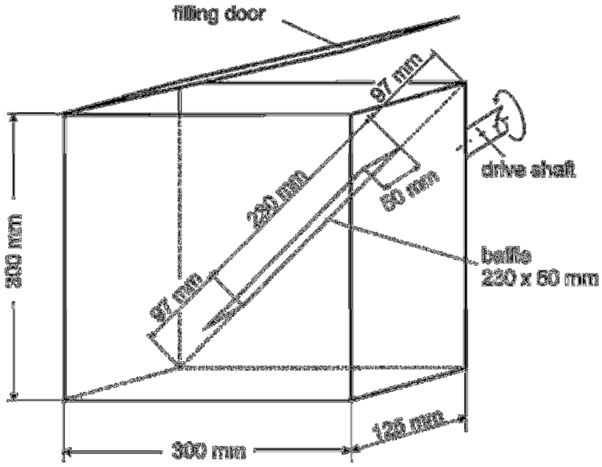

Figure 2. ASAE S269.4 apparatus for durability testing of pellets (Temmerman *et al*., 2006).

The apparatus used to determine the mechanical durability is the described by the standard ASAE S 269.4, as explained by Temmerman *et al*. (2006). A tumbling device, like the one represented in Fig. 2, made of stainless steel, was used. Welded to one surface of this container is a baffle with 230 × 50 mm, located along the diagonal of the container. This container tumbled 500 g samples at 50 rpm for 10 min. The resulting material, after these experiments were done, was manually calibrated with a 3.15 mm sieve with round holes, according to ISO 3310.2 (Temmerman *et al*., 2006). The mechanical durability was then determined considering the weight percentage of the unbroken pellets.

2.3.2. Physical properties

To determine the particle density, the ÖNORM M 7135/6 (ON, 2002) was followed, as it establishes the method to determine the dimensions by measurement of the diameter and length. It states that 15 randomly picked individual pellets must be used as a sample to calculate the ratio length/diameter.

The bulk density of the pellets was determined using the referred sample, weighed with a laboratory scale. That sample was dropped from a height of 15 cm into a container, which volume was previously using atmospheric pressure and ambient temperature. The density was calculated considering that the pellets have a cylindrical shape.

3. EXPERIMENTAL DATA

3.1. Visual analysis

Due to the large number of samples created, only the most relevant pictures of the different type of pure compression pellets created with different *Acacia* contents, different moistures and different pressures are presented in Fig 3.


40 % *A* + 60 % N
33 % wb + 8 kN


40 % *A* + 60 % N
33 % wb + 16 kN


40 % *A* + 60 % N
23 % wb + 8 kN


40 % *A* + 60 % N
23 % wb + 16 kN


100 % *A*
33 % wb + 8 kN


100 % *A*
33 % wb + 16 kN


100 % *A*
23 % wb + 8 kN

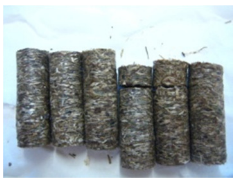
100 % *A*
23 % wb + 16 kN

Figure 3. Images of pellets made by pure compression using different mixtures, moistures and applied pressures. (A-Acacia, N- Nutshells)

For the same mixture, differences between the applied pressures can be identified, once the pellets produced with the lower pressure are, as expected, more fragile. Similarly, different moisture contents also affect the pellets fragility. It can also be noticed that the yields obtained from sole *Acacia* are less fragile.

3.2. Dimensions

The pellets created by pure pressure had the dimensions that can be observed in Fig. 4.:

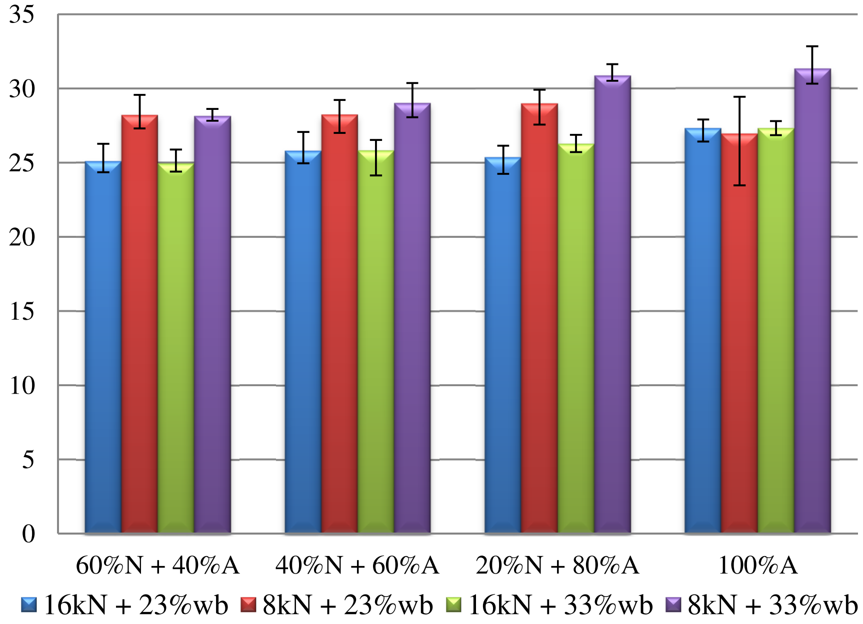

Figure 4. Length of the pure compression pellets produced (mm).
(A – *Acacia*, N – Nutshells)

In the case of the industrial pellets, the length can be the seen in the Fig. 5:

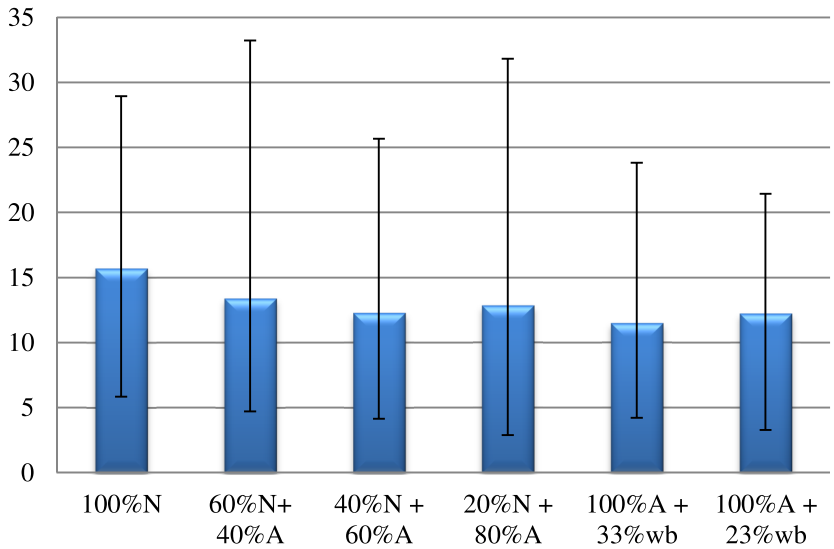

Figure 5. Length of the industrial pellets (mm).
(A – *Acacia*, N – Nutshells)

In the case of the industrial pellets, made with a matrix of 6 mm internal diameter, it was also determined the diameter, thus verifying that the diameter is slightly lower than of the matrix used, but not significantly.

In the case of the industrial pellets, one other important aspect is ratio between the length and the diameter. A representation if this ratio can be seen in the Fig. 6:

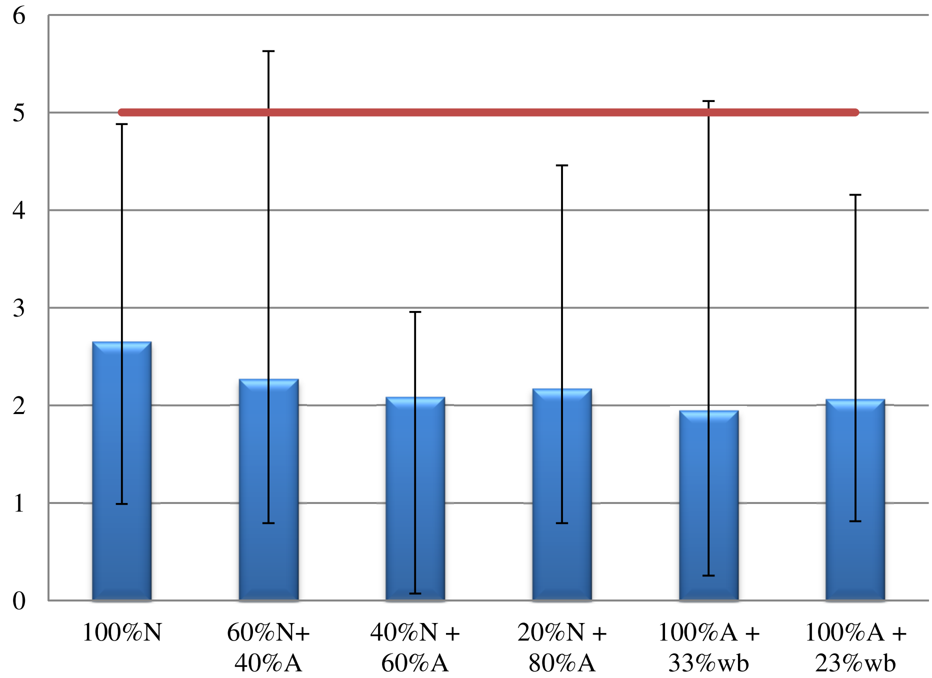

Figure 6. Ratio length/diameter (straight red line- maximum desirable value, 5).
(A – *Acacia*, N – Nutshells)

3.3. Particle density and bulk density

As referred in section 2.3.2., 15 industrial pellets randomly picked were weighted. Corresponding data is presented in Fig. 7:

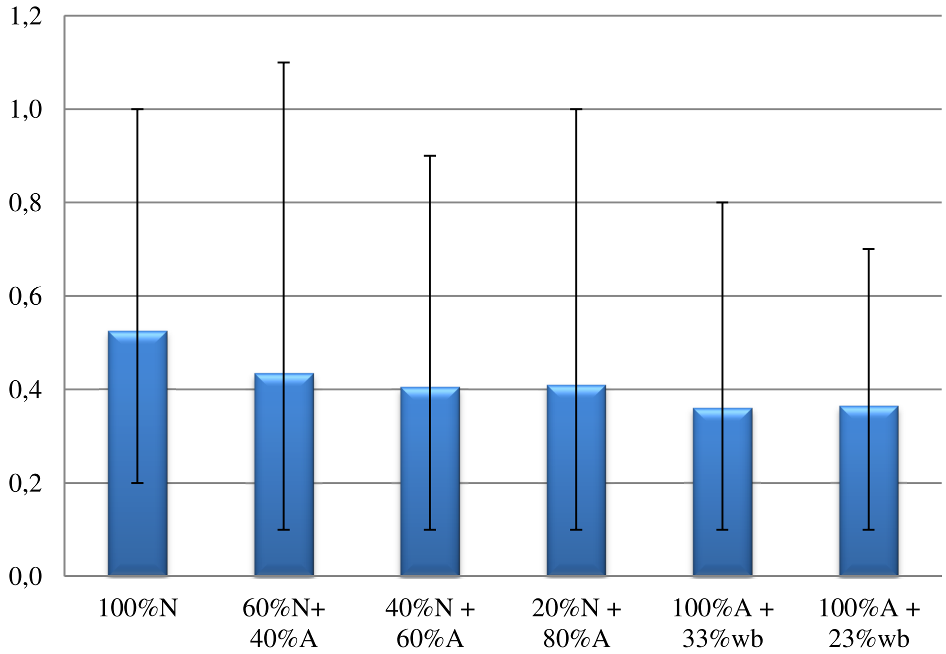

Figure 7. Weight of the industrial pellets.
(A – *Acacia*, N – Nutshells)

The density was calculated according to the methods indicated earlier, and can be observed in Fig. 8:

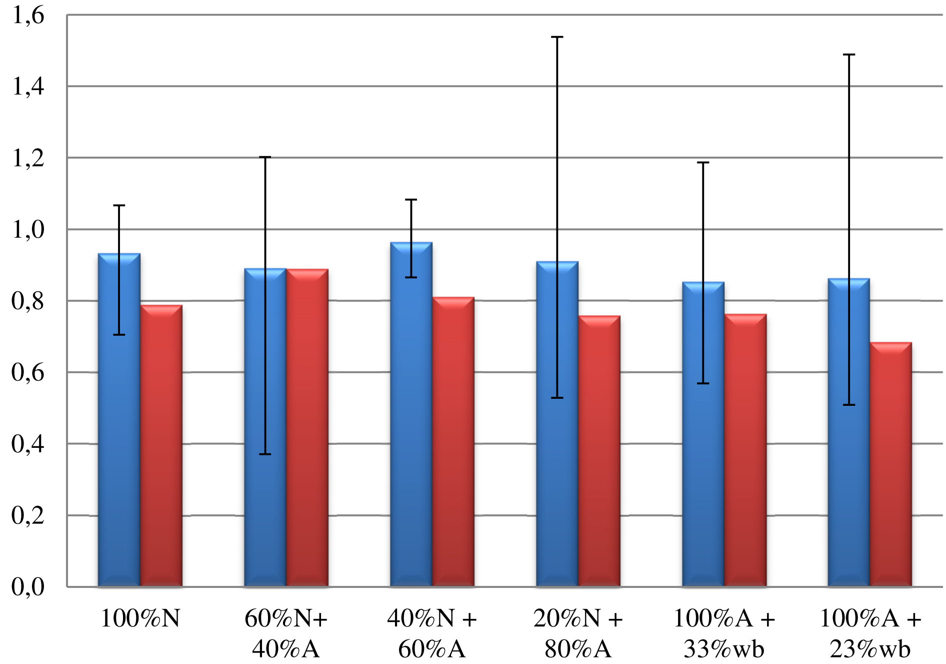

Figure 8. Particle density (blue) and particles bulk density (red).
(A – *Acacia*, N – Nutshells)

3.4. Durability

In Figure , the values of the mechanical durability obtained for the different mixtures of materials can be observed.

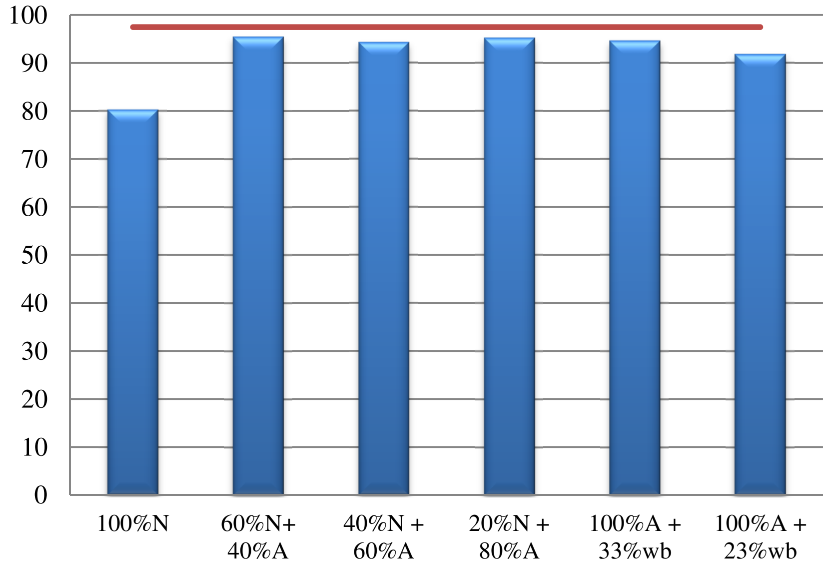

Figure 9. Mechanical durability obtained for different mixtures.
(A – *Acacia*, N – Nutshells)

The red line indicates the desirable index quality value of 97.5, a minimum value under certain European standards (that will most certainly become the European Union standard).

4. RESULTS

With the data shown in Fig.s 4 to 9, SPSS was used to determine the level of correlation between the variables. The results can be seen in Table 1.

Table 1. Correlation Table. 'PC' is the Pearson correlation and 'Sig' is the Significance level (2-tailed). Weak correlations are highlighted in blue, strong correlations in red.

		Acacia	DU	Moisture	LPCP	LIP	OD	Weight	Density	L/OD
Acacia content	PC	1	.553	-.259	.671	-.358	.074	-.387	.278	-.356
	Sig		.198	.575	.215	.430	.874	.391	.546	.433
Durability– DU	PC	.553	1	-.447	-.878	.271	.186	.258	-.509	.268
	Sig	.198		.314	.051	.556	.690	.576	.243	.561
Moisture	PC	-.259	-.447	1	.265	-.584	-.834*	-.528	.275	-.537
	Sig	.575	.314		.667	.168	.020	.223	.550	.213
Length pure compression pellets– LPCP	PC	.671	-.878	.265	1	-.842	.060	-.538	.779	-.292
	Sig	.215	.051	.667		.074	.923	.350	.121	.633
Length industrial pellets– LIP	PC	-.358	.271	-.584	-.842	1	.692	.997**	-.499	.997**
	Sig	.430	.556	.168	.074		.085	.000	.254	.000
Outer diameter– OD	PC	.074	.186	-.834*	.060	.692	1	.655	-.311	.663
	Sig	.874	.690	.020	.923	.085		.110	.497	.104
Weight	PC	-.387	.258	-.528	-.538	.997**	.655	1	-.504	.999**
	Sig	.391	.576	.223	.350	.000	.110		.249	.000
Density	PC	.278	-.509	.275	.779	-.499	-.311	-.504	1	-.478
	Sig	.546	.243	.550	.121	.254	.497	.249		.278
Ratio length/OD	PC	-.356	.268	-.537	-.292	.997**	.663	.999**	-.478	1
	Sig	.433	.561	.213	.633	.000	.104	.000	.278	

*- Correlation is significant at the 0.05 level (2-tailed).
**- Correlation is significant at the 0.01 level (2-tailed).

As was observed in Fig. 9, the studied mixtures do not reach the desirable value of 97.5%, concerning the mechanical durability. For most of the pellets created, the ratio length/diameter is less than 5, which represents a constraint for automatic feeding systems. Nonetheless, these were pellets produced without using a device called 'knife' that can limit the length. Particle density and the particles bulk density present the expected values for such wooden materials. The results of the statistical treatment carried out with SPSS, analyzed considering Pearson correlations (PC) values higher than ±0.7 as 'strong correlation', values between 0.3 and 0.7, 'moderate correlation', and below 0.3, 'weak correlation', show a single strong correspondence of the quality index with the variable 'length'.

As stated by Mani *et al.* (2006), pellets density, expectedly, not only is affected by the applied compression level, but also by the moisture content, namely decreasing with the increase of the moisture content for values between 28 and 44% (w.b.) and, between 6 and 25%, a better durability. This is not the case of the pellets produced with *Acacia*, where the behavior appears to be the opposite, once the better durability is obtained with a wetter material.

5. CONCLUSIONS

Durability, as one of the critical quality parameters in pellets production, has still an insufficient value when these samples are considered. Pellets quality depends strongly on applied pressure and durability shows a strong negative correlation with length, which confirms that shorter pellets break less. The manufacturing of pellets with mixtures of different levels of *Acacia* leads to different characteristics, the obtained results confirming the influence of the raw materials used.

For all of the samples studied, moisture does not seem to have a strong influence on the quality and does not show a significant correlation with any of the variables considered. This not only contradicts expectations but also the industrial pellets behaviour produced with 100% of *Acacia* and must be investigated under the fact that *Acacia* appears to have a similar behavior to some hardwoods. Also, further studies must be developed to establish more clearly the role of moisture on the durability of this kind of pellets.

The applied pressure of the pure compression pellets produced show to be relevant to the fragility of the pellets produced, thus confirming Mani *et al.* (2006) results for grasses. Higher pressure values should, nevertheless, be experimented, as pellets have shown to be frailer than expected.

The use of *Acacia* for the production of pellets appears to be an interesting opportunity for the industrial production of pellets as it values the use of materials that currently do not have any application. The influence of nutshells needs further experimental data. This very preliminary study should be continued to investigate set of mixtures and moistures that will enable determining specific compositions that demonstrate optimal behavior.

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