Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252021v34n305rc

CHARACTERIZATION OF OAT BIOMASS FOR ENERGY PRODUCTION[1]

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ABSTRACT - Biomass produced in agricultural areas stores energy that can be used, contributing to regional development. Among the widely cultivated agricultural species is oats, destined for the production of not only grains and forage, but also biomass. The objective of this study was to characterize oat biomass in terms of the potential for energy generation considering the genetic and cultivation environment variability. Four field experiments were conducted in the state of Paraná and one in the state of São Paulo, Brazil, with black oat (*Avena strigosa*) and white oat (*Avena sativa*) cultivars. At the milky grain stage, plants were collected to quantify the production of shoot biomass and its qualitative variables for energy production and energy potential. Biomass yield varied between cultivars and cultivation sites. The mean higher calorific value was 17.9 MJ Kg^{-1}, varying more between cultivation sites than between cultivars, being inversely proportional to the ash content. The contents of carbon, fixed carbon, volatile materials and nitrogen in the biomass did not vary between oat cultivars. The power generation potential varied widely between cultivars and cultivation sites, from 1557 to 3091 KWh ha^{-1}, influenced mainly by the biomass yield, which overlaps the effects of the variations found in biomass quality. We concluded that oats are a species with high potential for use as an energy product, and the selection of the most productive cultivars regionally is crucial.

Keywords: Bioenergy. Calorific power. Immediate analysis. *Avena strigosa*. *Avena sativa*.

CARACTERIZAÇÃO DA BIOMASSA DA AVEIA PARA PRODUÇÃO DE ENERGIA

RESUMO - A biomassa produzida em áreas agrícolas armazena energia que pode ser aproveitada, contribuindo para o desenvolvimento regional. Entre as espécies agrícolas amplamente cultivadas está a aveia, destinada tanto para a produção de grãos e forragem quanto de biomassa. Este trabalho teve por objetivo caracterizar a biomassa da aveia quanto ao potencial de geração de energia considerando a variabilidade genética e de ambiente de cultivo. Para isso, foram conduzidos quatro experimentos a campo no estado do Paraná e um no estado de São Paulo, Brasil, com cultivares de aveia preta (*Avena strigosa*) e branca (*Avena sativa*). No estádio de grão leitoso as plantas foram coletadas para quantificar a produção de biomassa aérea e suas variáveis qualitativas para produção de energia e o potencial energético. A produtividade de biomassa variou entre as cultivares e locais de cultivo. A média do poder calorífico superior foi de 17,9 MJ Kg^{-1}, variando mais entre os locais de cultivo que entre as cultivares, e sendo inversamente proporcional ao teor de cinzas. Os teores de carbono, carbono fixo, materiais voláteis e de nitrogênio na biomassa não variaram entre as aveias. O potencial de geração de energia variou amplamente entre cultivares e locais de cultivo, desde 1557 até 3091 KWh ha^{-1}, influenciado principalmente pela produtividade de biomassa, que sobrepõe os efeitos das variações encontradas na qualidade da biomassa. Concluímos que a aveia é uma espécie com elevado potencial para uso como produto energético, sendo determinante a seleção das cultivares mais produtivas regionalmente.

Palavras-chave: Bioenergia. Poder calorífico. Análise imediata. *Avena strigosa*. *Avena sativa*.

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[1] Received for publication in 06/29/2020; accepted in 03/25/2021.
Paper extracted from the masters dissertation of the first author.

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INTRODUCTION

Biomass is one of the main raw materials used for energy generation on the planet. In Brazil, for instance, it contributes with about 12% of the energy produced (EPE, 2019), mainly using firewood and sugarcane bagasse. The main advantages of using biomass as a fuel particularly include: being considered neutral in relation to CO_2 emissions since it is formed through photosynthetic reactions; having low sulfur and nitrogen contents, generating low emissions of gases such as N_2O (nitrous oxide) and SO_2 (sulfur dioxide); reduces dependence on external energy sources of a region; and can be the last use of biomass, making it economically competitive.

In agricultural areas, a lot of biomass that can be used in energy production is generated as a secondary product of food production (AMBRÓSIO et al., 2017; PIERRI et al., 2019). In some regions, it could fully meet the local energy demand (PIERRI et al., 2016).

The characteristics of biomass that most interfere in its calorific value are those related to immediate chemical analysis (including ash, volatile materials and fixed carbon content) and elemental chemical analysis (contents of C, N, H, among others) (KHAN et al., 2009; CORREIA et al., 2020), which may vary with species, variety and crop management. Calorific power is used to assess the energy potential of the fuel. It is defined as the amount of energy released in the complete combustion of a unit of mass of the combustible material. In general, the higher the calorific power, the greater the potential for using the material for power generation. The calorific value is said to be higher (HCV) when combustion occurs at constant volume and when water formed during combustion is condensed and the latent heat of water vapor is restored. The lower calorific value (LCV) is the available energy per unit of fuel mass after discounting energy losses with water evaporation.

Oat (*Avena spp.*) is an annual winter grass used for both grain and forage production or soil cover. The two most cultivated species are *Avena strigosa Schreb* and *Avena sativa L.*, the former being used for forage production or soil cover and the latter also for grain production. The biomass production of these species can be greater than 7000 kg ha^{-1} of dry mass, varying according to the region of cultivation, cultivar used and management (CARVALHO; STRACK, 2014; COELHO et al., 2020). Oats are grown in all continents and, in 2018, approximately 9.8 million hectares were cultivated for grain production alone, of which 473,000 were grown in Brazil (FAO, 2020). There is no information on the area destined for soil cover, but in some regions, it is estimated that it is ten times the area of cultivation for grain production (MORI; FONTANELI; SANTOS, 2012).

In this context, the objective of this study was to determine the potential use of oat biomass in energy production, considering genetic variability and the cultivation environment.

MATERIAL AND METHODS

Field experiments were conducted in the municipalities of Arapoti (24º11’36”S and 49º52’33”W), Tibagi (24º31’31”S and 50º22’2”W), Castro (24º51’31”S and 49º56’18”W), Ponta Grossa (25º0’42”S and 50º9’13”W) in the State of Paraná and Itaberá (24º3’54”S and 49º9’24”W) in the State of São Paulo, at the altitudes of 887, 832, 1026, 877 and 723 m, respectively.

The climate of Arapoti, Tibagi and Itaberá is Cfa, subtropical humid, and the climate of Castro and Ponta Grossa is Cfb, which corresponds to the temperate climate, according to Köppen’s climatic classification (ALVARES et al., 2014). The average monthly temperatures during the oat cultivation period (May to October 2012 – Figure 1) were 17.4, 16.9, 17.7, 15.1, 16.3 ºC, respectively, and precipitations in the period of 555.8, 598.1, 398.6, 671.8 and 640.4 mm, respectively.

The treatments consisted of 10 cultivars, seven of black oats (*Avena strigosa*), Agrocoxilha, Agroijuí, Agroplanalto, Agrozebu, Embrapa 29, Iapar 61 and UPFA 21, and three of white oats (*Avena sativa*), Fundacep Fapa 43, IPR 126 and UTF Iguaçu, distributed in randomized blocks with three replicates. The plot size was 5.00 x 0.85 m and the cultivation system was no-tillage, already used for more than 20 years in all experimental areas. The crop cultivated prior to oats was soybean in all sites. Table 1 shows the results of soil analyses before the installation of the experiments.

At the beginning of the experiment in Arapoti, 58.5 kg ha^{-1} of KCl, 250 kg ha^{-1} of mixed fertilizer NPK (10:30:10) and 150 kg ha^{-1} of urea were used. Fertilization was not performed in the other sites. Sowing was carried out on May 3, 10, 10, 11 and 15, 2012, in Castro, Arapoti, Ponta Grossa, Itaberá and Tibagi, respectively, at spacing between rows of 0.17 m and 51 seeds per linear meter. During cultivation, pest and disease control was carried out according to regional recommendations (LÂNGARO; CARVALHO, 2014).

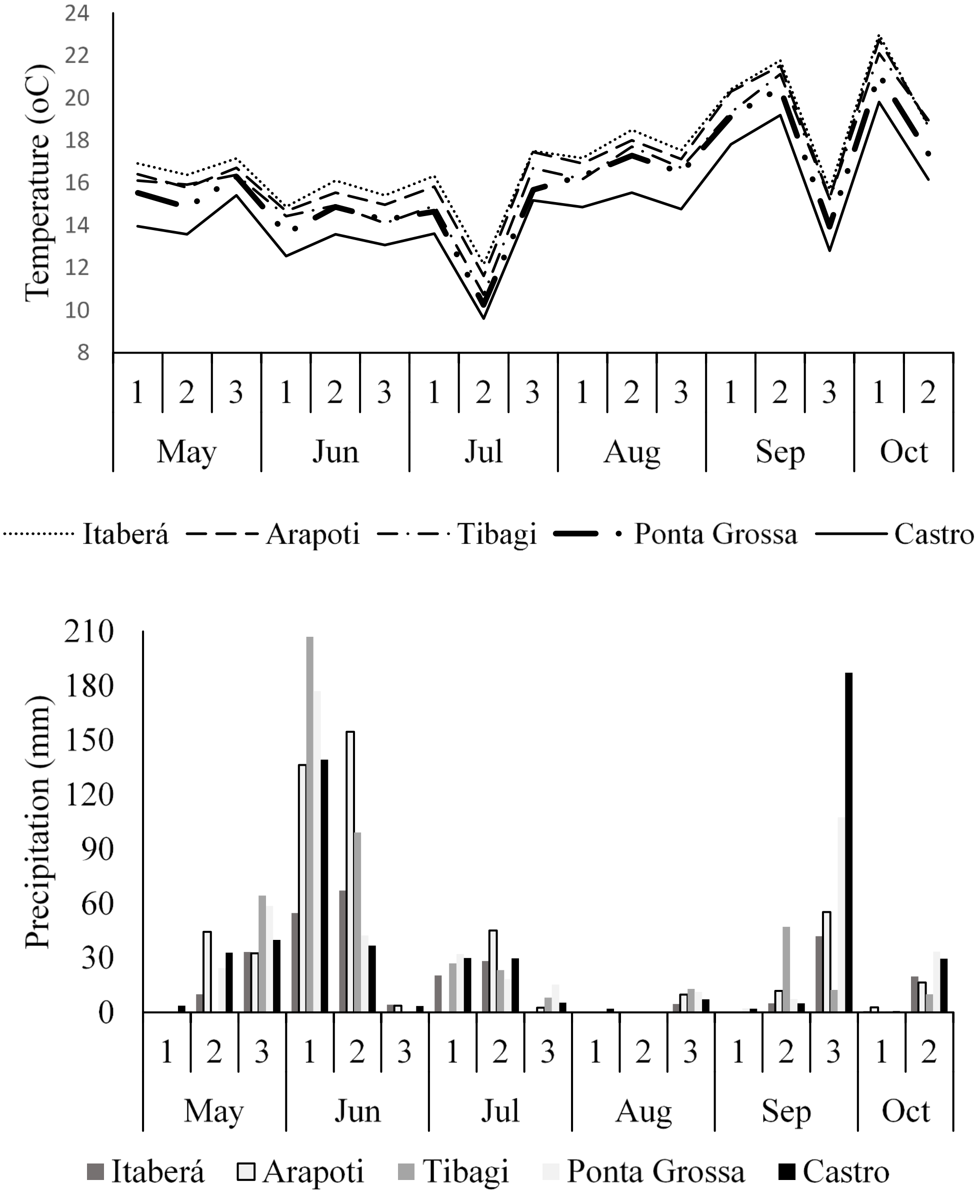

Figure 1. Variation of temperature and ten-day rainfall during the evaluated period (May to October 2012), in the different cultivation sites.

Table 1. Chemical analysis and clay content of the soil of the experiment sites, before the installation of the experiments, at 0.0-0.2 m depth.

Site	Clay %	P$^{(1)}$ mg dm^{-3}	OM$^{(2)}$ g dm^{-3}	pH CaCl$_2$	H+Al^{+3}	Al^{+3}	K^{+}	Ca^{+2}	Mg^{2+}	T$^{(3)}$
					cmol$_c$ dm^{-3}					
Itaberá	47	35	27	5.0	3.7	0.18	0.18	2.3	1.4	3.88
Arapoti	23	34	34	4.8	3.1	0.14	0.03	1.9	0.5	2.43
Castro	59	21	43	4.5	6.8	0.42	0.11	2.3	0.7	3.11
PG$^{(4)}$	34	16	24	4.8	3.4	0.17	0.16	2.5	1.0	3.66
Tibagi	62	55	42	5.2	5.0	<0.01	0.23	7.7	2.6	10.5

$^{(1)}$P = phosphorus extracted by resin; $^{(2)}$OM = organic matter; $^{(3)}$T = potential cation exchange capacity; $^{(4)}$PG =Ponta Grossa.

The biomass was harvested at the milky grain stage throughout the plot (4.25 m^2), with cutting height from the soil surface of approximately 4 cm and analyzed for fresh mass. The harvests were carried out in August, September and October in the 5 cultivation sites, depending on the cycle of the cultivar. After weighing the total mass collected, samples of approximately 200 g were taken and subsequently dried at 60 ºC for 72 hours, to determine moisture content and calculate the dry biomass yield produced. Then, the samples were ground with a Wiley knife mill to determine the biomass quality variables for energy, calorific power and analysis of carbon and nitrogen contents.

The determinations of the contents of volatile materials (gaseous combustion fraction or flame), fixed carbon (solid combustion fraction or ember) and ash (residual mineral oxides of combustion) followed the NBR 8112 standard (ABNT, 1983). The higher calorific value (HCV) was determined according to the NBR 8633/84 standard (ABNT, 1984). In this procedure, 0.5 g of the previously dried and ground samples was placed in a *IKA-WERNE® C5000* isothermal calorimetric bomb. The transformation of HCV values to lower calorific value (LCV) on dry basis was performed using the expression (1) as described in Kollmann and Côté (1968).

$$LCV = HCV - 600\,x\,9\,x\,(\frac{H}{100}) \qquad (1)$$

Where LCV represents the lower calorific value, in kcal kg^{-1}; HCV is the higher calorific value, in kcal kg^{-1}; 600 is the latent heat of water vaporization at 20 °C, in kcal kg^{-1}; 9 is the mass of water formed in combustion for every 1 kg of H in biomass, in kg; and H is the hydrogen content in biomass of 6.3%.

The theoretical potential of electric energy production from oat biomass was calculated using the expression (2) below, based on information from Nogueira and Lora (2003) and EPE (2019).

$$\text{PEP}= \{\frac{[(TBXPCI)X\ 0.3]}{860}\}X\ 0.2 \qquad (2)$$

Where PEP represents the theoretical potential of energy production, in kWh ha^{-1}; TB is the total biomass produced by oats, in kg ha^{-1}; LCV is the lower calorific value, in kcal kg^{-1}; 0.3 is the percentage of total biomass (TB) removal from the field (30%); 860 is the equivalence between the units kcal and kWh; and 0.2 is the average efficiency of boilers in electric conversion (20%). The percentage of removal of 30% of crop residues from the field is based on the works of Andrews (2006) and Powers et al. (2011), who demonstrated that the removal of this percentage of biomass does not cause a negative impact on the soil, also allowing the maintenance of 93% of its cover. C-total and N-total analyses were performed by dry combustion, with an elemental analyzer (VARIO EL III - Elementary®).

The data were subjected to the Shapiro-Wilk and Bartlett tests, and then to analysis of variance (ANOVA). When the relationship between the highest and lowest mean squared error (MSE) of the individual analyses (by location and in randomized blocks) was lower than 4, the analysis was performed by group of experiments, applying the Tukey test to compare the means at 5% probability level. When this relationship between the MSE was greater than 4, only individual analysis (by location), in randomized blocks, and the Tukey test were used to compare the means at 5% probability level. In addition, Pearson's linear correlation between the variables was also used, using SigmaPlot 12.0 software, which was also used to construct the graphs. The other statistical analyses were performed using the statistical software Assistat beta version 7.7. Data analysis was carried out through a group of experiments for dry biomass yield, higher and lower calorific values and theoretical potential of energy generation. For the other variables, the data were evaluated individually, by cultivation site.

RESULTS AND DISCUSSION

There was interaction between cultivation site and cultivars for biomass yield, indicating effect of interaction between genotype and environment on plant growth. The average temperatures observed during crop development ranged from 15.1 to 17.7 ºC and the accumulated precipitation from 399 to 640 mm, favorable conditions for oats (CASTRO; COSTA; FERRARI NETO, 2012), which justifies the high yields observed in all locations (Table 2).

The biomass yield of most cultivars varied with the site of cultivation, except for Agroijuí, and in general were higher in Castro-PR, with an average of 9153 kg ha^{-1} (Table 2). This is one of the sites with higher OM content in the soil (Table 1), which may have provided greater N availability for plants, since more than 95% of the soil N is in the organic fraction and can be mineralized to forms absorbable by plants. This may have been decisive because, with the exception of Arapoti, nitrogen fertilization was not performed, and oats respond to the application of this nutrient (LÂNGARO; CARVALHO, 2014).

The average biomass yield of oats is also higher in Itaberá-SP. This is a region of higher temperatures, lower altitude and which had the lowest rainfall in the cultivation period, 399 mm, compared to the other study regions. The occurrence of clear days with high luminosity favors the capacity of the crop to produce tillers, because these are affected by the quality of the light received, thus producing more biomass per hectare (ALMEIDA; MUNDSTOCK, 2001). These variations in yield demonstrate that the growing environment and management have a high influence on oat development.

Table 2. Shoot dry biomass yield of oat cultivars in different cultivation sites.

Cultivar	Dry biomass (kg ha^{-1})									
	Cultivation site									
	Ponta Grossa		Tibagi		Arapoti		Castro		Itaberá	
Agrocoxilha	7303	bcABC**	8666	abcA	6864	cA	9799	aABCD	9128	abBC
Agroijuí	7840	aABC	8326	aA	7683	aA	9316	aABCD	8770	aBC
Agroplanalto	6850	bABC	7700	bA	7199	bA	10340	aAB	8506	abBC
Agrozebu	8486	aAB	8753	aA	6472	bA	10008	aABC	9518	aAB
Embrapa 29	6267	bBC	7620	abA	5711	bA	7672	abDE	8687	aBC
Fundacep Fapa 43*	5827	bC	8211	aA	6279	abA	6478	abE	7213	abC
Iapar 61	7267	bcABC	9226	abA	7077	cA	11064	aA	7806	bcBC
IPR 126*	9036	abA	9829	aA	7383	bA	8021	abCDE	8728	abBC
UPFA 21	7421	cABC	8992	bcA	7918	cA	10642	abA	11434	aA
UTF Iguaçu*	6227	bBC	8638	aA	5855	bA	8194	aBCDE	7709	abBC
Mean	7252		8596		6844		9153		8750	

*White oats. **Values followed by different lowercase letters in the row and uppercase letters in the column differ statistically (Tukey; $p<0.05$), CV= 10.65%.

Among cultivars, there was no variation in Arapoti and Tibagi, but in terms of yield, the following cultivars stood out: IPR 126 and Agrozebu for the region of Ponta Grossa, UPFA 21 in Itaberá, and Iapar 61, UPFA 21 and Agroplanalto in Castro. Considering all sites, the cultivars with the highest biomass yields were Agroplanalto, IPR 126 and UPFA 21. On the other hand, the least productive cultivars in general were Embrapa 29 and Fundacep Fapa 43.

The difference in biomass yield between the cultivation sites was smaller than between cultivars in the same cultivation site. Among sites, the yield of the cultivars varied on average by 26%, while among cultivars, considering the means of all sites, the variation was equal to 36%. Among the cultivars, the one which varied the least with the cultivation site was Agroijuí (21%), indicating genetic stability as a function of the variation of the growing environment. This should be considered in the selection of cultivars for biomass production, since the higher the yield, the greater the energy potential, and the lower the variability in biomass yield, the more stable the biomass supply, which is important for energy generation.

The HCV of all cultivars varied with the cultivation site (Table 3). Overall, they were higher in Tibagi-PR and lower in Itaberá-SP, with values between 17.2 and 18.4 MJ kg^{-1}. These values are slightly lower than those of eucalyptus, from 19.3 to 20 MJ kg^{-1} (GUERRA et al., 2014; SIMETTI et al., 2018), and close to those observed in other materials such as sugarcane bagasse, from 17.9 MJ kg^{-1} to 19.4 MJ kg^{-1} (PAULA et al., 2011; CORREIA et al., 2020), soybean stem and pod residues, from 16.47 to 18.20 MJ kg^{-1} (PAULA et al., 2011; PIERRI et al., 2019) and white oat straw, from 17.9 to 18.0 MJ kg^{-1} (GARCÍA et al., 2012; PIERRI et al., 2019).

In Itaberá-SP, where the lowest HCVs occurred, there were also higher ash contents in biomass, 11% on average (Table 4). This deleterious effect of ash content is evidenced by the negative correlation with the HCV (Figure 2). The higher contents of ash (mineral oxides) and volatile materials indicate lower amount of organic materials (fixed carbon) that can be burned per unit of mass.

Table 3. Higher calorific value of shoot biomass of oat cultivars in different cultivation sites.

Cultivar	Higher calorific value (MJ Kg^{-1})									
	Cultivation sites									
	Ponta Grossa		Tibagi		Arapoti		Castro		Itaberá	
Agrocoxilha	17.8	bcAB**	18.2	aA	17.7	bcA	18.2	abA	17.4	cBC
Agroijuí	18.4	abA	18.0	aA	17.8	bcA	18.0	aA	17.5	cABC
Agroplanalto	18.1	aAB	18.3	aA	17.8	aA	18.3	aA	17.2	bBC
Agrozebu	18.0	abAB	18.3	aA	17.7	bcA	18.1	abA	17.2	cC
Embrapa 29	17.4	bB	18.1	aA	17.7	bA	18.0	aA	17.6	bABC
Fundacep Fapa 43*	18.4	abA	18.0	aA	18.1	abA	18.3	abA	17.9	bAB
Iapar 61	17.9	bAB	18.1	aA	18.0	abA	17.8	bA	17.7	bABC
IPR 126*	18.0	abAB	18,4	aA	17.7	bA	18.2	abA	17.7	bABC
UPFA 21	17.9	bcAB	18.0	aA	18.0	abcA	18.2	abA	17.6	cABC
UTF Iguaçu*	18.0	bAB	18.2	aA	18.0	abA	18.1	abA	18.1	abA
Mean	17.9		18.1		17.8		18.1		17.6	

*White oat. **Values followed by different lowercase letters in the row and uppercase letters in the column differ statistically (Tukey; $p<0.05$), CV= 1.46%.

Table 4. Ash content in the shoot biomass of oat cultivars in different cultivation sites.

Cultivar	Ash content (%)									
	Cultivation site									
	Ponta Grossa		Tibagi		Arapoti		Castro		Itaberá	
Agrocoxilha	7.4	a**	5.0	abc	8.7	abcd	4.6	a	12.0	a
Agroijuí	6.3	a	5.0	abc	11.6	ab	5.4	a	11.0	a
Agroplanalto	6.4	a	5.9	a	11.7	a	5.4	a	12.6	a
Agrozebu	6.4	a	5.5	abc	11.0	abc	5.5	a	12.7	a
Embrapa 29	6.9	a	5.1	abc	6.1	cd	4.9	a	11.5	a
Fundacep Fapa 43*	6.0	a	4.4	c	4.8	d	5.2	a	11.3	a
Iapar 61	5.8	a	5.2	abc	6.5	abcd	5.4	a	9.6	a
IPR 126*	5.3	a	4.5	bc	6.2	bcd	3.7	a	8.7	a
UPFA 21	7.4	a	5.8	ab	4.8	d	5.2	a	11.7	a
UTF Iguaçu*	5.3	a	5.4	abc	5.8	cd	5.1	a	11.0	a
Mean	6.0		5.0		8.0		5.0		11.0	
CV%	17.78		8.88		24.10		14.03		22.48	

*White oats; ** Values followed by different letters in the column differ statistically (Tukey; $p<0.05$).

The cultivars varied in terms of HCV in Ponta Grossa and Itaberá, while in the other locations they were equal to each other (Table 3). The little variation of HCV is due to the small amplitude in the C contents of oat biomass, generating a moderate correlation between these two variables (Figure 2). The high energy density of C causes this element to directly influence the HCV of lignocellulosic materials; the higher the C content, the higher the HCV (SHENG; AZEVEDO, 2005; BRUN et al., 2018).

Most cultivars showed variation in LCV with the change in cultivation site, except only for Fundacep Fapa 43 (Table 5), and in general, the values were higher in Tibagi-PR and lower in Castro -PR, with an amplitude of 15.8 to 17.0 MJ kg^{-1}. Among the cultivars, there was variation in the LCV in Ponta Grossa-PR and Castro-PR and in the other regions the values were equal to each other, as observed for HCV (Table 3). This result was expected, since the difference between both is the H content, which in our study was considered constant at 6.3% for all cultivars.

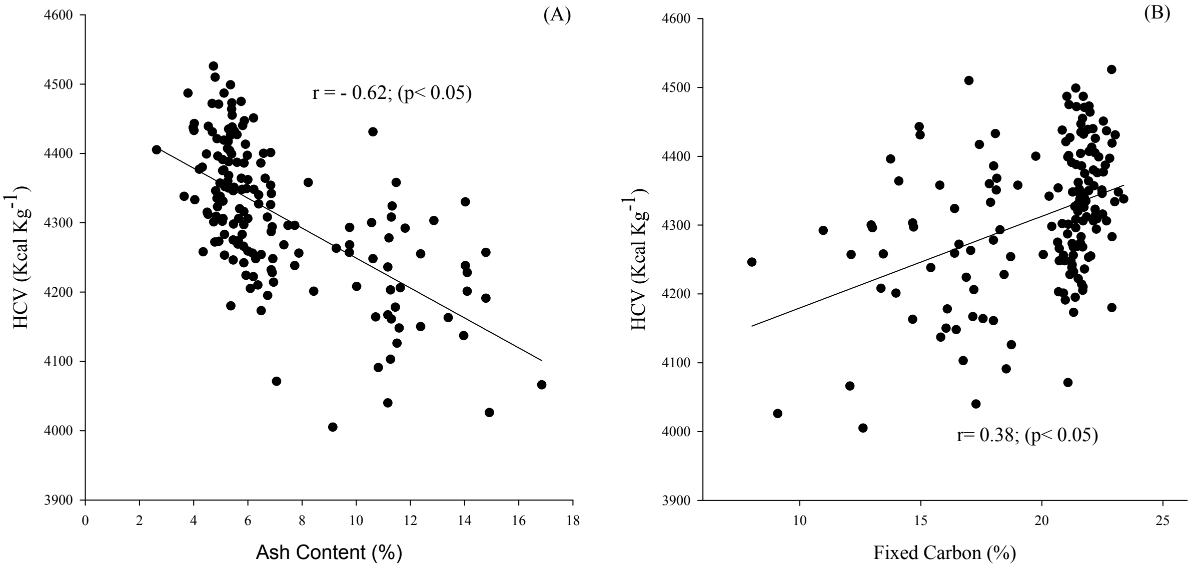

Figure 2. Relationship between higher calorific value (HCV) and ash content (A) and fixed carbon (B) of the shoot biomass of oat cultivars.

Table 5. Lower calorific value of the shoot biomass of oat cultivars in different cultivation sites.

Cultivar	Lower calorific value (MJ Kg^{-1})									
	Cultivation site									
	Ponta Grossa		Tibagi		Arapoti		Castro		Itaberá	
Agrocoxilha	16.3	bcAB**	17.0	aA	16.2	bcA	16.0	cABC	16.8	abA
Agroijuí	16.9	abA	17.1	aA	16.4	bcA	16.1	cABC	17.0	abA
Agroplanalto	16.6	aAB	16.9	aA	16.4	abA	15.8	bBC	16.8	aA
Agrozebu	16.6	abAB	16.9	aA	16.2	bcA	16.8	cC	16.7	abA
Embrapa 29	16.0	bB	17.1	aA	16.3	bA	16.2	bABC	17.0	aA
Fundacep Fapa 43*	17.0	aA	17.1	aA	16.7	aA	16.5	aAB	16.9	aA
Iapar 61	16.5	abAB	17.1	aA	16.6	abA	16.3	bABC	16.4	bA
IPR 126*	16.6	abAB	17.0	aA	16.3	bA	16.3	bABC	16.8	abA
UPFA 21	16.4	bcAB	17.1	aA	16.6	abcA	16.2	cABC	16.8	abA
UTF Iguaçu*	16.5	bAB	17.2	aA	16.6	abA	16.7	abA	16.7	abA
Mean	16.5		17.1		16.4		16.3		16.8	

*White oat. **Values followed by different lowercase letters in the row and uppercase letters in the column differ statistically (Tukey; $p<0.05$)

The fixed carbon content (FC) ranged from 18.9 to 22.6% in Ponta Grossa, from 21.0 to 22.5% in Tibagi, from 19.8 to 22% in Castro and from 13.4 to 17.5% in Itaberá, with no statistical difference between cultivars. The FC refers to the remaining mass after the release of volatile compounds, excluding the ash content, representing the fraction of biomass with solid combustion, that is, burning in the form of embers, and is responsible for the greater contribution to the calorific value (PAULA et al., 2011). The lowest FC content was observed in Itaberá-SP, which in turn had the highest ash content and, consequently, the lowest HCV. The expected levels of FC in biomass residues vary between 7% and 20% (YAO et al., 2005); therefore, the values observed in oats can be considered high. Theis et al. (2006) found FC values for oat straw residues of 13.6%, while García et al. (2012) observed values of 18.85% for oats in bran and 20.67% for oat straw residues, which are close to those obtained in our study. It is desirable in the immediate chemical analysis that biomass contains high FC content and low levels of volatile materials and ash for energy purposes, because these variables are correlated with HCV, that is, the higher the FC and the lower the levels of VM and ash content, the higher the fuel HCV.

The C content also did not differ among the cultivars in all evaluated sites, with mean values between 41.94 and 43.29%. These are lower than those obtained by Theis et al. (2006), who found content of 48.8% in oat straw. For bioenergy production, it is desirable that biomass contains high C contents, due to the correlations between the elementary components and the HCV (BRUN et al., 2018). However, biomass fuels, when compared with fossil fuels, which contain 55 to 95% of C in their composition, have low levels of this element, which leads to lower HCV value. The absence of difference between cultivars regarding FC and C contents indicates that these variables are not determinant for defining those with higher energy potential.

In general, the highest energy potential of oat cultivars was observed in Castro and Itaberá and the lowest energy potential was observed in Arapoti-PR (Table 6), where the highest and lowest biomass yields also occurred (Table 2), respectively. The differences between cultivars also followed the variation of biomass yield, especially IPR 126 in Ponta Grossa-PR and UPFA 21 in Itaberá and Castro.

Table 6. Theoretical potential of energy generation from the biomass of oat cultivars in different cultivation sites.

Cultivar	Theoretical potential of energy generation (kWh ha^{-1})									
	Cultivation site									
	Ponta Grossa		Tibagi		Arapoti		Castro		Itaberá	
Agrocoxilha	1985	bcABC**	2502	abA	1862	cA	2431	abB	2746	aABC
Agroijuí	2214	aABC	2373	aA	2104	aA	2347	aB	2652	aABC
Agroplanalto	1905	bABC	2171	bA	1972	bA	2248	bB	2902	aAB
Agrozebu	2350	aAB	2473	aA	1754	bA	2510	aAB	2799	aABC
Embrapa 29	1675	bcC	2179	abA	1557	cA	2350	aB	2183	abCD
Fundacep Fapa 43*	1651	bC	2342	aA	1752	bA	1984	abB	1825	abD
Iapar 61	1997	cABC	2632	abA	1958	cA	2127	bcB	3030	aA
IPR 126*	2505	abA	2783	aA	2012	bA	2371	abB	2247	abCD
UPFA 21	2036	bABC	2556	abA	2192	bA	3091	aA	2981	aA
UTF Iguaçu*	1721	bBC	2474	aA	1623	bA	2145	abB	2280	aBCD
Mean	2004		2449		1879		2360		2565	

*White oat. **Values followed by different lowercase letters in the row and uppercase letters in the column differ statistically (Tukey; $p<0.05$), CV=10.85%.

Therefore, it is noted that the energy potential of the different oat genotypes accompanies biomass yield, that is, the higher the biomass yield, the greater the theoretical potential of energy production. Thus, the energy potential of biomass is affected by the cultivation site and cultural practices adopted, which, despite influencing the quality of biomass for energy, has a strong influence on the yield of the different cultivars.

The contents of volatile materials (VM), which represent the fraction of biomass that oxidizes in the gaseous form, that is, in the form of flame, did not vary between cultivars in all evaluated sites, with an average value of 74.0% (Table 7). This content found for oats is similar to that of other types of biomass such as eucalyptus (84.4%) (BRUN et al., 2018) and oat residue (72%) and bran (78%) (GARCÍA et al., 2012). In oat straw, Theis et al. (2006) observed 80.5% of VM, a value higher than those observed in the present experiment. Biomass fuels generally have a high volatile content, ranging from 75% to 90% (KHAN et al., 2009) and hence easily burn even at relatively low temperatures (GARCÍA et al., 2012, BRUN et al., 2018), hindering the control of combustion.

The N content varied between the cultivars only in Tibagi-PR and Arapoti-PR (Table 7). The highest N contents in biomass were found in the cultivars Agroijuí and Embrapa 29 grown in Tibagi-PR and Agroplanalto grown in Arapoti-PR, whereas the lowest concentration was found in IPR126 in both cultivation sites. This cultivar was the one which maintained one of the lowest N contents in its biomass, but it was one of the most productive, which indicates higher efficiency in converting this nutrient into biomass, compared to the others.

Table 7. Volatile materials (VM) and nitrogen (N) contents in the shoot biomass of oat cultivars grown in different locations.

Cultivar	Volatile material (%) and nitrogen (%) contents									
	Cultivation site									
	Ponta Grossa		Tibagi		Arapoti		Castro		Itaberá	
	VM	N	VM	N	VM	N	VM	N	VM	N
Agrocoxilha	73.7^{ns}	2.15^{ns}	73.4^{ns}	2.20 ab**	73.8^{ns}	1.88 ab**	77.2^{ns}	1.15^{ns}	70.4^{ns}	2.17^{ns}
Agroijuí	74.0	1.77	73.7	2.41 a	73.3	1.87 ab	75.5	1.50	71.5	2.30
Agroplanalto	74.1	1.89	73.1	2.08 ab	72.3	2.37 a	72.5	1.49	70.9	2.36
Agrozebu	72.1	2.00	72.5	1.84 ab	72.6	1.85 ab	71.7	1.27	73.5	2.30
Embrapa 29	71.9	2.33	73.3	2.50 a	72.3	1.99 ab	75.7	1.42	73.1	2.38
Fundacep Fapa 43*	71.4	2.19	73.1	1.95 ab	73.3	1.72 ab	75.7	1.71	74.5	2.15
Iapar 61	73.5	1.40	72.8	1.68 ab	74.4	1.87 ab	75.8	1.21	74.6	1.80
IPR 126*	75.6	1.62	73.1	1.44 b	73.0	1.61 b	74.3	1.20	77.8	1.71
UPFA 21	71.5	2.29	73.1	2.03 ab	73.4	1.67 ab	74.8	1.31	71.5	2.18
UTF Iguaçu*	74.5	1.76	73.0	1.90 ab	73.2	1.73 ab	72.9	1.45	75.6	1.83
Mean	73.2	1.94	73.1	2.00	73.0	1.86	74.7	1.37	73.3	2.12
CV%	3.1	18.2	0.7	16.2	1.6	13.5	4.6	25.4	4.5	12.3

*White oat; ** Values followed by different letters in the column differ statistically (Tukey; $p<0.05$).

The N content in materials for combustion contributes to the emissions of toxic compounds and pollutants to the atmosphere (GARCÍA et al., 2012), mainly forming nitrogen oxides, which are the main reason for the negative environmental impact caused by biomass burning (RAVINDRA et al., 2019). Therefore, low levels of this elemental compound in biomass for energy use are desirable. The mean N content in oats (Table 7) is higher than those found in eucalyptus (0.07%) and pine (0.09%) (PROTÁSIO et al., 2012), and also in sugarcane bagasse, rice husk, coffee stem, bean stalk, corn stem, leaf and straw, and soybean stem, 0.5%, 0.3%, 0.5%, 0.7%, 0.9%, 0.9%, 0.3% and 0.6%, respectively (PAULA et al., 2011).

ACKNOWLEDGMENTS

The authors thank the National Council for Scientific and Technological Development (CNPq) for granting a master's scholarship to the first author and for the financial support through Project 482016/2012-4 Universal 14/2012.

CONCLUSIONS

Oat biomass yield is influenced by the cultivation site and cultivar, and the most productive ones were Agroplanalto, IPR 126 and UPFA 21. The only cultivar whose biomass yield did not vary between cultivation sites was Agroijuí, showing stability in production as a function of the variation in the cultivation environment. The calorific value of oats is inversely related to the ash content in biomass. The use of oats as an energy source can generate more than 3000 KWh ha^{-1} of energy, varying with the quality and mainly with the yield of biomass of the cultivar.

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