PHYSICAL CHARACTERISTICS OF MISCANTHUS PLANTS AND POWER DEMAND AT GRINDING PROCESS

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Abstract. In this paper there are the main characteristics of miscanthus plants harvested in two different years, 2010 and 2011, after the second and the third year of crop presented. To prominence the differences between the 2 lots of plants, the plant distribution after its height and weight was done, and also the distribution using the plant diameter at the down, the top and middle internodes. For the plants harvested in 2011 the size reduction process of stalks and leaves was done, starting from a known granulation determined ahead. For the experiments the grinder mill lab Grindomix GM-200 was fitted with knives and a drum made from stainless steel. The ground material at different speed of the cutting drum, was sieved with a set of sieves of different dimensions 6.3 mm, 5 mm, 3.15 m, the obtained results were processed with the help of Excel program. There was also drawn the material fraction mass variation according to the equipment speed. Also the maximum power consumed in each case was determined and the specific energy at grinding was determined according to it, for the grinding time used in the experiments. The obtained values and the data from our paper are of real use for the specialists in the field.

Keywords: miscanthus stalk, height distribution, plant mass, size reduction, needed power, energy consumption

Introduction

There is an important variety of energetic plant cultures used both for liquid bio-fuel production and also gas and solid bio-fuels. An important role is given to mischantus plant culture as a renewable energy plant, a perennial plant with a high biomass production, beginning with its third year of cultivation [1].

The main operation to which mischantus is being subjected to during the technological process of transformation into solid bio-fuel is “size reduction”, an operation that can begin through plant grinding just after harvesting. After grinding, the size reduction and densification of the ground material is done with specific equipment, in biomass processing units [2].

The plant physical characteristics significantly influence the size reduction process and the characteristics of the ground material, but mainly it offers agronomists information regarding maintaining and developing the crop [3; 4]. So, it is important to know, amongst others, the plant distribution according to their height, individual mass, internode number, diameter and length of each internode. The initial dimensions of the ground material, if it was subjected to a shredding operation, as well as resistance characteristics and hardness significantly influence the energy consumption and the needed power for grinding [5].

Hammer mills are the best known equipment used for shredding/grinding, in which the miscanthus stems or material fragments are subjected to mechanical complex forces and then the resulted particles are used in the following operations from the pellet obtaining technology [6; 7].

To understand these processes, the paper presents an analysis of two sets of probes of 100 mischantus plants, harvested manually, during harvest time, in two consecutive years, respectively in the second and third harvest year. For showing the differences between them distribution of the plants according to their size was done. Grinding of mischantus plants (leaves and stems, individually), begins of a known initial length of fragments, with the help of a laboratory mill, determining the maximum power at grinding and the specific energy consumption.

Materials and methods

Mischantus plants, used during the experiments, have been harvested manually, during harvest time, in 2010, respectively 2011 (according to the second and third year of cultivation), from the experimental field of the National Institute of Agricultural Machinery Bucharest. For determining the distribution after one of the physical characteristics, 100 plants have been harvested each year, the following determinations were done: plant mass M_p (g), height H (cm), average internode diameter at the end, D_d and D_t (cm) and the middle D_m (cm), length of the first internode L_d (cm) etc. The leaves where pealed of the stems and weighed separately, leading to the following percentages: 17.9 % – leaves, 82.1 % – stems.

The length of the miscanthus stems was determined through roulette measurement, as well as the plant mass through weighing with an electronic scale Kern RH 120-3, with measuring precision of 10^{-1}g. The diameter of plants was measured in two perpendicular planes, the form of the transversal section being elliptical, and the average diameter in the measured area was noted. Plant humidity was determined, both for leaves (about 9.8 %) as well as for stems (approx. 8.9 %), with the help of a drying cabinet Memmert Celsius 2007, maintaining the material at the temperature of 105 degrees C, inside the drying room, for 8 hours.

Plus for the plants that were harvested in 2011, grinding was done (for leaves and stems, separately) with the help of a laboratory mill Grindomix GM-200, with knives and a stainless steel tray. In order to determine the specific energy consumption and the necessary grinding power, 20 g of leaves were weighted and then subjected to grinding at different revolution speed: 3000, 4000, 5000, 6000 and 7000 rpm. The initial material distribution according to the leave length was random, this been ground almost in the initial shape they were taken off the stalk. After the grinding process, the material obtained was strained during one minute through a set sieve with square holes, of a sieve shaker for granulometric analysis with sizes: 6.3 mm, 5mm and 3.15 mm.

a) b) c)

Fig. 1. **Laboratory mill Grindomix GM-200 (a); stainless steel tray and knives (b); power clamp meter EXTECH model 380976 (c)**

In order to determine the analyzed characteristics distribution and drawing the distribution curves, the regression analysis of the experimental data with the normal distribution law (eq. 1), and for drawing the power variation curve, respectively the grinding specific energy, according to the rotor torque, we used the power type distribution function, respectively the function of log-normal distribution (eq. 2, eq. 3):

Normal distribution function:

$$f(x) = a \cdot e^{-b(x-c)^2} \tag{1}$$

Power type distribution function:

$$f(x) = a \cdot x^b \tag{2}$$

Log-normal distribution function:

$$f(x) = \frac{a}{x} \cdot e^{-b(\ln x - c)^2} \tag{3}$$

The regression analysis was made with the help of the Microcal Origin 7.0 program. For determining the necessary power for leaves and stems grinding we used a power clamp meter EXTECH model 380976, the values presented in Table 3 and 4 representing the maximum power indicated by the apparatus during a sample grinding process, and for determining the specific grinding energy a commercial active energy counter was used. The length of the experimental sample was one minute, at the beginning and at the end of it the material temperature was determined with a digital thermometer with a temperature probe TES 1310, type K.

Results and discussion

The limits of the intervals in which the values of the measured physical characteristics of miscanthus plants were read, as well as the average of measurements and dispersion, given by the Microsoft Excel programme, are presented in Table 1.

Table 1

Physical characteristics of mischantus plants in the second and third year of harvest

Characteristics		**Mass of plants M_p, g**	**Heigth *H*, cm**	**Mean diameter at internode (mm)**			**Length of first internode L_d, cm**
				Down, D_d	**Middle, D_m**	**Top, D_t**	
2010							
Limits	Min	8.9	80	4.9	4.1	1.3	6
	Max	37.6	285	9.9	7.98	5.2	21
Average		20.4	186.9	7.4	5.9	3.7	12.9
StdDv		6.3	37.8	0.8	0.8	0.8	3.4
2011							
Limits	Min	6.4	94.5	5.1	5.5	4.35	8
	Max	57.1	247.5	11.9	9.7	8.32	32
Average		29.8	199.7	8.6	7.3	6.32	19.03
StdDv		13.1	34.1	1.4	0.96	1.04	5.13

On the basis of the determined physical characteristics values, the variation curves were dragged, through non-linear regression analysis on the computer in Microcal Origin 7.0 programme, of the experimental data with normal distribution function (eq. 1), these being graphic presented in Fig. 3.

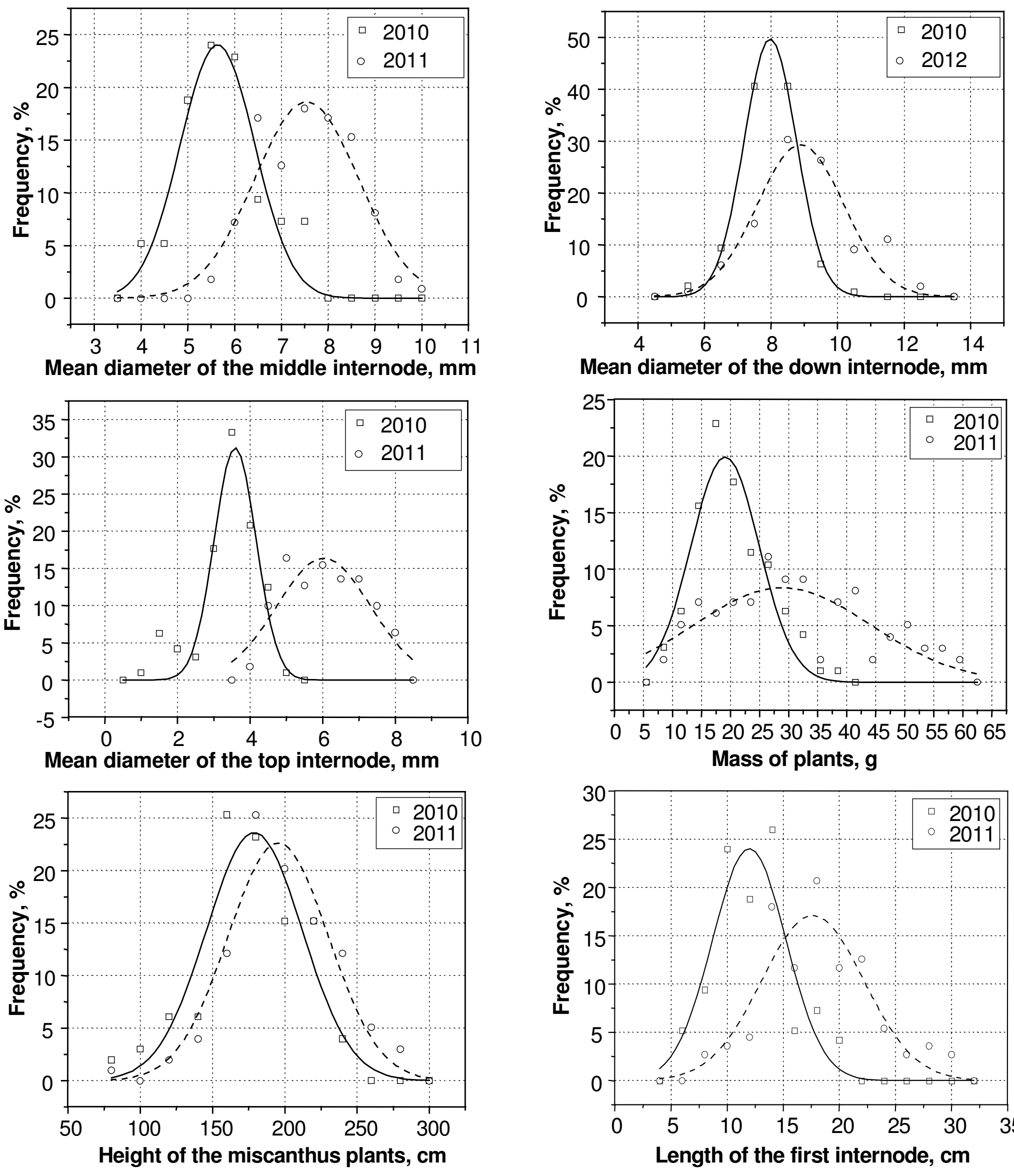

Fig.2. **Curves of distribution of the physical characteristics of mischantus plants, in two consecutive years of cultivation:** □, ○ – experimental points; ——- distribution curves

Analyzing the graphs presented in Figure 2, we can observe that in the second cultivation year, the plants were more uniform presenting average values, in general, higher for all the analyzed characteristics, but with a larger dispersion, even if there are cases where the distribution of the analyzed characteristics present a more pronounced maximum for the first year of cultivation (the plants where being rarer had the possibility of an arbitrary development).

The regression function coefficients (eq. 1) and the correlation coefficient R^2, for the six analyzed characteristics are analyzed and experimentally determined, and presented in Table 2. It can be seen that the values of R^2 are high (exception the plants mass for 2011 determinations), which proves the distribution of these characteristics according to the normal law distribution, very often used in these analysis. Because of the data in Table 2 it can also be observed that the difference between the values of the standard deviation and average data calculated given by the regression equation is quite insignificant (b and c coefficients in eq. 1) and those measured and presented in Table 1.

Table 2

Regression function coefficients (eq. 1) and the correlation coefficient values R^2, for the six analyzed physical characteristics of mischantus plants

Parameter	*a*	*b*	*c*	R^2	*a*	*b*	*c*	R^2
	2010				2011			
D_d, mm	49.669	0.809	7.979	0.997	29.247	0.296	8.891	0.919
D_m, mm	24.042	0.790	5.639	0.908	18.608	0.402	7.543	0.919
D_t, mm	31.213	1.503	3.593	0.925	16.334	0.297	6.032	0.841
M_g, g	19.932	0.015	19.097	0.920	8.341	0.002	28.936	0.613
H, mm·10	23.600	0.001	179.07	0.886	22.610	0.001	195.598	0.935
L_i, mm·10	24.027	0.047	11.983	0.877	17.102	0.024	17.646	0.834

After the sample grinding process for leaves the balance between the four obtained fractions in the initial material was determined and the variation curves were dragged according to the revolution of the mill rotor. The experimental points, together with the variation curves obtained through non-linear regression analysis with the power type distribution functions (eq. 2) or of log-normal (eq. 3) are presented in Fig.3, a and the experimentally obtained results are presented in Table 3 and Table 4.

Table 3

The grinding maximum power and the ground material distribution (leaves)

No.	Revolution speed, rpm	Final temperature, °C	Max. power, W	Material refused by sieve, g			
				0 mm	3.15 mm	5 mm	6.3 mm
1	3000	38.0	425	3.40	4.55	4.30	7.60
2	4000	38.0	420	7.35	8.10	2.90	1.60
3	5000	38.5	415	9.50	8.35	1.65	0.35
4	6000	39.0	475	16.50	3.20	0.15	0.05
5	7000	39.0	445	17.90	1.75	0.00	0.00

Table 4

The grinding maximum power and the ground material distribution (stalks)

No.	Rotary speed, rpm	Final temperature, °C	Max. power, W	Material refused by sieve, g				Grinding specific energy, MJ·kg^{-1}
				0 mm	3.15 mm	5 mm	6.3 mm	
1	5000	38.5	435	3.90	2.40	0.10	3.45	0.594
2	6000	38.0	440	6.15	2.40	1.15	0.25	0.738
3	7000	39.0	460	7.90	1.65	0.35	0.00	0.918
4	8000	39.0	455	8.40	1.40	0.00	0.00	1.062
5	9000	40.0	480	9.45	0.45	0.00	0.00	1.080

During the grinding experiments of mischantus stems, probes of stems of different plant internodes were prepared, with the length of 15 mm, 10 g of the material were weighed, that ground, with the help of the laboratory mill, at the same revolutions for the mill rotor as the plants leaves.

The ground material was screened through the same set of sieves, during one minute, the balance between the fractions obtained being registered. Based on the obtained result in the stalk grinding process the experimental points and variation curve of the sieved fraction material were drawn with the distribution function remembered before, obtained through the regression analysis. These are graphic presented in Fig.3, b.

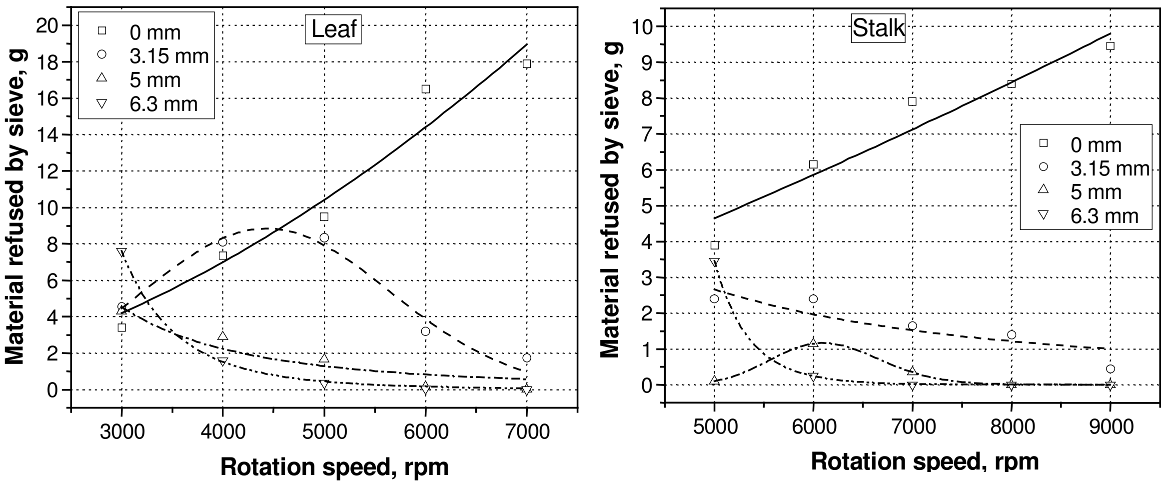

Fig.3. **The ground material distribution, on dimension classes, according to the mill rotor revolution**

In the case of leaves grinding process, the fraction with the dimensions between 3.15 – 5 mm presented at first a growing mass variation along with the mills revolution enhance, after which it begins to descend thus the distribution law best correlates the experimental date with the distribution laws. The same thing happens in the grinding stalks case, but this time for the fraction dimensions between 5 – 6.3 mm, the best fit is for lognormal distribution law (eq. 3).

Also it can be appreciated that the mills revolution necessary for stalk grinding is higher than that for leaves grinding, in order to reach an according granulation of the material subjected to grinding, the stalk hardness being allot higher that the leave hardness. This could be seen in the experimental determinations when the grinding process at the same stage of revolution speed as for grinding leaves (3000 and 4000 rpm), stalk could not be ground, the necessary centrifugal force of the knives been much higher, which could be obtained only at the revolution speed above 5000 rpm.

Table 5

The regression coefficients (eq. 1 and eq.2) for the ground material distribution

Sieves	**Eq.**	***a***	***b***	***c***	R^2	**Eq.**	***a***	***b***	***c***	R^2
	Leaves					Stalk				
0 mm	(2)	$2.7\cdot10^{-6}$	1.779	-	0.953	(2)	$0.9\cdot10^{-4}$	1.269	-	0.927
3.15 mm	(1)	8.845	$3.3\cdot10^{-7}$	4428.7	0.963	(2)	$3.9\cdot10^{6}$	-1.66	-	0.767
5 mm	(2)	$1.54\cdot10^{9}$	-2.454	-	0.895	(3)	7145.759	62.90	8.723	0.999
6.3 mm	(2)	$2.19\cdot10^{20}$	-5.59	-	0.999	(2)	$4.88\cdot10^{54}$	-14.513	-	0.999

Based on the obtained results during the experiments, regarding the maximum power necessary and the specific grinding energy, at different rotary speed steps of the mill rotor, the experimental points and variation curves obtained through the regression analysis with the linear respectively the exponential distribution law, were drawn. From the graph analysis we can see a good correlation of the experimental data both with the linear law, as well as exponential law, for both analyzed characteristics (power and specific energy), considered through the correlation coefficient value R^2 ($R^2 > 0.975$ for specific energy grinding).

It also needs to be said that the grinding process of miscanthus plants is a process with heat emission because through the initial particle division in smaller particles, the ground material temperature grew to about 16 – 18 ºC, the initial material temperature (stalks and leaves) been roughly as the environmental temperature (20 – 22 ºC).

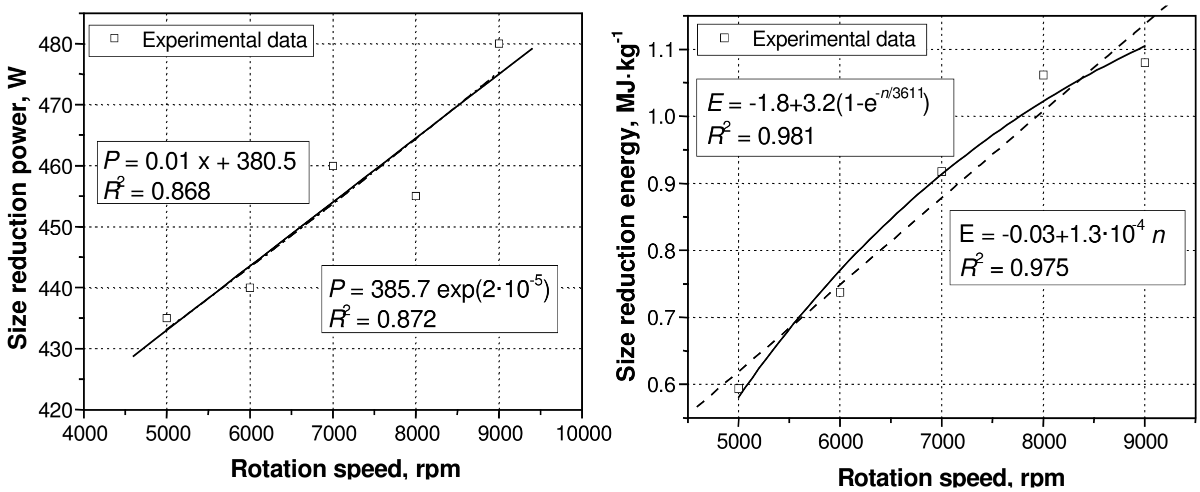

Fig.4. **The variation curves of power and grinding specific energy**

Conclusions

As a conclusion from the analyzed data we observed that the mischantus energy plant presents a development degree higher in 2011 than in 2010, this becoming a mature crop in the third year of cultivation. The data that show this are the average plant diameter that grew for example, from 4.9 to 5.5 mm for the base internode or the plant height that presents a growth from 186.9 cm to 199.7 cm, as well as the plant mass which grew from 20 g to about 30 g for one stalk.

All the physical characteristics analyzed present a normal distribution with a high correlation coefficient ($R^2 > 0.830$ for the five of the six analyzed characteristics) both for the plants harvested in 2010 as well as for those harvested in 2011. The ground mass material distribution on class dimensions shows a decrease both for leaves as well as for stalks along with the rotor speed rise of the grinding machine. The variation of the ground mass material distribution on class dimensions, follows in most cases a power type distribution (eq. 2), valued for the correlation coefficient high value R^2 ($R^2 > 0.890$). It is considered that for stalk grinding, the speed rotor of the grinding machine needs to be higher with about 2000 rpm than in the case of leaves grinding which means a growth in peripheral velocity with about 10 $m \cdot s^{-1}$.

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