ABSTRACT: The purpose of this work was to study the influence of different varieties, sowing dates, plant populations and the harvest date on the kenaf biomass quality and productivity, in Portugal, in order to access its potential as an industrial and energy feedstock. Biometrical parameters and the productivity of the biomass were evaluated at the end of each growing season, in the period 2003-2005. The following parameters were analysed: main stem height, diameter at the base, measurement of the leaf area index and of the specific leaf area and the total aerial dry weight. Biomass quality was also determined at the end of the growing season. The organic matter content, the nitrogen content, the phosphorous content, the fiber content and the heat of combustion were determined in order to evaluate the potentiality of this crop for pulp, fuel and other industrial purposes. Biometrical parameters, productivity and biomass quality were affected by the sowing date. Plants sowed earlier were higher, with a higher diameter at the base and higher leaf area index, presented higher productivities and higher energy content with lower N and P content than plants sowed later. Fields with higher plant populations also presented higher leaf area index and higher productivities but those plants presented a similar chemical composition to plants obtained from fields with lower plant populations. Everglades 41 presented higher leaf area index and higher productivities than Tainung 2, although this difference was not significant. Both varieties presented similar nitrogen and phosphorus composition. Everglades 41 showed higher energy content and Tainung 2 higher fiber content. Biometrical parameters, productivity and biomass quality were not affected by the date of harvest. The late October/early November harvest dates presented similar productivities and similar biomass quality than the December/January harvest dates.

Keywords: kenaf, crop cultivation, biomass composition
furnace (Heraeus Electronic); b) nitrogen content: by the Kjeldahl method (Nitrogen Analyser Tecator 1002, Nitrogen Digester Tecator 2006); c) phosphorus content: by the ascorbic acid method, after digestion of the sample (Spectrometer UV/Vis Cecil 9000); d) fiber: by the Weende method (Fiber Analyser Tecator Fibertec M1017); e) gross heat of combustion: using an adiabatic calorimeter (Parr).

3 RESULTS AND DISCUSSION

3.1 Meteorological Data (2003-2005)

Table I shows a resume of the meteorological data during the three year experimental period.

Table I: Meteorological Data during the three year experimental period

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum temperature</td>
<td>12.4</td>
<td>13.2</td>
<td>13.0</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>21.5</td>
<td>21.4</td>
<td>21.6</td>
</tr>
<tr>
<td>Total Precipitation</td>
<td>812</td>
<td>451</td>
<td>451</td>
</tr>
<tr>
<td>Total Evaporation</td>
<td>1090</td>
<td>1645</td>
<td>1318</td>
</tr>
<tr>
<td>Air humidity (%) at 9.00H</td>
<td>81</td>
<td>73</td>
<td>70</td>
</tr>
<tr>
<td>Wind speed (m/s)*</td>
<td>1.6</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Global solar radiation (kJ/m²)*</td>
<td>19179</td>
<td>18084</td>
<td>18207</td>
</tr>
</tbody>
</table>

* Average

During the three year experimental period, the average minimum temperature was 12.9°C and the average maximum temperature was 21.5°C, with an average of 571 mm total rainfall per year. Average minimum and average maximum temperatures were in accordance with average results 1961-1990, respectively 12.8 and 20.8°C. 2004 and 2005 were drier years when compared with average precipitation 1961-1990 (753 mm). 2003 was the year with higher precipitation and higher global solar radiation. 2004 was the year where a higher evaporation was observed.

3.2 Biomass Biometrical Parameters

Fig. 1, 2, 3 and 4 show the effect of different sowing dates on the biometrical parameters.

Figure 1: Effect of different sowing dates on the stem height

Figure 2: Effect of different sowing dates on the diameter of the stem at the base

Figure 3: Effect of different sowing dates on the LAI

Figure 4: Effect of different sowing dates on the SLA

According to these results, at harvest, plants sowed earlier were significantly higher (Fig. 1), presented a higher diameter of the stem at the base (Fig. 2) and a higher LAI (Fig. 3) than plants sowed later. At harvest, no significant differences were observed in terms of the specific leaf area among different sowing dates (Fig. 4). Nevertheless, it was observed an increase of SLA from plants sowed in the beginning of May to plants sowed in the middle of June and then a decrease to plants sowed in July and August (Fig. 4).

Fig. 5, 6, 7 and 8 show the effect of different varieties, different plant densities and different harvest dates on the biometrical parameters.
According to these results, at harvest, in terms of the stem height (Fig. 5) and in terms of the diameter of the stem at the base (Fig. 6), no significant differences were observed between Tainung 2 and Everglades 41, between plants obtained in fields sowed with different densities and between plants harvested at different dates. In terms of the LAI, plants obtained in the fields sowed with the higher plant density (40 plants/m²) presented higher values than those obtained in the fields sowed with the lower density (20 plants/m²), due, logically, to the higher number of plants/m² (Fig. 7). Everglades 41 presented higher LAI than Tainung 2, due, mainly, to the shape of the leaf (Fig. 7). The early harvest presented also higher LAI than the late harvest (Fig. 7). This significant decrease was due to the fall of the leaves that occurred between the early and the late harvests. No significant differences were observed, in terms of the SLA, between Tainung 2 and Everglades 41 and between plants harvested at different dates (Fig. 8). Plants harvested earlier showed higher SLA (Fig. 8) because at the late harvest a major part of the leaves had already fallen down.

3.3 Biomass Productivity

Fig. 9 shows the effect of different sowing dates on the productivity of the fields.

Fig. 10 shows the effect of different varieties, different plant densities and different harvest dates on the productivity of the fields.
According to the results expressed in Fig. 9, fields sowed earlier presented significantly higher productivities than fields sowed later. So, according to these results, at the pedoclimatic conditions of South Portugal, kenaf should be sowed in early May.

According to Fig. 10, Everglades 41 presented higher productivities than Tainung 2, although this difference was not significant. This result was already expected since both varieties belong to the same group of the late maturity varieties. This group is considered to be more productive than the group of the early maturity varieties, due to the fact that they have a longer vegetative phase [3].

Productivities obtained in the fields sowed with the higher plant density (40 plants/m²) were higher than those obtained in the fields sowed with the lower density (20 plants/m²) (Fig. 10). This difference was statistically significant, although Kenaf reduces its population during the growing season, being this effect more pronounced in the fields sowed with a higher density [4].

Productivities of the fields at October/November are similar to the productivities obtained at December/January (Fig. 10).

At the end of the growing season, the bast fiber represents 35-40% of the dry weight of the mature defoliated plant and the core represents the balance.

3.4 Biomass Quality

Table II, show the moisture content, the nitrogen content and the phosphorus content of the plant material at the end of the vegetative cycle.

**Table II**: Moisture content (%), nitrogen content and phosphorus content (% dry matter) of Kenaf, in core and bark, at the end of the growing season.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Core</th>
<th>Bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>79 ± 4</td>
<td>75 ± 5</td>
</tr>
<tr>
<td>Nitrogen (% dm)</td>
<td>0.35 ± 0.25</td>
<td>0.79 ± 0.36</td>
</tr>
<tr>
<td>Phosphorus (% dm)</td>
<td>0.30 ± 0.17</td>
<td>0.36 ± 0.18</td>
</tr>
</tbody>
</table>

dm – dry matter

In terms of moisture content, nitrogen content and phosphorus content, at harvest, no effects were observed due to the different varieties, the different plant populations and the different harvest dates [5]. In terms of the moisture content, no effect was observed due to the sowing date [5].

In terms of nitrogen and the phosphorus content, at harvest, plants sowed early, presented significant lower nitrogen and phosphorus content than plants sowed later (Fig. 11).

At harvest, bark material presented less moisture and higher nitrogen and phosphorus content than core material (Table II). Nevertheless those differences are not statistically significant.

According to Table III, core is more suitable for energy purposes than bark, due to its higher organic matter content and due to its higher gross heat of combustion, at harvest.

In terms of the organic matter content, at harvest, no effects were observed due to the different varieties (Table III), the different plant populations, the different sowing dates and the different harvest dates [5].

In terms of the gross heat of combustion, at harvest, no effects were observed due to the different plant populations and the different harvest dates [5]. But, Everglades 41 presented higher energy content than Tainung 2 (Table III) and the calorific values of the plants decrease with late sowing (Fig. 12).

**Table III**: Organic matter content (% dry matter) and Gross heat of combustion (kJ.g⁻¹ dry matter) of two varieties of Kenaf, Tainung 2 and Everglades 41, in core and bark, at the end of the growing season

<table>
<thead>
<tr>
<th></th>
<th>Tainung 2</th>
<th>Everglades 41</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Bark</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Organic matter (% dry matter)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross heat of combustion (kJ.g⁻¹ dry matter)</td>
<td>15</td>
<td>12</td>
</tr>
</tbody>
</table>

According to Table III, core is more suitable for energy purposes than bark, due to its higher organic matter content and due to its higher gross heat of combustion, at harvest.

In terms of the organic matter content, at harvest, no effects were observed due to the different varieties (Table III), the different plant populations, the different sowing dates and the different harvest dates [5].

In terms of the gross heat of combustion, at harvest, no effects were observed due to the different plant populations and the different harvest dates [5]. But, Everglades 41 presented higher energy content than Tainung 2 (Table III) and the calorific values of the plants decrease with late sowing (Fig. 12).

**Figure 11**: Effect of different sowing dates on the nitrogen and phosphorus content

The fuel quality of the harvested biomass was evaluated in terms of the organic matter content and in terms of the gross heat of combustion analyzed at the end of the growing season (Table III).

**Figure 12**: Effect of different sowing dates on the gross heat of combustion

In order to evaluate the quality of kenaf biomass for pulp production, the fiber content was determined at the end of the growing season (Table IV).
Table IV: Fiber content (% dry matter) of two varieties of Kenaf, Tainung 2 and Everglades 41, in core and bark, at the end of the growing season. 

<table>
<thead>
<tr>
<th></th>
<th>Tainung 2</th>
<th>Everglades 41</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>40</td>
<td>38</td>
</tr>
<tr>
<td>Bark</td>
<td>37</td>
<td>33</td>
</tr>
</tbody>
</table>

In terms of the fiber content, there were no significant differences among plants obtained in fields sowed at different dates and between plants obtained in fields sowed with two different plant densities [5]. Harvest date didn’t affect the fiber content, also [5]. Tainung 2 presented a higher fiber value than Everglades 41, at harvest (Table IV). Core material presented a higher fiber value than bark material, but this difference was not significant (Table IV).

4 CONCLUSIONS

Stem height, stem diameter, leaf area index, productivity, energy content, nitrogen and phosphorus content were affected by the sowing date but not by the harvest date. Plants from fields sowed earlier presented higher productivities, higher energy content and low nitrogen and phosphorus content than plants from fields sowed later.

Fields with higher plant populations presented higher leaf area index and higher productivities but those plants presented a similar chemical composition to plants obtained from fields with lower plant populations.

Everglades 41 presented higher leaf area index and higher productivities than Tainung 2, although this difference was not significant. Both varieties presented similar nitrogen and phosphorus composition. Everglades 41 showed higher energy content and Tainung 2 higher fiber content.

According to the results presented and discussed, Kenaf, at the pedoclimatic conditions of South Portugal, should be sowed in early May. To obtain a higher production, a higher seed density should be used in the fields (e.g. 40 seeds/m²). Nevertheless, a detailed studied is needed in order to conclude if the increment in productivity is sustainable.

Before taking a decision concerning industrial utilization, assays at pilot level should be done. Figures obtained concerning actual biomass characterisation values of the crops tested must be considered as indicative ones.

There is a need for further integration of agricultural practices and the energy and pulp production sectors. Energy crops for power and pulp purposes require quality specifications which, in some cases, are not fully met yet.

5 ACKNOWLEDGEMENTS

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6 REFERENCES