SLOVAK UNIVERSITY OF AGRICULTURE IN NITRA
FACULTY OF ENGINEERING
Department of machines and production systems

Using of crop biomass for energy purpose
(Processing, pelleting and pellets properties)

Short review of Ph.D. thesis
to obtain scientific and academic degree of doctor philosophy
of sciences: 6.1.14
Technology and mechanization of agricultural and forestry production

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ABSTRACT

Five different kinds of biomass feedstock's namely; alfalfa *(Medicago sativa*) hay, prickly lettuce (*Lactuca serriola*), wheat (*Triticum spp*.) straw, miscanthus (*Miscanthus*) and corn *(Zea mays* L.*)* stover are used. Pellets were produced without and with preheating to 85°C and four different moisture contents (5, 10, 15 and 20%), all pellets had pressed with pressure force of 150 MPa and diameter of 20 mm. The pellets produced were tested for durability and their bulk density was determined. Pellets had produced from mixtures of some biomass materials in different ratios with preheating at 5% moisture content.

Increasing biomass materials moisture content caused on decreasing the unit density of pellets considerably even at high applied pressures. The maximum pellet density of 1238.1kg.m^{-3} was observed at the moisture of 5% in a prickly lettuce, while it decreased to 926.5kg.m^{-3} in the moisture content of 20%. Similar results were observed in all biomass materials compacted without preheating.

Preheating increased the unit density of pellets in corn stover, the unit bulk density of miscanthus and wheat straw significantly increased at the moisture content of 5%, whereas unit pellet density of alfalfa hay and prickly lettuce decreased at the same moisture content.

Moisture content had a negative effect on the durability of pellets made with or without preheating; increasing the moisture content from 5% to 20% had decreased the durability of the biomass materials; however, the durability of preheated pellets was higher in comparison with the pellets made without preheating. The highest durability of (96%) was achieved in corn stover pellets made with preheating

Storing the pellets of all biomass materials for 3 weeks under room temperature conditions had a negative effect on the durability of pellets made without preheating under different moisture contents, on the other hand, there was some positive response to storing of pellets made with preheating; in corn stover, wheat straw and miscanthus pellets at moisture content of 5% the durability increased with storing.

Making blends by mixing 25% miscanthus with 75% corn stover increased the durability of miscanthus significantly; however, the durability of corn stover had decreased, but this reduction was statistically not significant. Wheat straw was similar to miscanthus in the same ratio of mixing.

ABSTRAKT

Päť rôznych druhov surovín, a to lucerna *(Medicago sativa)* na seno, šalát kompasový (*Lactuca serriola*), pšeničná (*Triticum spp.*) slama, miskantus (*Miscanthus*) a kukuričná *(Zea mays L.)* slama. Pelety boli vyrábané pri štyroch rozdielne stanovených vlhkostiach (5, 10, 15 a 20%), výroba prebiehala pri bežnej teplote v miestnosti bez možnosti predhrievania, ako aj s predhrievaním na 85°C. Všetky pelety boli lisované s tlakom 150 MPa a priemerom piesta 20 mm. Vyrobené pelety boli testované na oteruvzdornosť s určením ich objemovej hmotnosti. Pelety boli vyrobené zo zmesí biomasy v rôznych pomeroch s predhrievaním pri 5% vlhkosti materiálu.

Výrazné zvýšenie vlhkosti materiálov určených na výrobu biomasy spôsobilo zníženie objemovej hmotnosti peliet dokonca aj pri pôsobení vysokých tlakov. Maximálna objemová hmotnosť peliet 1238,1 $kg.m^{-3}$ bola dosiahnutá u kompasového šalátu pri vlhkosti 5%, ktorá sa znížila na hodnotu 926,5 $kg.m^{-3}$ pri vlhkosti 20%. Podobné výsledky boli dosiahnuté u všetkých materiálov na výrobu biomasy, ktoré boli lisované bez predhrievania. Predhrievaním sa zvýšila objemová hmotnosť peliet u kukuričnej slamy. U miskantusu a pšeničnej slamy sa objemová hmotnosť významne zvýšila pri vlhkosti peliet 5% a u lucerny na seno a kompasového šalátu sa objemová hmotnosť pri tej istej vlhkosti znížila.

Vlhkosť peliet sa vyznačovala negatívnym vplyvom na trvanlivosť peliet vyrobených či už s predhrievaním, alebo bez predhrievania. Zvýšenie vlhkosti z 5% na 20% spôsobilo zníženie oteruvzdornosti materiálov na výrobu biomasy, avšak oteruvzdornosť predhrievaných peliet bola vyššia v porovnaní s peletami bez predhrievania. Najvyššia oteruvzdornosť 96% bola dosiahnutá u kukuričnej slamy vyrobenej s predhrievaním.

Uskladnenie peliet všetkých materiálov na výrobu biomasy na dobu troch týždňov pri bežnej teplote miestnosti malo negatívny vplyv na oteruvzdornosť peliet vyrobených bez predhrievania v prípade rôznych vlhkostí. Naopak u uskladnených peliet vyrobených s predhrievaním, menovite u kukuričnej slamy, pšeničnej slamy a miskantusu, došlo pri vlhkosti 5% k pozitívnej reakcii a uskladnením peliet sa ich oteruvzdornosť zvýšila.

Tvorba zmesi zmiešaním 25% miscanthus s 75% kukurice slamy zaznamenalo signifikantne zvýšenú oteruvzdornosť pri miscanthuse, avšak oteruvzdornosť obilia slamy bola znížená, ale toto zníženie nie je štatisticky významné. Pšeničná slama bola podobná miscanthusu pri rovnakom pomere miešania.

INTRODUCTION

Increasing energy demand and decreasing oil reserves make it necessary to find alternative sources of energy. Cellulose materials are attractive as a sustainable source of fuels and chemicals because of their plentiful supply and relatively low cost. The world governments and petrochemical industry alike are looking at biomass as a substitute refinery feedstock for liquid fuels and other bulk chemicals. New large plantations are being established in many countries. . Disadvantages of biomass as an energy source include inefficient transportation and large volumes required for storage, solving these problems by densification the biomass will gains extreme importance. Biomass densification is defined as compression or compaction of biomass to remove inter-particle voids. Compression baling can reduce biomass volume to one-fifth of its loose bulk volume.

OBJECTIVES

The study will be aimed on the following steps.

1. Comparing different kinds of biomass materials (crop residues and grasses) and their mixtures.
2. Comparing the effect of chopping the biomass materials in coarse particle size with other studies results which they used fine particle size of the chopped materials. The preparation of biomass material consuming energy, the highest amount of the consumed energy is going to chopping with hammer mills. Reducing the final energy consumption is our main goal in this study.
3. Studying the effect of pressure force and die diameter, selecting the optimal pressure and diameter which gives the best results in the point of pellets properties.
4. To study the effect of pressing pellets with and without preheating on the physical and mechanical properties of produced pellets.
5. Selecting the proper moisture content of the particles before pelleting for producing high quality of densified products which resisting the handling and storing for a long time.
6. According to the results obtained, some blends of biomass materials will be formulated by mixing the worst material for compacting and the best one. Enhancing the worst materials properties without adding any additional binders only by mixing with other biomass materials.

MATERIALS AND METHODS

Five different kinds of biomass feedstock's namely; alfalfa *(Medicago sativa*) hay, prickly lettuce (*Lactuca serriola*), wheat (*Triticum spp.*) straw, miscanthus (*Miscanthus*) and corn *(Zea mays L.)* stover are used. Figure 1 is shows the layout of the experiment. All materials chopped by using a manual straw chopper when they reached the desire moisture content. The particle size distribution was determined according to **ANSI/ASAE S424.1 (R2008)**. The geometric mean diameter ($\bar{x}_{gm}$) of the samples and geometric standard deviation of the particles (S_{gm}) was calculated according to the above mentioned standard. Moisture content of the raw materials was determined according to **ASAE S358.2 (2008)**. The unit density of the pellets was determined by direct measurement method depending on the **ASABE S269.4, (2007)** standard.

Durability of pellets was measured according to the **ASAE S269.4, (2007**) standard method of which is intended to assess the durability of Cubes, Pellets and Crumbles.

All biomass grinds pressed by a hydraulic press with pressure force of 150 MPa. A single die cylinder and plunger of 20mm diameter was used. Biomass materials had been pelleted under room temperature conditions without preheating and with preheating to 85^{o}C before compacting. The die cylinder heated by means of external oven to 200 ^{o}C and surrounded by a 5cm thick of fiber glass insulating material, which prevents heat losses as much as possible for heating the biomass materials before compressing. A preheating temperature of 85°C was chosen because the glass transition temperature of corn stover averaged on it **(Kaliyan and Morey, 2006)**. Furthermore, **Kaliyan and Morey (2007)** reported that temperatures of around 85°C can occur in conventional ring-die pelleting machines due to frictional heating. The die core temperature measured using a digital thermometer. A known amount of 5g of each biomass feedstock was allowed to flow freely from a funnel and fills the cylindrical die for compacting, then the compacted material pellets pushed out of the bottom of the die by releasing the top piston and letting the bottom piston to move freely. The pellets directly after been pushed out from the cylinder their diameter and length was measured by a digital vernier caliper and after 1 hour the same measurement repeated to recording pellets expanding and their durability had been tested according to the standard aforementioned. All statistical analyses were performed using the software SPSS 11.5 for Windows® (SPSS Inc., Chicago, IL) at 1% significance level.

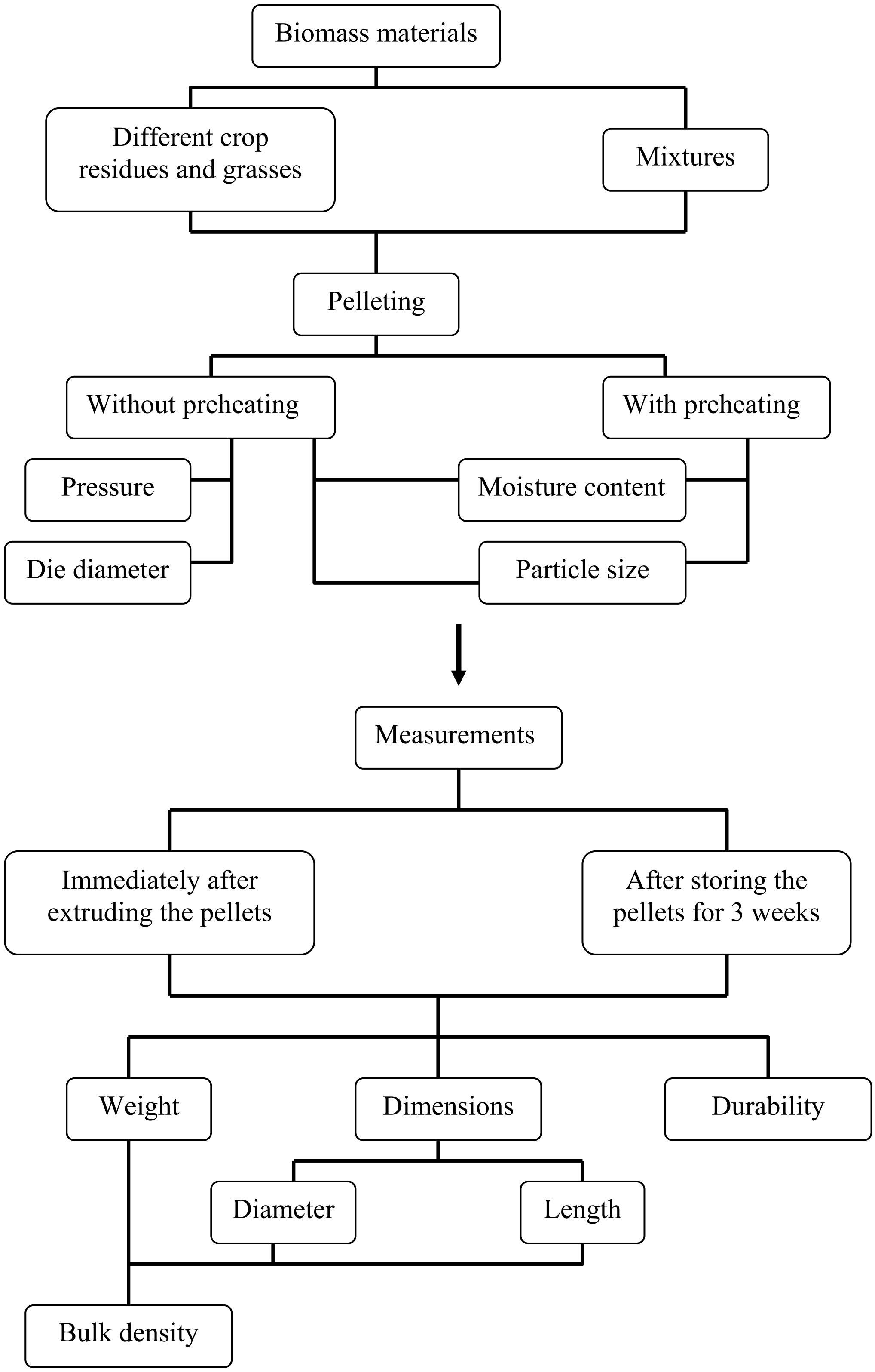

Figure 1. Layout of the experiment work.

RESULTS AND DISCUSSION AND BRIEF CONCLUSIONS

Effect of chopping biomass materials on the particle size distribution

Size reduction is an important pretreatment of biomass for energy conversion. Size reduction is also crucial to the densification process. For example, in the production of fuel pellets and briquettes, the feedstock has to be ground before being transformed into a denser product. Particle size reduction increases the total surface area, pore size of the material and the number of contact points for inter-particle bonding in the compaction process. The performance of any chopping machine is measured in terms of energy consumption and geometric mean diameter and particle size distribution of the ground product. Geometric mean diameter and particle size distribution of biomass grinds are important factors that affect the binding characteristics for densification.

As shown in Fig 2 the finest geometric mean diameter of (3.32 mm) was for alfalfa hay particles among all biomass samples, whereas the corn stover particles had the coarser geometric mean diameter of (8.5 mm), and the other biomass materials distributed between this rang. This difference might be due to the variation in moisture content of all the materials in the time of chopping as well as difference in the mechanical properties. **Mani et al. (2004) and Mani et al (2006a)** mentioned that during compaction, smaller particles rearrange and fill in the void space more than larger (coarse) particles and producing denser and durable compacts. Coarse particles are also suitable feed for boilers and gasifiers. Narrow range particle size distribution with more fines is suitable for enzymatic hydrolysis of lignocelluloses due to the generation of more surface area and pore spaces during fine grinding. But fine grinding of biomass requires high energy. An ideal particle size distribution remains to be determined for each bioconversion process. **Tabil (1996)** found that the compressive behavior varying due to the different size of alfalfa chops.

<u>Conclusion:</u> *From this results we conclude that chopping the biomass materials two coarse particle did not affecting in properties of the densified products, also each biomass material had different shape and mechanical properties which leads to a different cutting and particles.*

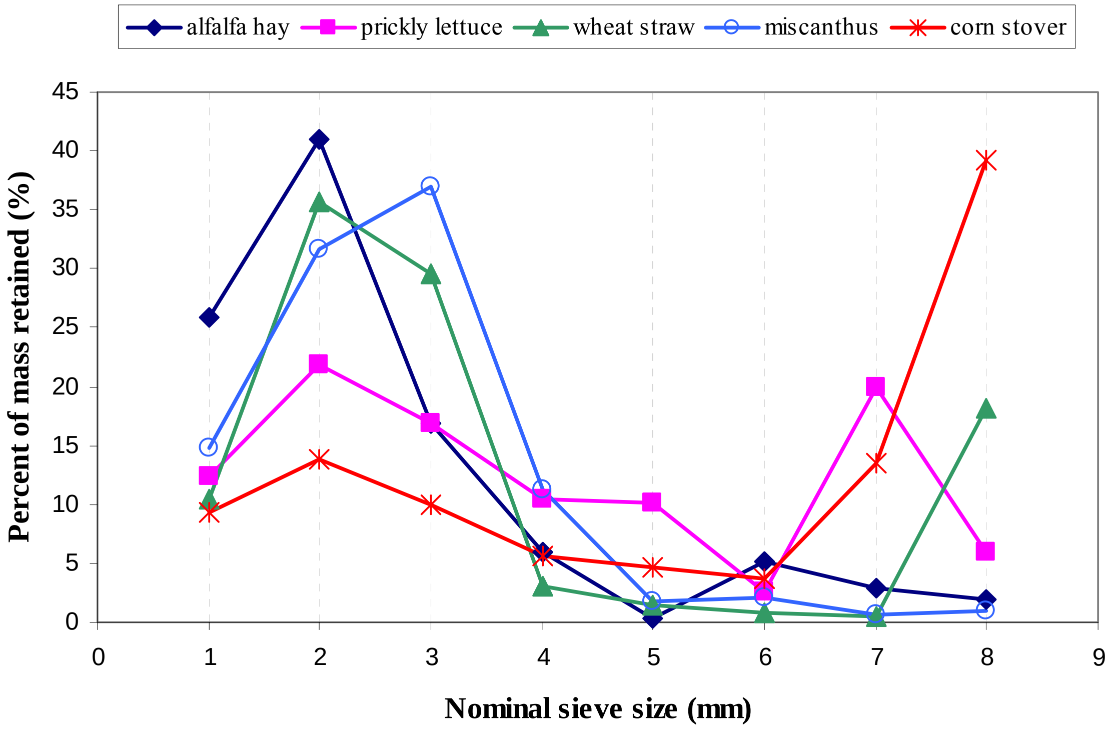

Figure 2. Particle size distribution of different biomass materials

Bulk density of chopped loose materials and pellets

Bulk density of chopped loose materials varied between the biomass materials and each material it bulk density varied depending on its moisture content. In Tab. 1, it can be observed that the lowest bulk density of the particles (53.3 kg.m^{-3}) was for corn stover with the moisture content of 5%, this might be due to the coarse particle size of corn stover which leaves a lot of gaps and voids between the particles. Whereas the highest bulk density of particles (109.6kg.m^{-3}) was for prickly lettuce. These results agreed with **(Sokhansanj and Turhollow, 2004)**. They found that bulk density of loose plant-based biomass ranges from (50 to 130 kg.m^{-3}) depending on the plant species and particle size and its distribution. The results obtained from the experiment showed that the bulk density was increasing as the particle size was decreasing, and almost increased with increasing the moisture content. This result came in agreement with the results obtained by **(Lam, et al, 2008)**. Generally it was noticed that the larger the screen openings, the lower were the bulk and particle densities, that was just what **(Mani et al, 2002)** found in their study.

Moisture content plays a major role in determining density and strength of the densified masses. An increase in biomass materials moisture content considerably decreased the pellets density even at high applied pressures. The maximum pellet density of (1238.1 $kg.m^{-3}$) was observed in the moisture of 5% for prickly lettuce, while it reduced to (926.5 $kg.m^{-3}$) in the moisture content of 20%. The same results observed for all biomass materials. At high moisture, more surface cracks and axial expansions were observed on the pellets. Therefore, optimal moisture content exists for each feedstock to produce high pellet density and strength. We claim that the biomass materials can be compacted into high density briquettes at low feed moisture (about 5%). **Grover and Mishra (1996)** recommended low feed moisture content (8 - 10%) for biomass materials to produce strong and crack-free pellets. **Mani et al, (2004)** their results showed that the effect of pressure and moisture content on briquette density were highly significant at 5% probability. The interaction effect of moisture content and pressure on briquette density data was also statistically significant. However, there were no significant differences between the briquette densities produced at 5 and 10% moisture content.

Conclusion: From the results obtained we can conclude that the bulk density increasing as the particle size was decreasing, and increased with increasing the moisture content.

Effect of preheating and moisture content on the durability of pellets

Durability of pellets made without preheating from different biomass species in different moisture contents are give in Fig. 3. It's obvious that the moisture content had affected negatively on the durability of pellets made without preheating, increasing the moisture content from 5% to 20% had decreased the durability of the biomass materials. This result disagreed with the results obtained by **(Andrejko and Grochowicz . 2007)**, while it came in agreement with the results of **(Mani et al, 2006b)**. They found that the moisture content had affected the durability of pellets. Figure 4 shows the durability of pellets made with preheating in different moisture content from all biomass materials. It can be observed that with elevating the moisture content, the durability of all biomass materials had reduced, whereas the durability had increased for all biomass species if it compared with the pellets made without preheating.

Table 1. Bulk density of all biomass particles, geometric mean diameter and geometric standard deviation of particles, unit density of pellets made with different moisture contents, with and without preheating, before and after storing.

Biomass materials	**Moisture content, % w.b**	***Bulk density of chopped loose materials, kg.m^{-3}**	**Geometric Mean diameter of particles, mm**	**Geometric Standard deviation of particles**	***Unit density of pellets produced without preheating, kg.m^{-3}**		***Unit density of pellets produced with Preheating for 85^{o}C, kg.m^{-3}**	
					Immediately after ejection before storing	**After relaxation and storing for 3 weeks**	**Immediately after ejection before storing**	**After relaxation and storing for 3 weeks**
Alfalfa hay	7	79.04±0.9	3.32	1.9	1226.1±6.7**	1116.3±6.1**	1191.4±6.7	1159.7±6.3
	10	97.4±1.4			1203.03±5.6	1083.4±6.1	1054.33±5.9	1079.35±6.1
	15	91.7±1.1			1077.1±6.1	846.54±5.9	1052.9±6.6	1044.1±5.9
	20	90.8±1.1			981.24±4.9	707.3±5.1	1017.5±5.8	927.1±4.9
Prickly lettuce	7	68.6±0.8	5.34	1.9	1238.1±6.5**	1070.1±5.9	1160±5.9	1192.5±5.4
	10	96.7±1.3			1200.5±5.8	1008±5.3	1185.5±6.3	1174.3±6.1
	15	109.6±1.5**			1023±6.1	724.9±5.1	990.9±6.1	926.6±5.1
	20	102.4±1.3**			926.5±5.1	613.03±6.1	0±0.0	0±0.0
Wheat straw	5	59.8±0.8	4.61	1.86	1093.8±4.9	872±4.9	1167.7±6.3	1182.7±5.9
	10	76.7±0.9			997.24±5.1	808.7±4.1	0±0.0	0±0.0
	15	79.14±1.0			820.14±4.7	632.6±5.1	0±0.0	0±0.0
	20	76.8±0.8			534.1±4.1	0±0.0	0±0.0	0±0.0
Miscanthus	5	92.7±1.3	3.94	1.62	1054.4±6.6	820.9±4.9	1098.41±6.6	1090.3±6.7
	10	102.3±1.5**			948.12±6.1	771.9±6.2	912.3±5.8	928±6.1
	15	100.8±1.5**			930.8±5.9	0±0.0	0±0.0	0±0.0
	20	102.6±1.6**			0±0.0	0±0.0	0±0.0	0±0.0
Corn stover	5	53.5±0.7	8.5	2.25	1172±6.1	969±3.9	1228±6.9**	1272.5±6.8**
	10	57.04±0.7			1045±5.7	1005.3±4.8	1175.6±6.7	1125±6.1
	15	65.9±0.9			920.44±6.1	721±4.1	907.1±6.1	829.3±4.9
	20	61.5±0.9			714.7±5.9	505.3±4.0	838.4±6.3	588.4±5.6

*Mean ± standard deviation (n = 3) for chopped materials and (n = 5) for pellets.
** Mean values within the columns are statistically significant under level of (0.01).

Roughly all materials in the lowest moisture content (5%) recorded the highest values of the durability; this might be due to that the water acts as a film type binder by strengthening the bonding in pellets. Also, water helps in promoting bonding by van der Waals' forces by increasing the true area of contact of the particles. The right amount of moisture develops self-bonding properties in lignocelluloses substances at elevated temperatures and pressures prevalent in pelleting machines.

The value obtained from corn stover pellets durability was similar to the value which obtained by **(Kaliyan, 2008)**, but he mentioned that with pre heating some losses in moisture content will occur during compaction due to the tolerance between the piston and cylinder wall. This loss of moisture content may affect on the compressibility of pellets. To preheat the biomass grinds, the bottom opening of the pelleting cylinder was closed tightly with a steel base that had an O-ring seal, the top opening of the cylinder was closed with a specially designed cap. He used corn stover with geometric mean particles of 0.8 mm in moisture content of 10% and 15%. Our procedure and idea was to release the moisture going out during heating and compacting, and using coarse particle size, the geometric mean particles diameter was 8.5 mm. **Saptoadi, (2006)** found that for the best results of combustion, the pellets dimensions should be as small as possible with coarse particle size.

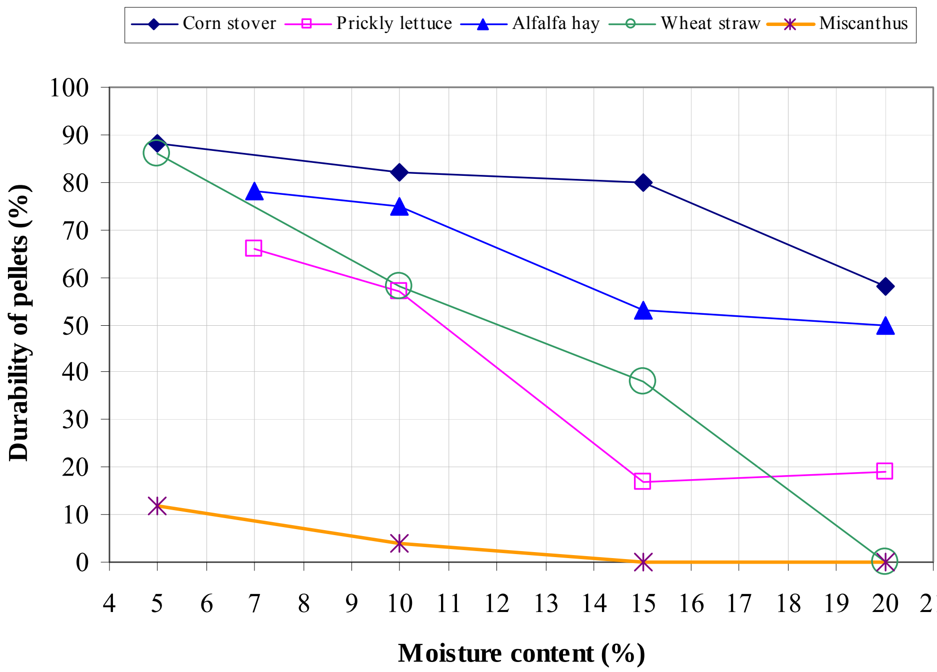

Figure 3. Durability of pellets made without preheating for all biomass materials

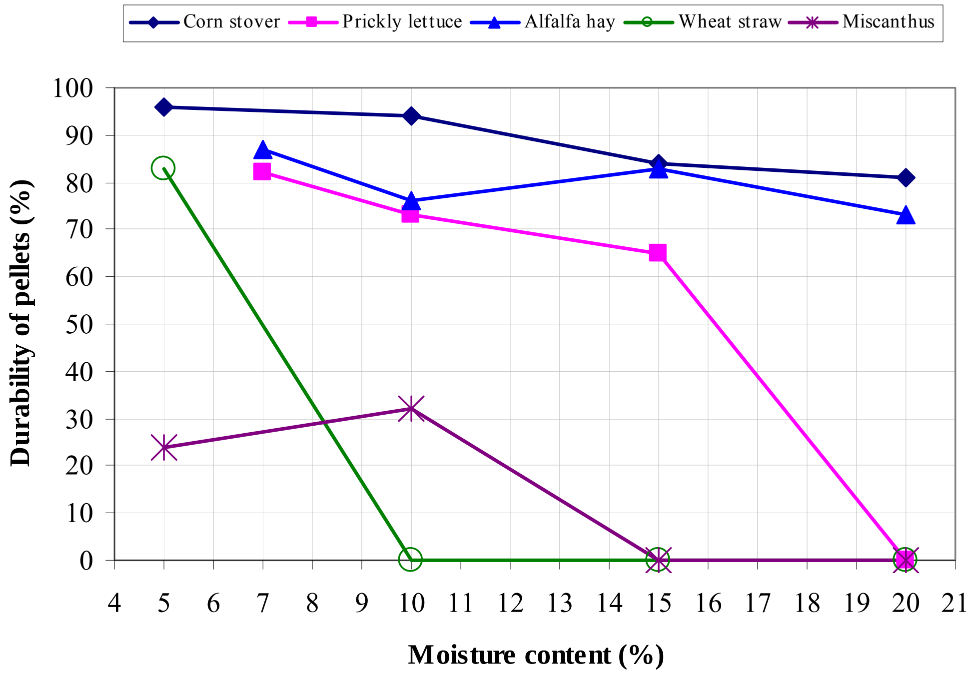

Figure 4. Durability of pellets made with preheating for all biomass materials

<u>Conclusion</u>: Increasing moisture content to 20% caused in decreasing the durability of pellets made with and without preheating. Preheating the biomass materials before pressing had enhanced the durability of pellets made with moisture content of 5%.

Effect of storing on the durability of pellets

Storing the pellets for 3 weeks under room temperature conditions approximately 22°C and 55% relative humidity for all biomass materials are shown in the tables (2, 3, 4, 5, and 6). Storage had negatively affected on the durability of pellets made without preheating for all kind of biomass materials in the different moisture contents, in the other hand there was some positive response for storing from pellets made with preheating, the corn stover, wheat straw and miscanthus pellets in moisture content of 5% their durability had enhanced with storing, this enhancement might be due to gaining some moisture from the surrounding atmosphere, the water acts as a film type binder by strengthening the bonding in pellets. Also, water helps in promoting bonding by van der Waals' forces by increasing the true area of contact of the particles. **Fasina and Sokhansanj (1996)** postulated that a small percentage of increase in moisture content (about 4%) could have helped strengthen the bond between the individual particles in the pellet due to the binding forces of water molecules. **Khoshtaghaza et al. (1999)** said that there is no effect on durability at low relative humidity levels (59 to 66%).

<u>Conclusion</u>**:** *storing the biomass materials had affected on the durability of pellets made without preheating for all biomass materials, while the durability of corn stover, wheat straw and miscanthus pellets made with preheating had increased after storage.*

Table 2. Durability of alfalfa hay pellets before and after storing produced with and without preheating with different moisture contents.

Moisture content, %	***Durability of pellets produced without preheating, %**		***Durability of pellets produced with preheating, %**	
	Before storage	**After storage**	**Before storage**	**After storage**
7	78±1.8	73±1.7	#$(87)_2$±1.9**	73±1.9
10	75±1.6	73±1.9	$(76)_2$±1.6	73±2.1
15	53±1.7	42±2.1	$(83)_2$±2.2	74±1.6
20	50±19	13±1.3	$(73)_2$±1.9	67±1.8

*Mean± standard deviation (n=5)., # Durability tested 2 hours after cooling
** Mean difference is significant at .01...

Table 3. Durability of prickly lettuce pellets before and after storing produced with and without preheating with different moisture contents

Moisture content, %	***Durability of pellets produced without preheating, %**		***Durability of pellets produced with preheating, %**	
	Before storage	**After storage**	**Before storage**	**After storage**
7	66±1.3	57±1.8	#$(82)_2$±1.9**	78±2.1
10	57±1.3	34±1.6	$(73)_2$±2.1	82±2.3
15	17±1.6	4±1.2	$(65)_2$±1.6	34±1.8
20	19±1.5	6±1.1	0±0.0	0±0.0

* Mean± standard deviation (n=5)., # Durability tested 2 hours after cooling
** Mean difference is significant at .01...

Table 4. Durability of wheat straw pellets before and after storing produced with and without preheating with different moisture contents

Moisture content, %	*Durability of pellets produced without preheating, %		*Durability of pellets produced with preheating, %	
	Before storage	After storage	Before storage	After storage
5	86±2.3	75±2.0	#$(83)_2$±2.1	89±2.4**
10	58±2.1	61±1.9	0±0.0	0±0.0
15	38±1.6	55±1.6	0±0.0	0±0.0
20	0±0.0	0±0.0	0±0.0	0±0.0

* Mean± standard deviation (n=5)., # Durability tested 2 hours after cooling
** Mean difference is significant at .01...

Table 5. Durability of miscanthus pellets before and after storing produced with and without preheating with different moisture contents

Moisture content, %	*Durability of pellets produced without preheating, %		*Durability of pellets produced with preheating, %	
	Before storage	After storage	Before storage	After storage
5	12±1.0	7±1.1	#$(24)_2$±1.1	50±1.9**
10	4±0.4	4±1.0	$(32)_2$±1.3	18±1.1
15	0±0.0	0±0.0	0±0.0	0±0.0
20	0±0.0	0±0.0	0±0.0	0±0.0

* Mean± standard deviation (n=5)., # Durability tested 2 hours after cooling
** Mean difference is significant at .01...

Table 6. Durability of corn stover pellets before and after storing produced with and without preheating with different moisture contents

Moisture content, %	*Durability of pellets produced without preheating, %		*Durability of pellets produced with preheating, %	
	Before storage	After storage	Before storage	After storage
5	88±1.9	79±2.1	#$(96)_2$±0.7	97±0.3**
10	82±2.3	78±1.8	#$(94)_2$±0.6	91±0.7
15	80±2.1	70±1.9	$(84)_2$±2.3	84±2.1
20	58±1.7	57±1.5	$(81)_2$±1.2	75±1.3

* Mean± standard deviation (n=5)., # Durability tested 2 hours after cooling
** Mean difference is significant at .01...

Effect of mixing biomass materials on the durability of pellets

Figure 5 demonstrates the durability of pellets produced with preheating with moisture content of 10% from miscanthus and corn stover and their blends (50% miscanthus + 50% corn stover and 25% miscanthus + 75% corn stover). It was obvious that there is a big difference between the unmixed miscanthus and corn stover in the point of durability, the durability of miscanthus was 24% whereas the durability of corn stover was 96%. By mixing the miscanthus with corn stover in the ratio (50% + 50%) the durability of the mixture was 80%, this ratio was enhancing the durability from 24% to 80% when compared with the durability of miscanthus and decreasing the durability from 96% to 80% if compared with the durability of corn stover, while the mixture of 25% miscanthus + 75% corn stover had enhanced the durability by 10 % and became 90%, this enhancement statistically had no significant differences when compared with the durability of corn stover, furthermore the miscanthus gained more durability than (50% + 50%).

Durability of wheat straw and corn stover and their mixtures (50% wheat straw + 50% corn stover and 25% wheat straw + 75% corn stover) are shown in Fig. 6. The mixture (50% + 50%) did not show any significant difference with the wheat straw in the point of durability which was 83%, while when it compared with the corn stover pellets durability there was a significant decrease in the corn stover pellets durability by 13%, but with the mixture of (25% wheat straw + 75% corn stover) the situation had changed an the durability of produced pellets had increased by 10% and became 93%, there was no significant difference when it was compared with the durability of corn stover pellets, but there was a significant difference when compared with the wheat straw pellets in the point of durability.

<u>Conclusion</u>: *Miscanthus considered as the worst biomass material for compaction. By mixing with corn stover in the ratio of 1:3 and moisture content of 5%, the durability had increased from 24% to 90%, however the durability of corn stover had reduced but it stayed in the acceptable range*.

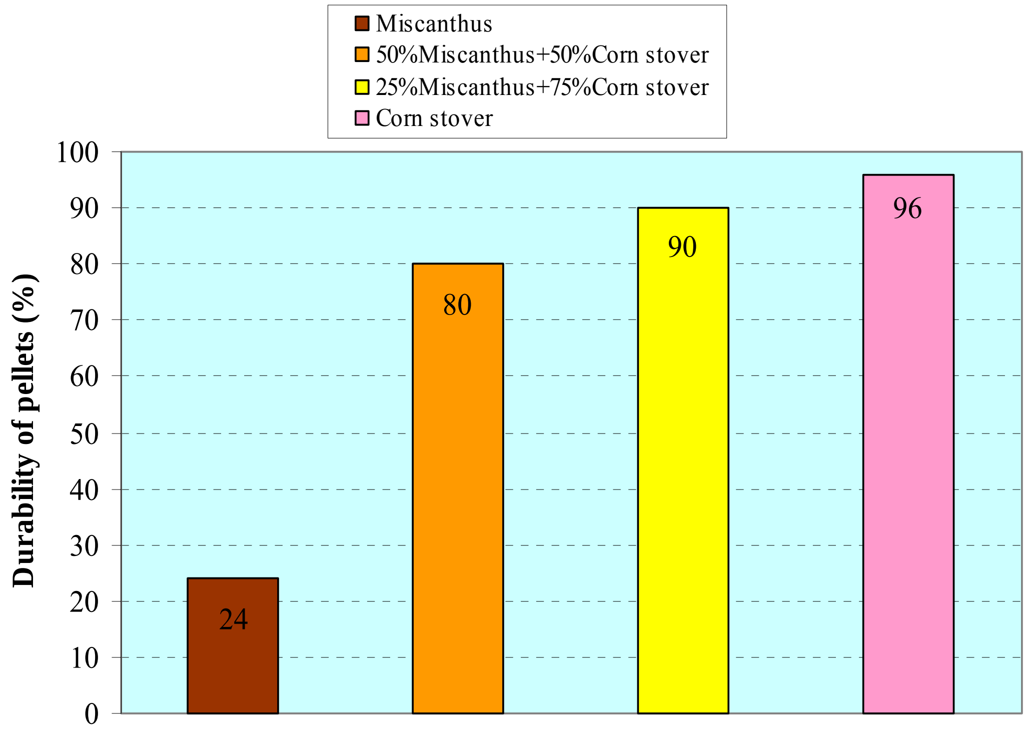

Figure 5. Durability of pellets made with preheating with moisture content of 5% from miscanthus and corn stover and their mixtures

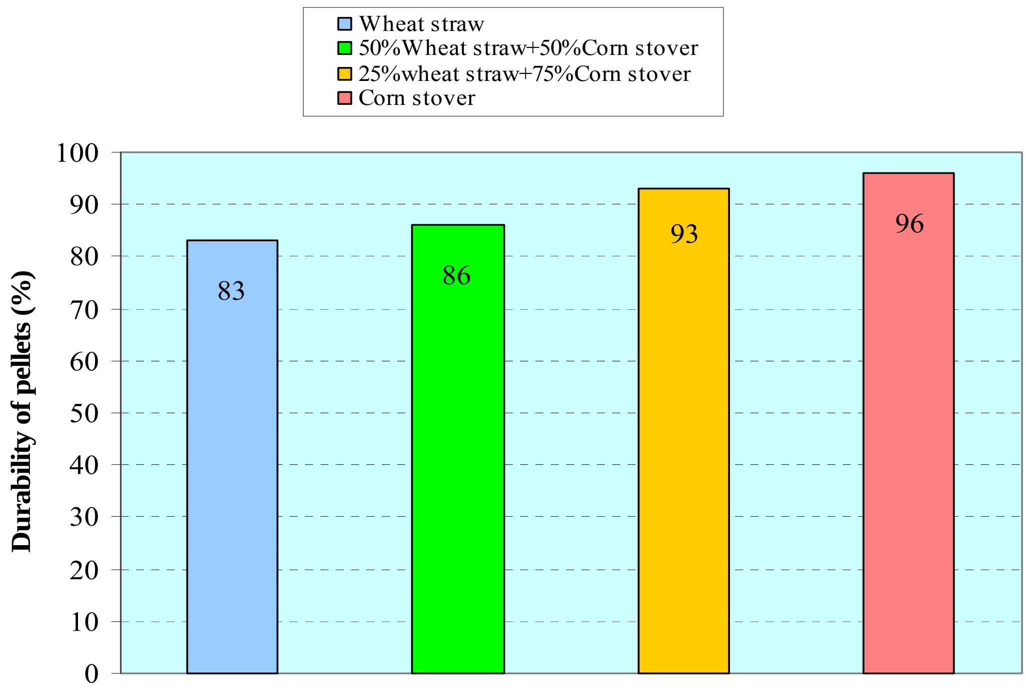

Figure 6. Durability of pellets made with preheating with moisture content of 5% from wheat straw and corn stover and their mixtures

CONCLUSIONS

From the results obtained we can conclude the following:

- Chopping the biomass materials two coarse particle did not affecting in properties of the densified products, also each biomass material had different shape and mechanical properties which leads to a different cutting and particles.
- The bulk density increasing as the particle size was decreasing, and increased with increasing the moisture content.
- Increasing moisture content to 20% caused in decreasing the durability of pellets made with and without preheating. Preheating the biomass materials before pressing had enhanced the durability of pellets made with moisture content of 5%.
- Storing the biomass materials had affected on the durability of pellets made without preheating for all biomass materials, while the durability of corn stover, wheat straw and miscanthus pellets made with preheating had increased after storage.
- Miscanthus considered as the worst biomass material for compaction. By mixing with corn stover in the ratio of 1:3 and moisture content of 5%, the durability had increased from 24% to 90%, however the durability of corn stover had reduced but it stayed in the acceptable range.

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