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Effect of different shapes of hummer mill blades and moisture content on mechanical and physical properties of grinded alfalfa hay and pelleting under different temperature and particle sizes

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Abstract

The work conducted at the field laboratories in Grdarasha affiliated to the college of agricultural engineering sciences / Salahaddin University in Erbil, Kurdistan region, Iraq. Two studies were conducted, the first study laid out by a 2×2 factorial experiments based on Complete Randomized Design (CRD) to examine the effect of Two Factors & its interactions, the first factor was hammer mill blade types, dull blade (B_1) and sharpened blade (B_2) while the second factor included two levels of alfalfa hay moisture content (M_1=16 and M_2=20) % on the particle size distribution and hammer mills power consumption. The second study laid out by a 2×2×2 factorial experiments based on Complete Randomized Design (CRD) for studying the effect of the three factors included different particle size (P_1=4 and P_2=8) mm, moisture content (M_1=16 and M_2=20) % and temperature (T_1=65 and T_2=75) ℃ and its interaction on the manufactured pellets durability index (PDI) directly after cooling and after storing in a room temperature conditions, pellets unit density also measured. The results showed that increasing moisture content led to an increase in the geometric mean length, also the interaction between the dull blade and moisture content (B_2M_2) increased and it was 5.44mm, also higher moisture content decreased in power consumption, the lowest power consumption during alfalfa hay grinding was 1.84 Kw recorded with the same treatment. The highest PDI value directly after cooling was recorded with the interaction of $P_2M_1T_1$ which was 85.65%. Pellets durability index (PDI) increased after storing for all treatments, the bigger particle sizes significantly effected on PDI after storing, the highest value recorded for the interaction treatment ($P_2M_2T_2$) and reached 93.58%. The highest pellets unit density value was 1009.71 Kgm^{-3} obtained with the interaction of $P_1M_1T_1$.

Keywords: Alfalfa pellets, hammer blades, particle size, pellets durability, unit density.

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Introduction

Hay is dried grasses, legumes or other herbaceous plants; Cuts, dried to about 20% moisture content and stored for animal feed. Hay if crucial for grazing animals' diets especially during times like winter, drought or when fresh pasture is unavailable. Alfalfa hay holds significant importance in maintaining the health of animals due to its rich nutrient composition; it provides a substantial amount of protein, fiber, calcium, and other essential minerals [1]. Alfalfa hay plays a key role in the digestive health of animals by stimulating salivation, promoting rumination and digestion, and providing the animals with all the necessary nutrients; In addition, quality hay enables a higher feed intake [2].

Hay bales are large in size and place occupying for storage which need to be minimizing and converting their physical shape for more efficient storage [3]. Grinding is necessary to convert large and bulky materials into smaller particles. This process is carried out using various types of mills, hammer mill is the most efficient type for animal feed industries. According to [4] the number of blades of hammer mills significantly affects the grinding capacity of the mill, with four blades resulting in a higher capacity compared to two blades. The particle size of the ground materials is also affected by the number of blades used. [5] found that changing the thickness of the hammer mill can result in more uniform grinded particle sizes. Thinner hammers resulted in an 11.1% increase in feed grinding rate and 13.6% less power consumption by changing the thickness of the hammer mill [6]. The same results were obtained by [5] when they modified the thickness of a hammer mill.

Feed pelleting is defined as a process in which the grinded ingredients are agglomerated and compressed into cylindrical shape. The quality and durability of pellets are measured by the pellet durability index (PDI), which evaluates their ability to withstand mechanical stress, handling and transportation without breaking apart [7]. To increase the pellets durability different procedures are applied during the process. Adding binders to low-quality grinded alfalfa hay significantly improving its hardness and durability [8]. Moisture content can improve the quality of pellets properties [9] and [10]. Temperature plays a big role for producing good quality of pellets, high temperatures within the range of (40 to 140) ˚C during pellet forming improving pellets durability [11], on the other hand the quality of the pellets decreased with the temperatures exceeding 140˚C [12]. Cooling the pellets directly after producing is important for maintaining the quality of pelleted feed products [13]. Storing herbaceous pellets for a period of time in controlled conditions may improve their physical and mechanical properties [14]. Because of the lack of information about alfalfa hay pelleting process, we decided to conduct this work to clarify the methods that produce pellets with acceptable physical and mechanical properties by determining the best pellet quality from different particle size, moisture, and temperature without using any binder.

Materials and methods

The study work conducted in the laboratories of the college of agricultural engineering sciences / Salahaddin University - Erbil in Grdarasha, Kurdistan region, Iraq. from 17/2/2022 to 27/12/2022 to study different procedures of alfalfa hay grinding and pelleting on their mechanical and physical properties. Two studies were conducted. The first study was to examine the effect of two shapes of hammer mill blades with two moisture content of alfalfa hay on the bulk density, particle size distribution and hammer mill power consumption, the second study was to examine the effect of different alfalfa hay particle size, moisture content and temperature on the manufactured pellets mechanical and physical properties.

Experimental layout

The first laboratory study laid out by a 2×2 factorial experiments based on Complete Randomized Design (CRD) to study the effect of Two Factors and its interactions, the first factor was hammer mill's blade type, dull (B_1) and sharpened blade (B_2) while the second factor included two levels of moisture content (M_1=16%) and (M_2=20%) on the particle size distribution, particles bulk density and hammer mill power consumption. The second study conducted by using a 2×2×2 factorial experiments also based on complete randomizes design (CRD) to examine the effect of three factors, different particle size (P_1=4 and P_2=8) mm, moisture content (M_1=16 and M_2=20) % and temperature (T_1=65 and T_2=75) ℃ and its interaction on the mechanical and physical properties of produced pellets without adding binders.

Material preparation

Ten bales of alfalfa (*Medicago sativa*) hay were taken randomly in a private farm with an average weight of 16.38 kilograms and dimensions of (31×46×90) cm.

Moisture content measurement and adjustment

The wet bases primary moisture content of the alfalfa hay bale samples was determined according to the [15] standard using the equation 1:

$$MC = \frac{Ww - Wd}{Ww} \times 100 \qquad (1)$$

Whereas:
MC = moisture content of the hay, (% w.b.)
Ww = weight of wet sample, (g)
Wd = weight after drying the sample, (g)

After determining the bales initial moisture content and for adjusting the two different moisture contents according to the study plan (M_1=16%) and (M_2=20%), alfalfa hay bales were spread out on a nylon surface and sprayed by a predetermined amount of distilled water over the sample to reach the desired moisture content. The amount of distilled water to be sprayed calculated by using the equation 2 which formulated by [16]:

$$mw = \frac{mi\ (Mwf - Mwi)}{1 - Mwf} \qquad (2)$$

Where:
mw = mass of water should be added to the sample, (g).
mi = initial mass of the sample, (g).
Mwf = Final desired moisture content of the sample, (%).
Mwi = Initial moisture content of the sample, (%).

After spraying the precalculated amount of water, the samples were placed in zip locked plastic bags and labeled, the samples then stored in a refrigerator at a temperature of 5 ℃ for a period at least of 48 hours to allow the samples to stabilize at the desired moisture content levels till the end of the study.

Grinding process

After the moisture content adjusted the samples were grinded with a hammer mill (KURTSAN model, made in Turkey) powered by a 220V, 3 HP, 50 HZ electric motor and operated at a rotational speed of 2800 rpm with an 8 mm screen size and 9 hammer blades of 2mm thickness. Two types of blades were used (B1=normal dull blade with 90o edge angle and B2= sharpened blade with 30o edge angle) for grinding the alfalfa hay with two moisture contents (M1=16% and M2=20%) (Figure 1).

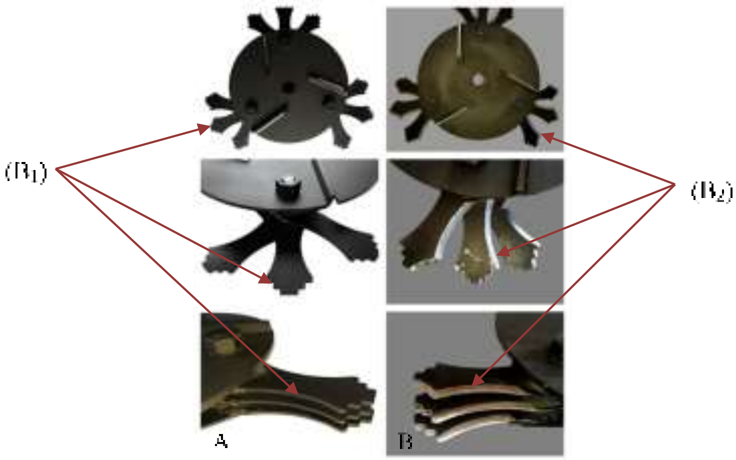

Figure 1: Blades of hammer mill machine, A. dull blade with 90o edge angle (B1), B. sharpened blade with 30o edge angle (B2)

Particle size distribution

The particle size distribution calculated according to the [17] standard. The geometric mean length (*Dgw*) and geometric standard deviation (*Sgw*) of the particles are determined according to equations 3, 4 and 5. A stack of sieves with square opening of 2, 3, 4, 5, 6, 7 mm respectively have been manufactured and based on a pan, 500 grams of sample was placed in sieves stack arranged vertically in a line from largest to smallest opening diameter and shake for 2 minutes. Particles retained on each sieve weighted by an electronic scale with accurate of ± 0.1 g.:

$$X_{gm} = log^{-1}\frac{\sum(Mi\log\overline{X_i})}{\sum M_i} \quad (3)$$

$$S_{gm} = \log^{-1}\left[\frac{\sum M_i(\log\overline{X_i} - \log X_{gm})^2}{\sum M_i}\right]^{1/2} \quad (4)$$

where:

X_{gm} = geometric mean length (mm)

Xi = diagonal of screen openings of the i^{th} screen

$\overline{X_i}$ = geometric mean length of particles on i^{th} screen = $(Xi \times Xi\text{-}1)^{1/2}$ (5)

$X(i\text{-}1)$ = diagonal of screen openings in next larger than the i^{th} screen (just above in a set)

M_i= mass on i^{th} screen (actual mass at the conditions of screening or percent of total; decimal or percent form)

S_{gm} = standard deviation

Bulk density of chopped sample

The bulk density of grinded samples was calculated using the grain bulk density apparatus according to [7] standard by freely dropping the grinded materials into a known volume of one liter glass container until full, then gently leveling the surface by a steel rod, the mass of the grinds in the known container volume weighted by a digital balance. Bulk density of chopped hay calculated according to the equation 6:

$$\text{Bulk density (kg.m}^{-3}) = \frac{M}{V} \quad (6)$$

Where:

M = Mass of grinded sample (g)

V = Volume (m^3)

Hammer mill power consumption calculation

The power consumption during the milling process is calculated according to equation 7 which formulated by [4]. A digital AC clamp meter (with accuracy of 0.09) was used to measure the current in amperes during hay chopping of all grinding treatments, the known voltage of 220V used to maintain the equation requirement as below:

$$PC = \frac{I \times E \times PF}{1000} \quad (7)$$

Where:

PC = power consumption (kilowatts)

I = current (amp)

E = volt (220V)

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PF= power factor (0.94)

Pelleting process

A single extruding pelleting die of 6mm internal diameter and 45mm external diameter to produce cylindrical pellets with 6mm diameter used for pelleting the grinded alfalfa hay for different treatments. The die cylinder is covered by an electric ring heater for heating the alfalfa grinds to the desired temperature. A piston shaft with an 6mm diameter and 125mm length used for pressing the grinds inside the pelleting die for pellet producing, a thermocouple sensor connected to the die cylinder and connected to an electrical control box for adjusting the temperature according to study plan. A manual hydraulic press used to apply a mechanical pressure of 150 MPa for all produced pellets (Figure 2). The produced pellets cooled and divided to two parts for applying the measurements on it, the first part was measured directly after cooling and the second part of the pellets stored for 4 weeks at room temperature and moisture to measure the effect of storing on the pellet's durability.

Figure 2: pellet extruding die in a manual hydraulic press with control box

Pellets unit density

Unit density of the pellets measured according to [7] standard by taking three replication and measuring the length and the diameter of every pellet using digital vernier, the weight of the pellets measured by a digital scale, then the unit density calculated using the equation 8, unit density is expressed in kg.m^{-3}:

$$Unit\ density\ of\ pellets = \frac{m}{\pi \times r^2 \times h} \qquad (8)$$

Where:
m= mass, (g).
r= pellet radius (mm)
h= pellet length (mm)

Pellet durability index (PDI)

Pellet durability was measured according to [7] standards by tumbling a pre weighted sample at 50 RPM for 10 minutes, after tumbling the samples sieved to remove the fines, the remained pellets were weighted. The same procedure was applied for the stored pellets to calculate the pellets durability after storing and comparing with the direct measured durability. The durability percentage calculated according to the equation 9:

$$Durability\ \ (\%)\ =\frac{Mass\ after\ tumbling}{Mass\ before\ tumbling}\times 100 \quad (9)$$

Statistical analysis

The statistical analysis calculated by SPSS software version 27.0.1 in windows 10 pro. The studies were carried out using a factorial experiment based on completely randomized design. The least significant difference (LSD) test was used to compare the means of different treatments at a statistical significance probability of $P \leq 0.01$ level.

Results and discussion

Particle size distribution and geometric mean length

Figure 3 shows the effect of the interactions between the blade type and moisture content of the alfalfa hay on the geometric mean length of particle size distribution. The geometric mean length increased with increasing moisture content and the interaction between the sharp blade and 20% moisture content (B_2M_2) recorded the highest geometric mean length of the particles which was 5.44mm while the lowest value was 4.16mm of the particles geometric mean length recorded with the interaction of dull blade and 16% moisture content (B_1M_1). This difference is referring to the easy destruction of grass materials when it exposed to an external hitting force especially with low moisture content [18].

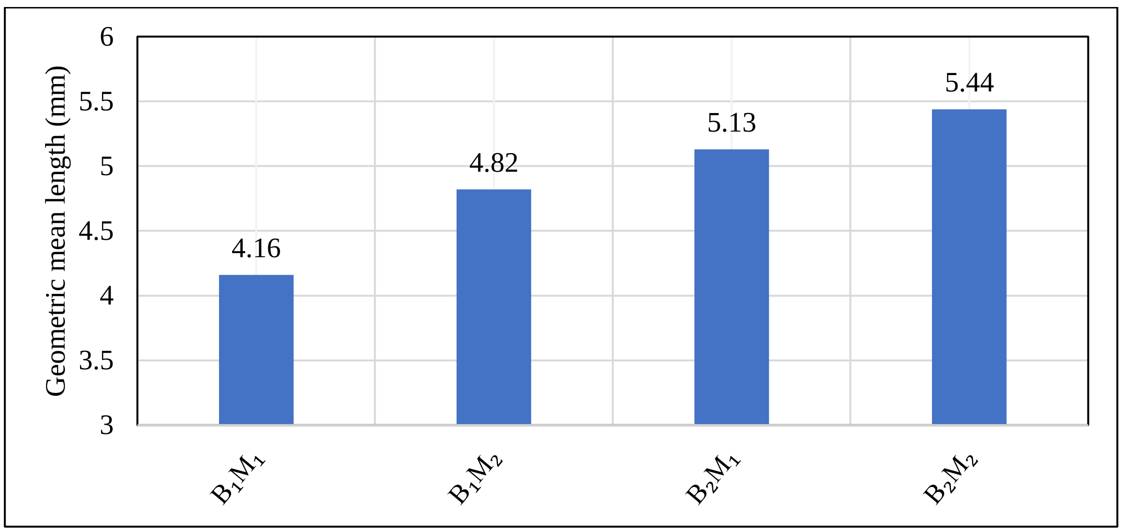

Figure 3: Effect of the interaction of blade type (B_1 & B_2) and moisture content (M_1 & M_2) on the geometric mean length of alfalfa hay particles (LSD=0.92)

Hammer mill power consumption

The effects of the interactions between the blade type and moisture content on the hammer mill power consumption are illustrated in figure 4. The results showed significant differences between the treatments in power consumption, increasing moisture content lead to decrease in power consumption and the lowest power consumption was 1.84 Kw recorded with the interaction of sharp blade and 20% moisture content (B_2M_2), while the highest power consumption value was 2.24 Kw recorded with the interaction between the sharp blade and 16% moisture content (B_2M_1), this low power consumption is due to the easy cutting by sharp blades against the dull blades [4].

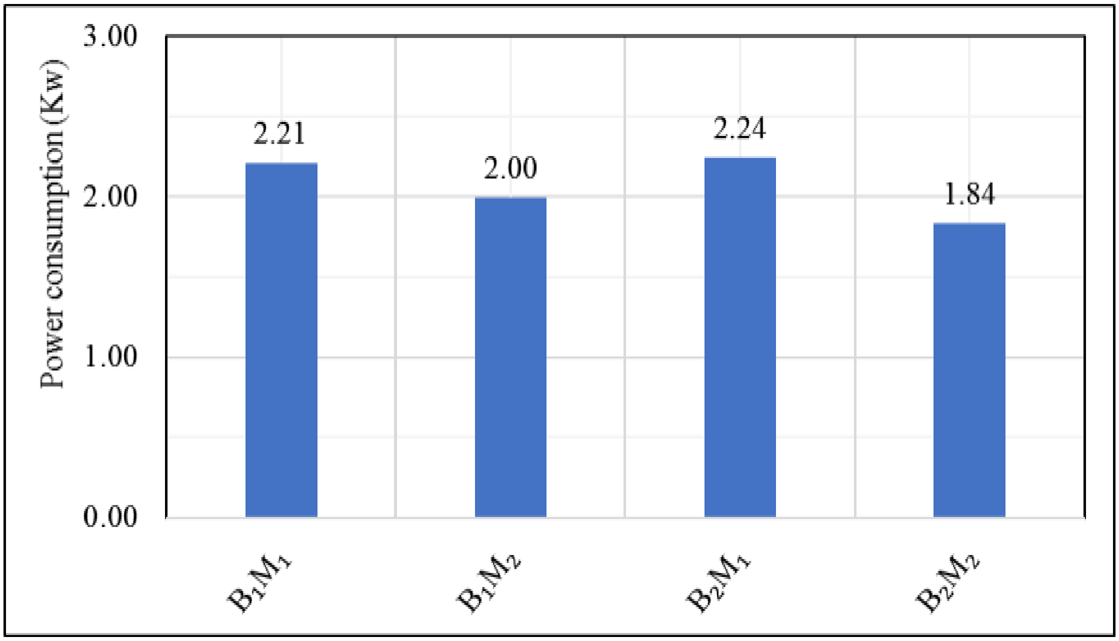

Figure 4: Effect of the interaction of blade type (B1 & B2) and alfalfa hay moisture content (M1 & M2) on the hammer mill power consumption (LSD=0.089)

Alfalfa hay grinds bulk density

Figure 5. showing the effect of the interactions between blade type and moisture content on the bulk density of grinded alfalfa hay, significant differences appear when the alfalfa hay grinded by using dull blade with both moisture content. The dull blade and moisture content 20% (B_1M_2) recorded highest bulk density resulting 80.11 kg.m^{-3} while the lowest value recorded with the interaction between the sharp blade and 20% moisture content (B_2M_2) resulting 73.36 kg.m^{-3}, this increment of bulk density occurs because the sharp blades producing particles with higher geometric mean lengths which resulting in more porousness between particles [19].

Pellet durability index after cooling directly:

The effect of the interactions between different particle size, moisture content and temperature on the pellet durability index of alfalfa hay pellets after cooling are represented in the figure 6, the larger particle size produced higher pellet durability index, the highest durable pellets produced with the interaction of 8mm particle size, 16% moisture content and 65℃ temperature ($P_2M_1T_1$) which was 85.65%, this is refer to the more adhesive surface of larger particles which led to producing pellets with higher durability index [14], while the lowest value recorded 81.19% using 4mm particle size with moisture content 20% at temperature 65℃ ($P_1M_2T_1$).

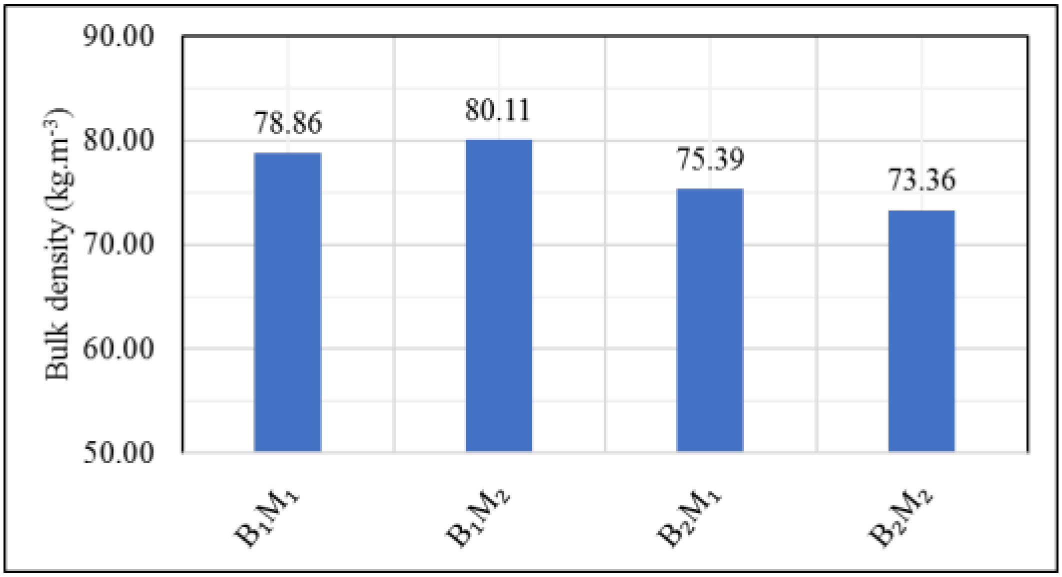

Figure 5: Effect of interaction of blade type (B1 & B2) and moisture content (M1 & M2) on the alfalfa particles bulk density (LSD=4.42)

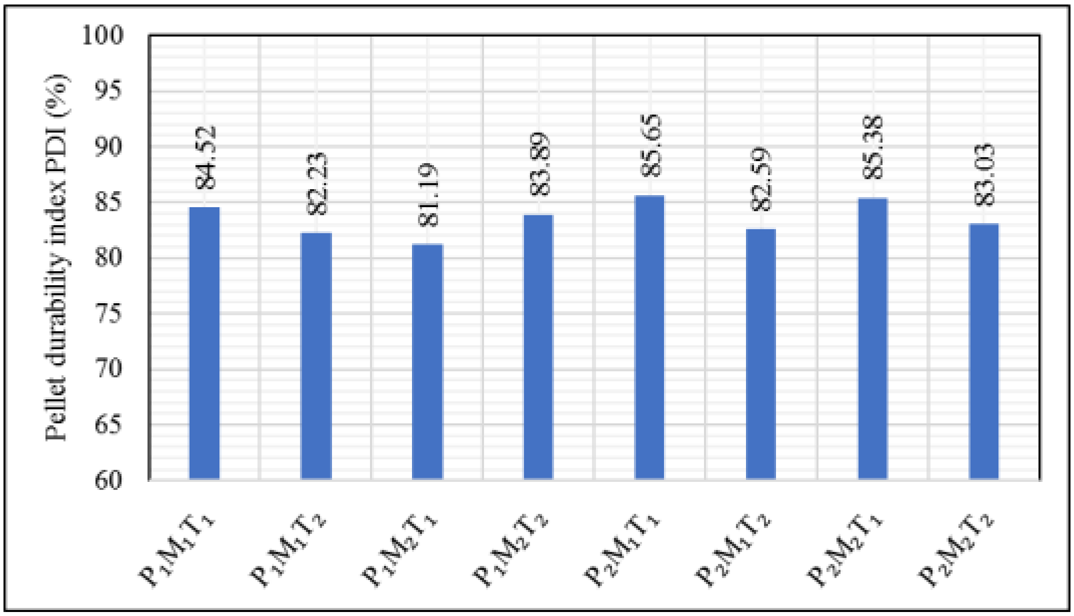

Figure 6: Effect of the interaction of particle size (P1 & P2), moisture content (M1 & M2) and temperature (T1 & T2) on alfalfa hay pellet durability index (PDI) after cooling (LSD=4.64)

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Pellet durability index after storing for 4 weeks

Figure 7 shows the comparison between durability of alfalfa hay pellets after producing and cooling directly with after storing for 4 weeks for the interaction of different particle size, moisture content and temperature, in general, the durability of pellets after storing has improved if it compared with the durability of pellets after producing and cooling directly, the stored pellets recorded the highest durable pellets of 93.58% for the interaction of 8mm particle size, 20% moisture content and 75℃ temperature ($P_2M_2T_2$), whilst the same treatment interaction before storing recorded 83.03% durability. From the results it seems that storing alfalfa pellets at room temperature and humidity enhances the durability of the pellets and it may be due to stabilizing the temperature of outside and the inside of the pellets [14].

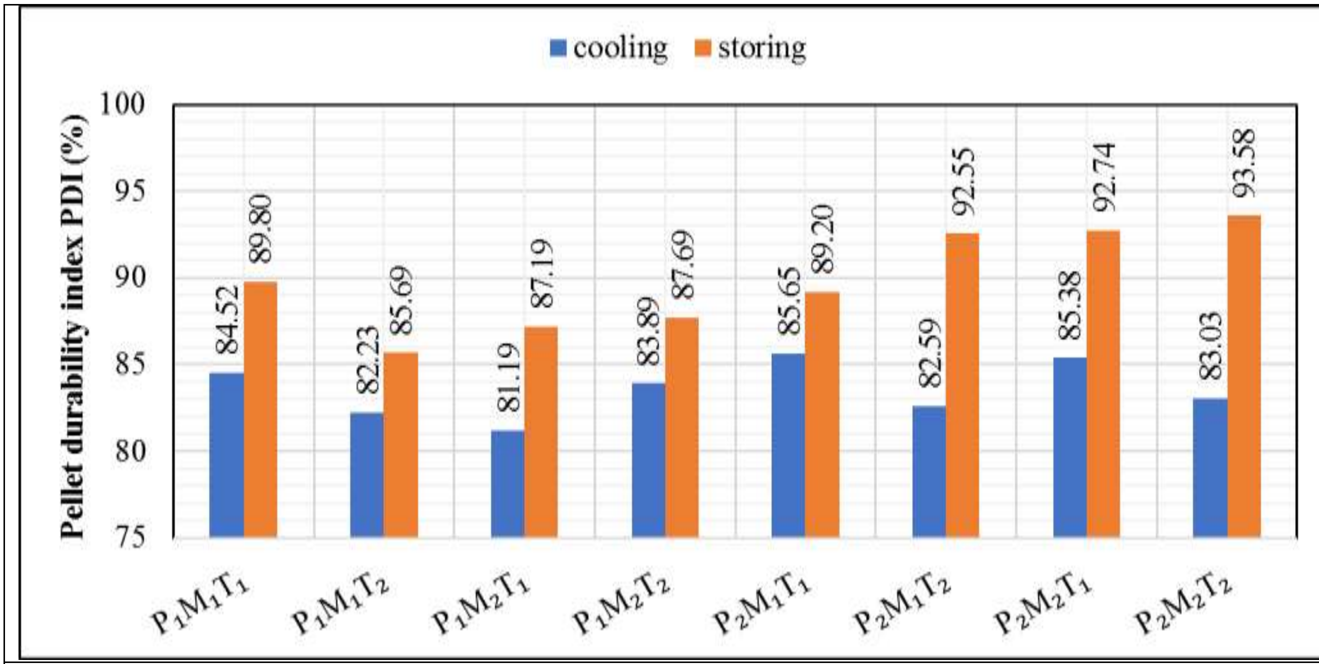

Figure 7: Comparison between alfalfa hay pellets durability index (PDI) after cooling and after storing that made with different particle size (P1 & P2), moisture content (M1 & M2) and temperature (T1 & T2) (LSD=4.64 for after cooling and LSD=3.177 for after storing)

Unit density of pellets

The effect of the interactions between different particle size, moisture content and temperature on unit density of alfalfa hay pellets are shown in the figure 8, the results showed statistically differences between the treatments, the highest pellet unit density value was 1009.71 kg.m^{-3} for the pellets produced with the interaction of 4mm particle size, 16% moisture content and 65℃ temperature ($P_1M_1T_1$), while the lowest value of 779.56 kg.m^{-3} was for the pellets produced with 8mm particle size, 20% moisture content and 75℃ temperature ($P_2M_2T_2$). It is evidence that the small particles produced denser pellets because the compaction of small particles eliminates any porous between them which leads to more dense pellets [20].

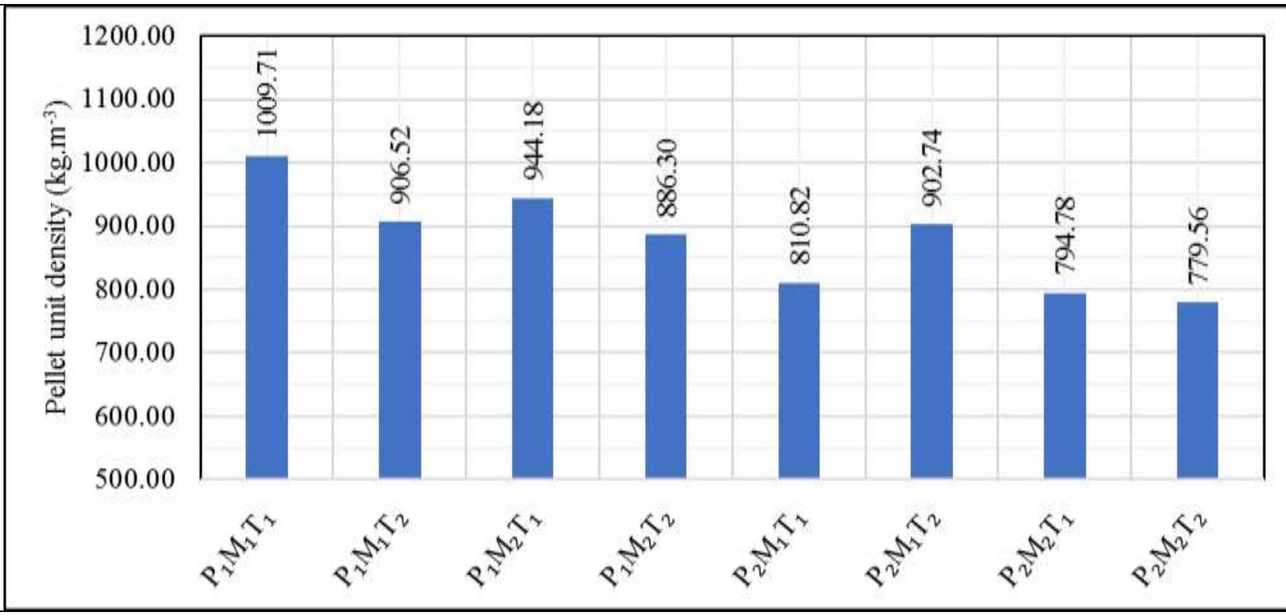

Figure 8: Effect of different particle size (P1 & P2), moisture content (M1 & M2) and temperature (T1 & T2) on the alfalfa pellets unit density (LSD=115.645)

Conclusions

From the results obtained it can be drawing the following conclusions: sharp blades of the hammer mills with higher moisture content of alfalfa hay can reduce the hammer mills power consumption during grinding process, but the bulk density of the particles decreased as a result of bigger geometric mean lengths of particles. The interaction of 8mm particle size, 16% moisture content and 65°C produced pellets with durability percentage of 85.65% without adding binders. Storing the pellets for a period of time improved their durability index for all treatments and reached to 93.58%.

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تاثير أشكال مختلفة لمطارق المجرشة المطرقية والمحتوى الرطوبي على الصفات الميكانيكية والفيزياوية لقطع دريس الجت وتصنيع الأقراص تحت مختلف درجات الحرارة والنعومة

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- تاريخ استلام البحث 16 /3/ 2024 وتاريخ قبوله2024/5/22 .

الخلاصة

أجريت التجارب في مختبرات حقل كردرشة التابعة لكلية علوم الهندسة الزراعية / جامعة صلاح الدين في أربيل، إقليم كردستان العراق. تم إجراء دراستين، نفذت الدراسة الأولى باستخدام تجربة عاملية بعاملين و مستويين لكل عامل 2×2 على اساس التصميم العشوائي الكامل (CRD) لدراسة تاثيرالعاملين و التداخلات بين أنواع المطارق على شكل الشفرات للمجرشة المطرقية ، الشفرة العادية الغير حادة (B_1) و الشفرة الحادة (B_2) مع مستويين من محتوى الرطوبة لدريس الجت (M_1=16 وM_2=20)% و تاثيرها على توزيع طول القطع واستهلاك الطاقة للمجرشة المطرقية. الدراسة الثانية تم تنفيذها بواسطة تجربة عاملية بثلاثة عوامل و مستويين لكل عامل 2×2×2 على اساس التصميم العشوائي الكامل (CRD) لدراسة تأثير ثلاث عوامل وتداخلهم منها طول القطع المختلفة (P_1=4 و P_2=8) ملم ومحتوى الرطوبة (M_1=16 وM_2=20)% ودرجة الحرارة (T_1=65 وT_2=75) درجة مئوية على مؤشر متانة الاقراص العلفية المصنعة (PDI) مباشرة بعد التبريد وبعد تخزينها في ظروف درجة حرارة الغرفة ، كما تم قياس كثافة الاقراص. أظهرت النتائج أن المتوسط الهندسي لطول قطع دريس الجت زاد بزيادة محتوى الرطوبة وان معاملة التداخل B_2M_2 كان 5,44 ملم، كما أن استهلاك للطاقة قلت بزيادة محتوى الرطوبة أثناء قطع دريس الجت وكان 1,84 كيلوواط والذي تم تسجيله ايضا مع المعاملة B_2M_2. أعلى قيمة PDI والتي بلغت 85,65% تم تسجيله مع معاملة تداخل $P_2M_1T_1$ بعد تبريد الاقراص العلفية مباشرة. ارتفع مؤشر متانة الاقراص بعد تخزينها لجميع المعاملات مع القطع الاطول حيث بلغت 93.58% والتي تم تسجيلها لمعاملة التداخل $P_2M_2T_2$. أعلى قيمة لكثافة الاقراص كانت 1009,71 كجم/ م^3 و التي تم الحصول عليها بتداخل $P_1M_1T_1$.

الكلمات المفتاحية: اقراص الدريس، شفرات المطرقية، حجم الجزيئات، متانة الاقراص، كثافة الاقراص.