The Effect of Chipping Method on the Geometry of Particles Produced from Date Palm Frond

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The aim of this research was to study the effect of chipping method on geometry of particles obtained from date palm frond as a lignocellulose residue. For this purpose, date palm fronds were chipped with four different equipment: chipper-flaker, chipper-hammer mill, flaker-hammer mill, and chipper-flaker-hammer mill. The geometry of the particle including particle size, particle size distribution, shape, and aspect ratio were investigated. The results showed that maximum weight percentage (more than 40%) was related to the particles sizes of +30/-40 mesh for all chipping methods and more than 50% of all generated particles had a needle shape. In the chipper-hammer mill method, both the weight percentage of useable particles in particleboard and the particle percentage of the rectangle or nearly rectangle particle were higher. Thus, the chipper-hammer mill method was judged to be the best method.

Key words: Chipping method; Particles geometry; Date palm; Frond; Particleboard

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INTRODUCTION

The shortage of the raw wood materials has become one of the biggest challenges for wood-based panels (WBP) industries in recent years (Yang *et al.* 2003). Material efficiency, reuse, recycling of wood, production of lightweight wood-based products, and use of non-wooden lignocellulosic raw materials including agricultural residue are important options for dealing with the aforementioned challenges (Shalbafan *et al.* 2018). Therefore, many studies have focused on the utilization of underutilized wood resources and alternative materials for application in these industries (Khedari *et al*. 2003; Ashori and Nourbakhsh 2008; Guler *et al*. 2008; Al-Oqla *et al*. 2014; Cosereanu *et al*. 2015).

Agricultural residues have a great potential to compensate for the wood shortages in WBP industries. Agricultural residues are inexpensive resources that are available in large quantities. Among various agricultural lignocellulosic residues, date palm shows high potential for particleboard manufacturing.

The date palm (*Phoenix dactylifera*) is a tropical and subtropical species with a lifetime of 150 to 300 years (Hegazy and Aref 2010; Ferrandez-Garcia *et al*. 2018). This species grows in arid and semi-arid regions of the world (Fig. 1), including southeast Asia, Middle East, North Africa, and some parts of central and southern America (Hosseinkhani *et al*. 2014; Alfaro-Viquez *et al*. 2018).

In phytology, the date palm frond consists of two main parts: rachis and leaflets (Zayed *et al.* 2014; Saadaoui *et al.* 2013). Large amounts of renewable and lignocellulose residues are produced in cultivating areas due to the annual pruning of date palm fronds (Hegazy and Ahmed 2015). In most areas, these residues are traditionally burned or landfilled. This process causes serious threats to the environment and human health

(Usman *et al*. 2015). These residues have great potential for wood substituting in wood-based panels such as particleboard, oriented strand board, cement board, and wood plastic composites (Rangavar and Hoseiny Fard 2015; Elaieb *et al*. 2018).

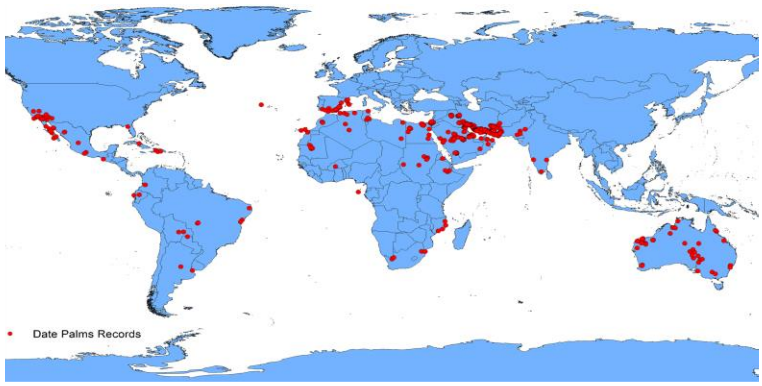


Fig. 1. Date palm global distribution (Shabani *et al*. 2014)

The date palm cultivation area in Iran is listed as 230,423 ha. In every hectare, approximately 156 date palms are planted. Each date palm produces nearly 49.3 kg of residue during annual pruning (Sajdak *et al.* 2014). Therefore, it is estimated that 980,000 tons of date palm pruning are annually produced throughout the country.

In recent years, the production of agro-based panels using agricultural residues instead of wood has come into focus. The industrial production of particleboard using date palm fronds has been considered in Iran, and two factories have been established, but the mechanical and physical properties of the products are low and do not meet the national and international standards (such as EN 312-2) limits.

An important problem inhibiting the use date palm fronds in the particleboard industry is the production of particles with inappropriate geometry. Many fine particles are generated during the conventional chipping process. Thus, it can be concluded that improper equipment is being used for chipping the fronds. Particle geometry, including particle shape and particle size, is an important parameter affecting the particleboard properties. Particle geometry determines the contact area for adhesive action which, accordingly, influences the physical and mechanical properties and machining of the particleboard panels (Sackey *et al.* 2008).

Particle geometry is directly influenced by the chipping method. Different chipping methods and machines are used in particleboard industries. Drum chippers are used for chipping logs and tree trunks and branches of small diameter (Ismail and Ghazy 2017). The hammer mill is used for size reduction of large particles (chips). The knife ring flaker changes the large size chips to suitable flakes for particleboard industries.

A shortage of raw materials resources for WBPs industries, especially particleboard in Iran, has increased in recent years. As mentioned above, a considerable amount of date palm fronds is annually available in Iran. Thus, palm date residues (fronds) can be an important resource for particleboard industries. There has been no comprehensive study on the possibility of using date palm frond in manufacturing of particleboard, and the production of particles with desirable geometry is one of the most important stages prior to particleboard production. Therefore, this study considered the effects of different chipping methods on the particle geometry of date palm fronds. The fronds were chipped using four different methods, and the geometry of generated particles was analyzed.

EXPERIMENTAL

Preparation of the Date Palm Fronds

About 500 date palm fronds (Mazafati cultivar) were collected from a farm in the south of Iran after pruning (Fig. 2). The length of the fronds was 1 to 6 m. All fronds were air-dried to reach a homogeneous moisture content before further processing. The moisture content of the fronds was 7 ± 1% before chipping. The fronds were cut into 200 mm and 300 mm pieces before feeding into the chipper and flaker, respectively (Fig. 3). Groups of 15 to 20 fronds were fed into the chipper machine (Fig. 3a).

Fig. 2. Palm date pruning and frond collecting

Chipping Process

Frond chipping operations were performed using four different chipping methods, including a chipper-flaker, chipper-hammer mill, flaker-hammer mill, and chipper-flaker-hammer mill with three different types of machines**.** The chipping machines were industrial, and chipping was performed in particleboard factories. The chipper was a drum chipper (PHT 240*850*9, Pallmann, Zweibrücken, Germany). The flaker was a knife ring flaker (PZKR 8-300, Pallmann). Finally, four types of particles were obtained. The fixed factors in the chipping process were date palm cultivar, time of pruning, and the moisture content of the raw material. The blades of the chipping machine were replaced before the process. The particles were dried to reach a moisture content of 2% prior to further analysis.

Investigation of Particle Geometry

Particle size and particle size distribution are the major factors determining the mechanical and physical properties of particleboard (Juliana *et al.* 2012). The particle size and particle size distribution were determined by screening 100 g of each type of particles using a vibrating machine and sieves of 8-, 10-, 18-, 30-, 40-, 50-, 60-, and 100-mesh. Crossed-openings in the mentioned sieves were respectively 2.38- 2- 1- 0.59- 0.40- 0.29- 0.25 and 0.14 mm. A laboratory vibratory shaker was used for particle size analysis. The particles were sieved for 10 min. The weight percentage of the remaining particles on each sieve was determined. Three different samples were analyzed for each type of particles.

To determine particle shape, a Dino-Lite digital microscope (Hsinchu, Taiwan) connecting to an image analyzer was used to measure the widths, thickness, and lengths of the particles. For this purpose, 20 particles from each fraction of 8, 10, 18, 30, 40 and 50 mesh (totally 120 particles for each chipping method) were randomly selected, and the mean values of aspect ratio for each fraction of each chipping method have been reported. The aspect ratios of the particles were determined as the ratio of the length to the width of particles. The particle shape analysis was carried out according to Juliana *et al*. (2012). In total, 6 main shape of particles were identified, and the numbers of particles in each shape were determined.

a

b

Fig. 3. The size of date palm fronds for feeding into the chipper (a) and knife-ring flaker (b)

Finally the particles were divided in two fractions of coarse and fine, and their aspect ratio and slenderness ratio (the ratio of length to thickness) resulting from each method were determined.

RESULTS AND DISCUSSION

Particle Size Analysis

The images of particles generated from four different chipping methods before and after screening (for size analyzing) are presented in Figs. 4 to 7. The four types of particles were clearly different in shape and size.

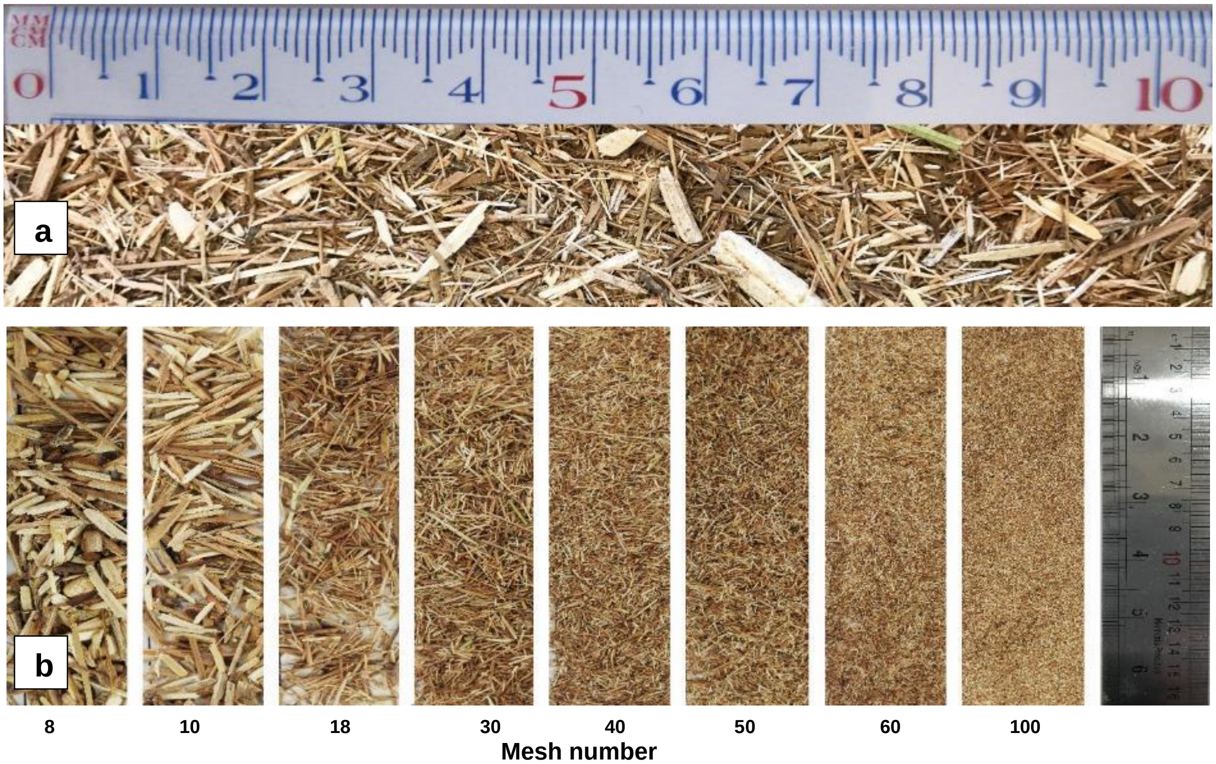


Fig. 4. Particles generated by chipper-hammer mill method (a) before and (b) after the size separation process

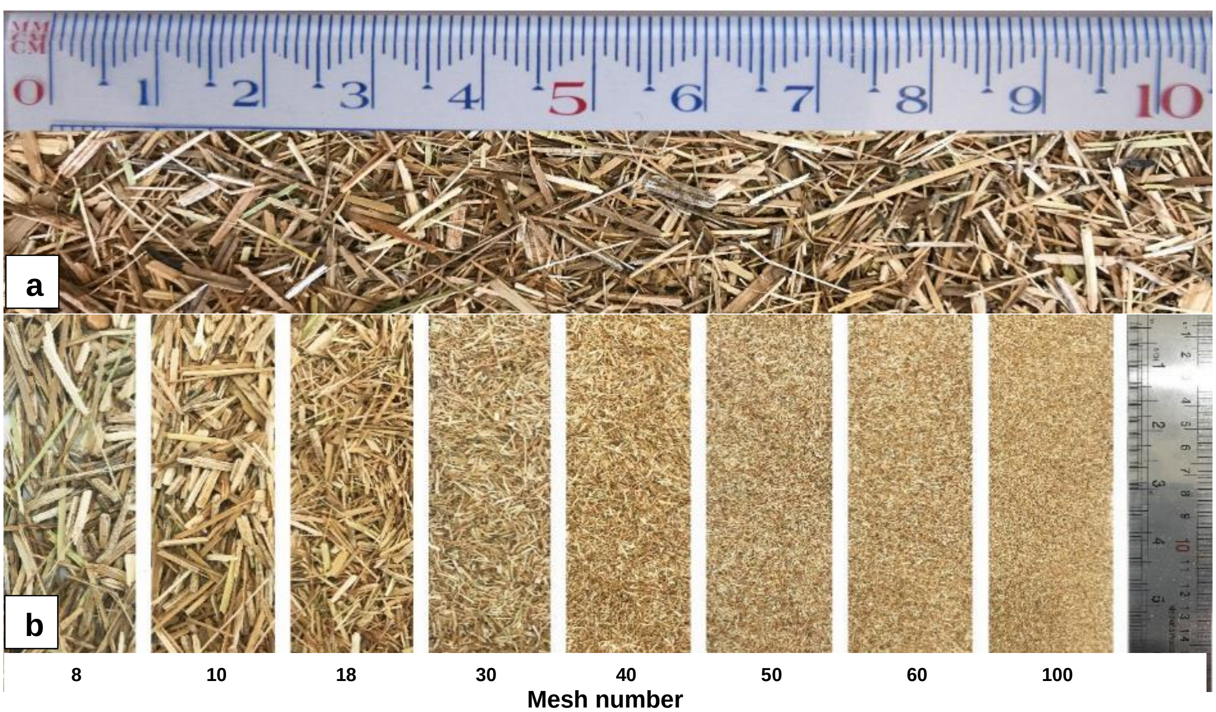


Fig. 5. Particles generated by flaker-hammer mill method (a) before and (b) after the size separation process

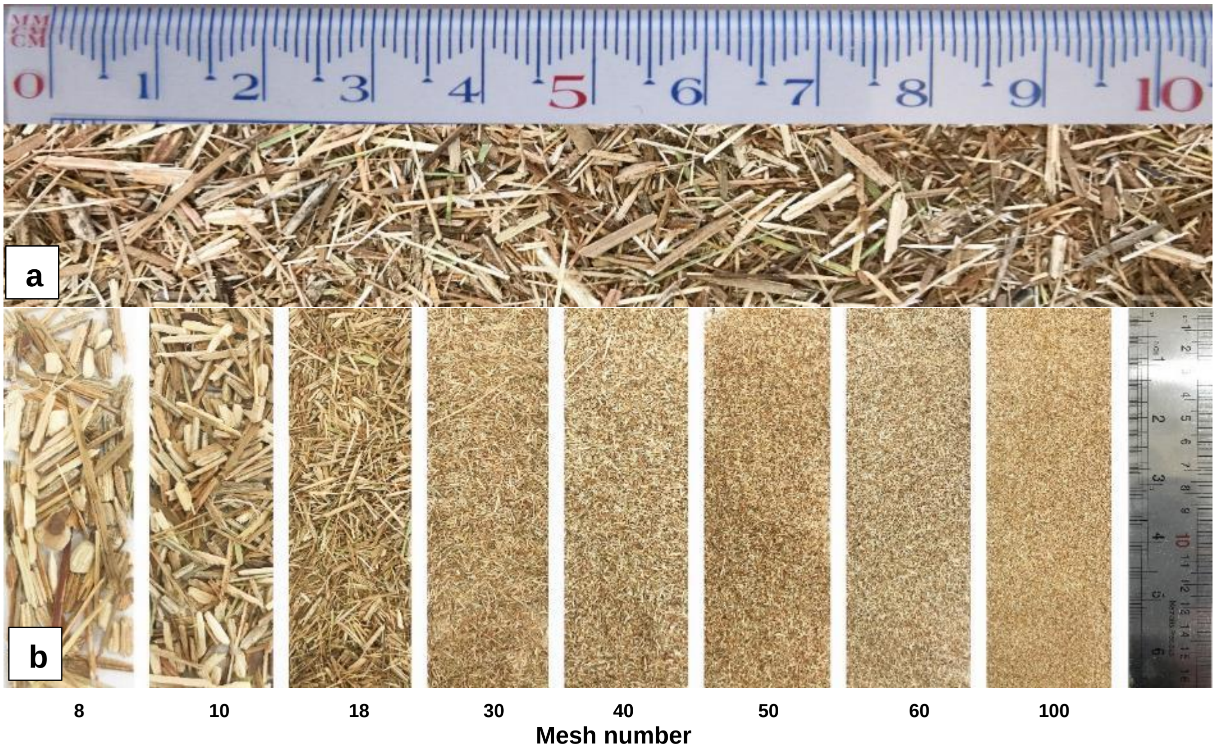


Fig. 6. Particles generated by chipper-flaker-hammer mill method (a) before and (b) after the size separation process

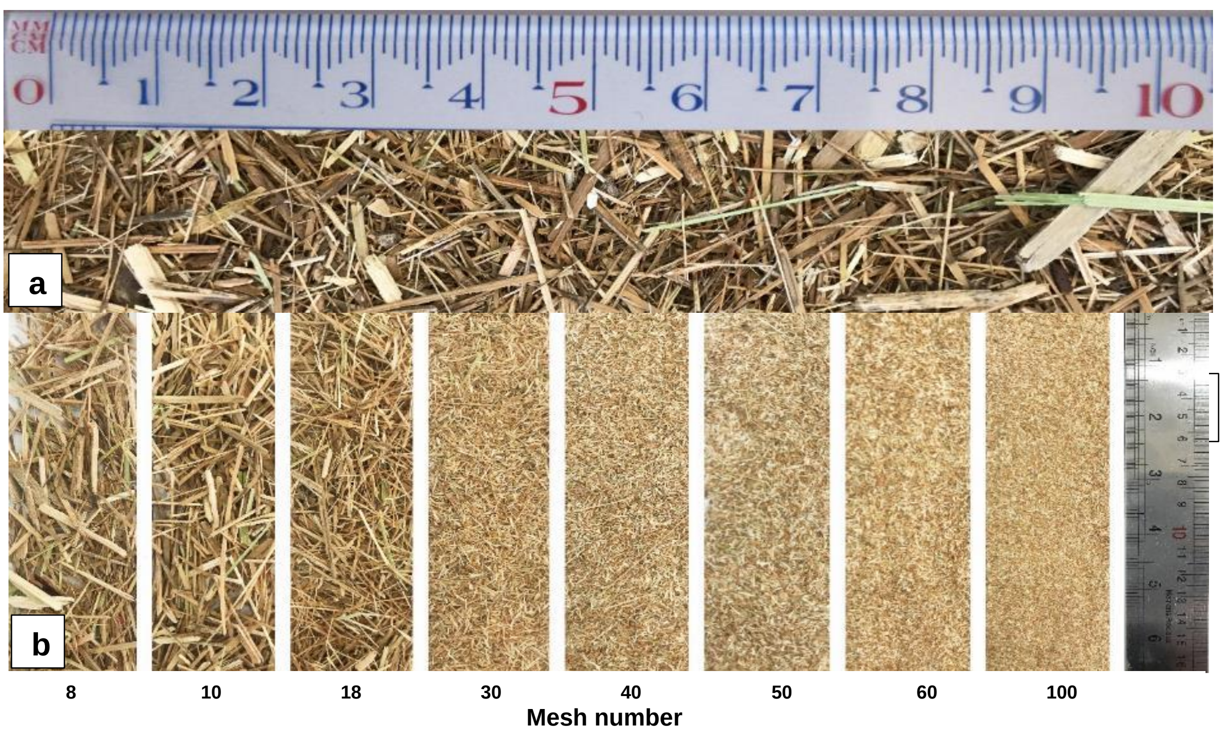


Fig. 7. Particles generated by chipper-flaker method (a) before and (b) after the size separation process

Figure 8 shows the weight percentage of particles remaining on the sieves of 8-, 10-, 18-, 30-, 40-, 50-, 60-, and 100-mesh. The maximum weight percentage (more than 40%) was for particles remaining on the sieve No. 30 for all chipping methods. On the other hand, the majority of particles had +30/-40 mesh size. The lowest weight percentage was for the particles remaining on the sieve No. 60, which was less than 0.5%. Notably, the weight percentage of larger particles (sieves No. 8 and 10) in the chipper-flaker method was considerably higher than the other methods. Unlike the three considered methods, the hammer mill was not used in chipper-flaker method, and probably for this reason a higher content of larger particles was obtained. Date palm fronds have a large number of parenchyma cells, leading to smaller particles during hammer milling. Parenchyma cells have thin, weak walls. The chipping process by hammer impacts generates fine particles.

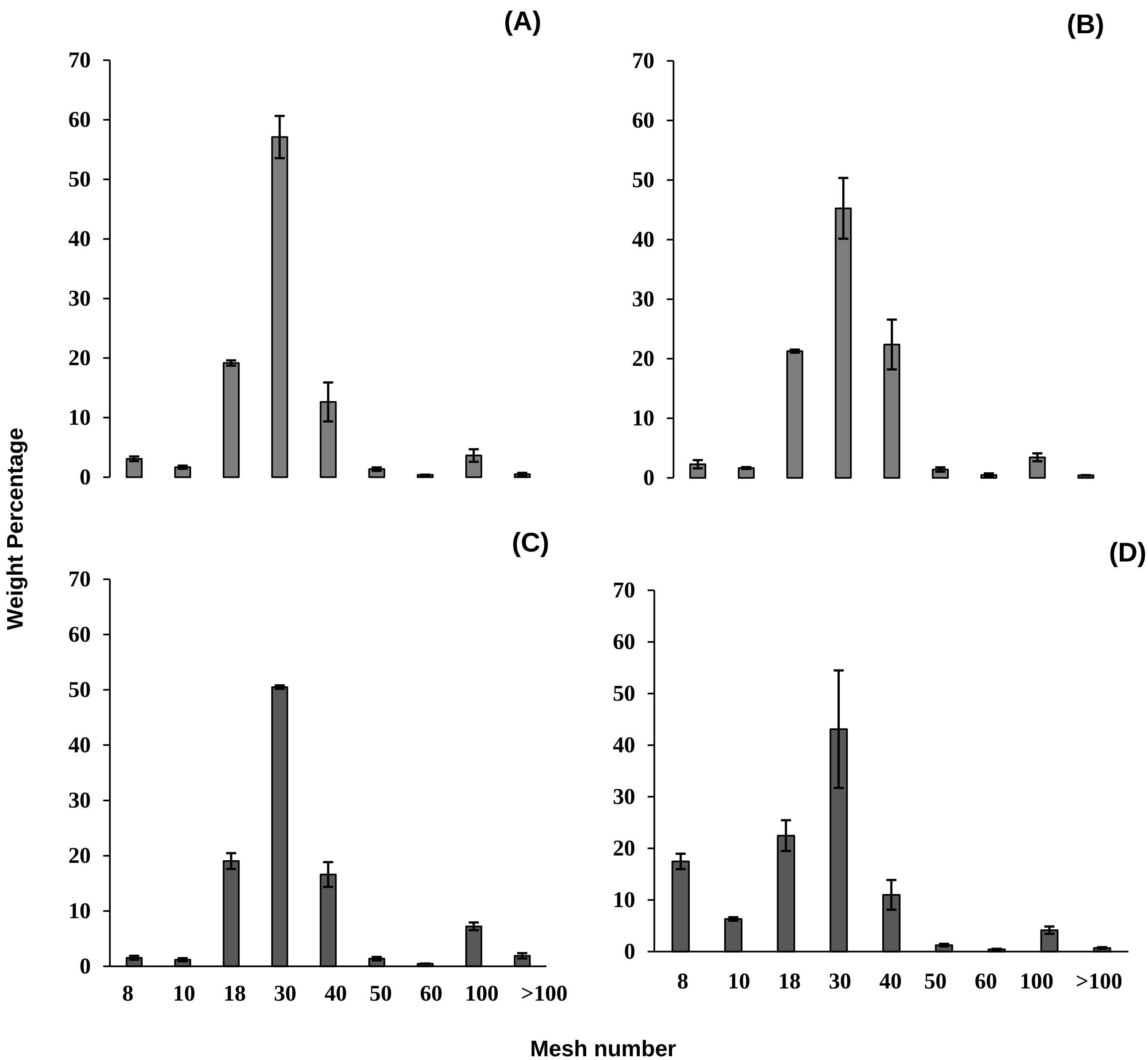


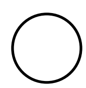
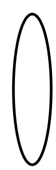
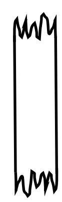
Fig. 8. The weight percentages of the particles formed by (A) chipper-hammer mill, (B), flaker-hammer mill, (C) chipper-flaker-hammer mill, and (D) chipper-flaker

Generally, particles that have passed through a 60-mesh sieve are non-usable in particleboard manufacturing processes because of the high specific surface area (Pan *et al*. 2007; Iskanderani 2009). A higher specific area results in higher resin consumption. The highest content (9%) of particles with lower size were observed for the chipper-flaker-hammer mill method. The sieves with 9-, 16-, and 32-mesh numbers are generally used in particleboard manufacturing factories (Sackey *et al*. 2008), and in the present research, the considerable amount of particles were obtained on sieves with mesh of 18, 30, and 40 almost for all chipping methods; and the chipper-flaker method exhibited the minimum amount in comparison to other ones.

Shape analysis of particles

The effect of chipping method on the particle shapes are illustrated in Table 1. More than 50% of all types of the generated particles had a needle shape. The highest percentage (65%) of particles with needle shape was observed for the chipper-flaker method. The chipper-flaker-hammer mill generated the minimum percentage (50%) of needle-shaped particles. In this method, the chipping operation was carried out to an extreme extent by three chipping machines. Therefore, the needle shape was changed to smaller particle sizes; only circular particles were found in this group.

Table 1. The Shapes, Number, and Percentage of Particles in Four Types of Particles

Observed shapes							
Chipping Method	Chipper-Hammer mill	70(58)	-	23(19)	-	2(1)	25(20)
	Flaker-Hammer mill	74(61)	-	19(15)	-	1(0.8)	26(21)
	Chipper-Flaker-Hammer mill	61(50)	24(20)	24(20)	-	2(1)	9(7)
	Chipper-Flaker	78(65)	-	3(2)	13(10)	-	26(21)

The numbers in parenthesis are in percentage.

Bendahou *et al*. (2009) reported that the vessels and the fibers of date palm frond form a structure similar to a slot. This slot consists of a bundle of vessel wrapped in a bundle of fibers. These bi-component structures are separated by parenchyma cells. The bundle of the vessel in a bundle of the fibers in this lignocellulosic material increased resistance to cut, breaking, and cleaving. Therefore, the needle shape of the particles is attributed to such structure of bundle of vessels or fibers. In the chipper-hammer mill method, 20% of the particles had a rectangle shape, and 19% of the particles had an ellipse shape. For the flaker-hammer mill method, the needle shapes comprised 61% of particles, followed by rectangle shape (21%) and ellipse shape (15%). In the knife ring flaker, large particle size or chips are converted to smaller flakes with cutting, but in the hammer mill device, chipping is done by breaking and cleaving. The particles resulting from the knife ring flaker have a better regular geometry or have shorter length-to-width ratios. Juliana *et* *al*. (2012) showed that most kenaf core particles were of rectangular or nearly rectangular shapes, whilst kenaf bast was in the curl and kneel form. By increasing the length and width of the particles (regardless of the resin content), larger specific contact areas are provided for bonding by resin, leading to particleboard with higher mechanical strength. Therefore, particle with rectangular or nearly rectangular shapes have more potential in particleboard. Although the size, size distribution, and shape of particles in chipper-hammer mill and flaker-hammer mill were very similar, the most important problem in flaker-hammer method is that the particles get stuck inside the flaker, and this phenomenon interrupts the chipping process (Fig. 9).

Fig. 9. The particles got stuck inside flaker

Aspect ratio

The influence of aspect ratio (ratio of the length of particles to the width) on physical and mechanical properties of particleboard is well known. The effect of chipping method on the aspect ratio of particles using different mesh numbers is shown in Fig. 10.

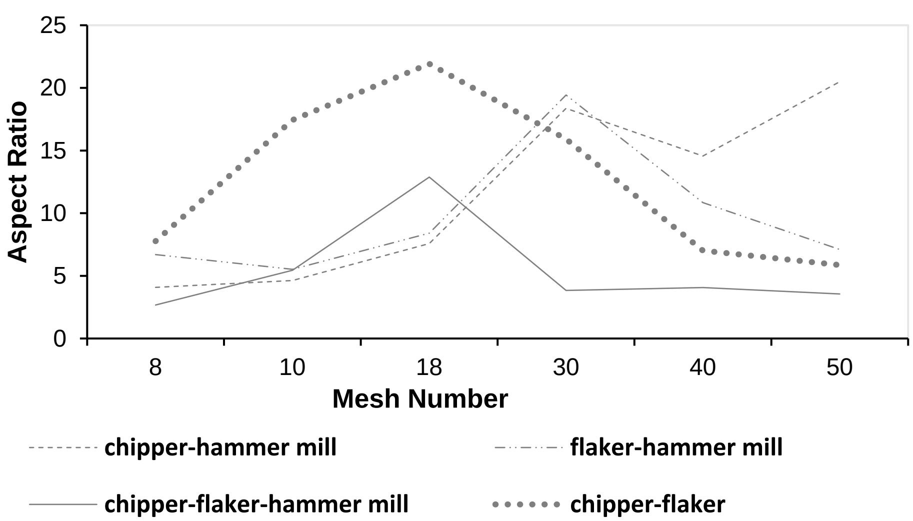


Fig. 10. Aspect ratio values of the four particle types

The aspect ratio of particles initially increased and then decreased with decreasing the particle size (increasing the mesh numbers). The highest aspect ratio was found for the particles with mesh No. 30 for the particles produced by chipper-hammer mill and flaker-hammer mill methods. The highest aspect ratio for chipper-flaker-hammer mill and chipper-flaker methods were obtained for particles with mesh No. 18.

According to Figs. 8 and 10, it can be concluded that at the highest content of particles (30 mesh), the particles generated by chipper-flaker-hammer mill method exhibited the lowest aspect ratio. This behavior was attributed to the severe chipping process on fronds.

The values of aspect ratio and slenderness ratio values of the fine and coarse particles in various chipping methods are given in Table 2. The chipper-flaker-hammer method exhibited the lowest aspect ratio and slenderness ratio for fine and coarse particle, and the highest values were obtained for the chipper- flaker method. The thicker and shorter coarse particles with a lower slenderness ratio increases internal bonding (IB). In fact, the specific surface area of shorter particles was higher than that of long particles, so these particles received more resin and provided higher IB values. On the other hand, the particle cross-sections of thicker particles may participate in adhesion. In two methods, namely the chipper-hammer mill and the chipper-flaker-hammer mill, the value of slenderness ratio was less than two other methods, so the chipper-hammer mill method was judged as superior.

Table 2. The Aspect Ratio and Slenderness Ratio of the Four Different Chipping Methods

Particle geometry	**Size fraction (mesh)**	Chipper-Hammer mill	Flaker-Hammer mill	Chipper-Flaker-Hammer mill	Chipper-Flaker
Aspect ratio	8<F<25 (coarse)	12.7(2.1)	16.7(15.9)	5.5(3.7)	16.5(10.8)
	25<F<50 (fine)	8.6(3.4)	12.7(7.0)	8.3(5.9)	26.9(13.2)
Slenderness ratio	8<F<25 (coarse)	15.6(19.3)	45.6(41.9)	11.6(7.7)	55.8(44.1)
	25<F<50 (fine)	28.9(11.2)	34.6(15.8)	25.3(11.2)	56.0(21.7)

Each value is an average of 50 particles. Values in parentheses are standard deviations.

The particle geometry may greatly affect the quality of bonding among particles and consequently influence the physical and mechanical properties of the manufactured boards. The particle geometry has much greater influence on the board properties than the inherent mechanical properties of the particles themselves (Juliana *et al*. 2012). In a constant resin consumption for particleboard manufacturing, the higher aspect ratio of particle causes the lower resin content per surface area unit. Therefore, aspect ratio influences the quality of bonding between the particles and, consequently, influences the physical and mechanical properties of the particleboard, especially internal bonding (IB) (Nishimura *et al*. 2004; Kord *et al*. 2016). Longer and thinner particles (high aspect ratio) give a higher modulus of rupture (MOR) value than shorter and thicker particles (Farrokhpayam *et al*. 2016). Hegazy and Ahmed (2015) cut rachis of the date palm into the length of 150 mm and then chipped them with a knife ring flaker. The aspect ratio factor of the particles was obtained from 12.4 to 20.9. They concluded that the dimensions of particles must be corrected to improve the mechanical properties of particleboard. However, the mean value of 4.87 was reported for aspect ratio of industrial wood particles in the particleboard factories in Iran. The obtained aspect ratio value of chipper-flaker-hammer mill method (5.4) is very close to aspect ratio value of industrial wood particles.

CONCLUSIONS

1. Date palm residue is a renewable natural resource. Despite its potential in producing wood-based composites, they are not extensively used in the wood-based composite manufacturing, especially in particleboard.
2. In this study, the effect of different chipping methods on the geometry of particles (for application in particleboard manufacturing) was investigated. According to the results, the chipping method influences on the geometry of the particle including the size, size distribution and shape of the particles.
3. Most particles had needle shapes, which was attributed to the anatomy of palm date fronds. The chipper-flaker-hammer mill method provided lower aspect ratio values than the others due to chipping operation by three chipping machines. According to the size analysis results, the flaker-hammer mill method exhibited a minimum amount of fines. In the chipper-hammer mill method, both the weight percentage of useable particles in particleboard and the particle percentage of the rectangle or nearly rectangle particle was greater.
4. Among the different methods, the chipper-hammer mill method was judged to be the most appropriate method for chipping date palm fronds because of more desirable particle geometry, relatively higher usable particles, two steps chipping, and less problems during chipping process.

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