Prototype for moulding poultry litter

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Abstract: This study presents the possibility of using poultry litter as an effective soil fertilizer, fattening ruminants, and energy production. But fresh poultry litter typically has high moisture content and high volume per unit weight. Therefore, the transportation of large volumes at low bulk densities over long distances is difficult and expensive. Furthermore, its nutrient composition is not constant, and it cannot be safely used as a feed ingredient because it contains pathogens. The main aim of this research is to solve all these problems by developing a prototype that moulds poultry litter to the desired shape and weight by compression and formation to enhance storage, transportation, and off-site utilization. Also, this research aims to determine the effects of moisture content on some physical-mechanical properties of moulded poultry litter. The moulding prototype consists of a power transmission unit, a mixing unit, and a formatting unit. The working principle of the moulding prototype is that the mixture of poultry litter will be formatted under mechanical pressure by rammers fitted into compaction moulds to increase the density of the mixture while converting it into blocks. The results show that the bulk density of poultry litter blocks decreased with increasing moisture content. Durability, rupture force, and decomposition are also affected by moisture content. Moulding increases the bulk density of poultry litter. Therefore, this process is more economical for transporting poultry litter to distant areas. The processed blocks retain their shape during storage and distribution.

Keywords: moulding, poultry litter, prototype, recycling

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1 Introduction

Poultry (*Gallus gallus domesticus*) is the fastest growing agricultural sub-sector, especially in developing countries (Mottet and Tempio, 2017). In Egypt, poultry production is expected to further increase as domestic consumption increases. Poultry litter is a mixture of manure, feathers, spilled feed, and bedding material (sawdust or straw) (Muduli et al., 2019). The average daily fresh litter production by broiler chickens is about 43 kg per 1000 kg live weight, which is a serious solid agricultural waste problem and needs to be recycled (Alkis and Celen, 2009).

Poultry litter is an excellent raw material for the production of organic fertilizers (Kyakuwaire et al., 2019). It is used to improve the physical-chemical condition of the soil (Lima et al., 2021), including fattening ruminants (Adli et al., 2017) and energy recovery options (Lee et al., 2017). With its positive effect on soil texture, its exploitation on agricultural soils is encouraged (Urra et al., 2019) as it can not only improve soil fertility and aeration, but also soil water-holding capacity (Li et al., 2021) and ruminants can metabolize it into amino acids required for growth and maintenance (Adli et al., 2017). Also, some research has been conducted to investigate energy recovery options for poultry litter by Yangin-Gomec et al. (2020) and Zhao et al. (2021). The

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reports included details on energy recovery technologies, including pyrolysis, biochar production, combustion, gasification, anaerobic digestion, and others.

Litter from poultry houses is periodically removed and stored in covered facilities or outdoors until transport and field application, which is usually done in winter or in the dry season before tillage. Fertilizer demand is seasonal, producing poultry litter at a roughly constant rate throughout the year. As a result, litter is often piled up and either has to be stored or leads to incorrect timing or excessive land application. Storage is often problematic, so litter is dumped as waste. Improper storage or field application of fresh poultry litter can lead to contamination problems such as nitrogen emissions to the atmosphere, chemical and microbiological contamination of water bodies, carrier insects, and odour nuisance (Wood et al., 2015; Janczak et al., 2017; Ranadheera et al., 2017; and Kabelitz et al., 2021), including transportation cost, handling, etc. (Gilbert et al., 2009). Inefficient use of poultry litter leads many to see it as a bad waste (Suppadit et al., 2008).

Moulding is a promising approach for reducing the problems or limitations of poultry litter. Manufacturing process of poultry litter improves the physical-mechanical properties of feedstock material and ensures easier handling, transportation, and storage (Gilvari et al., 2019). Many researchers (Yang et al., 2016; Gong et al., 2019; Pampuro et al., 2020) studied the effect of compression force during material forming. The results showed that the density of the particles in the material is greatly increased when the pressure increases, which indicates that pressure has a strong influence on the properties of the material formed. The physical properties of pellets made from poultry litter depend chiefly on their moisture content (Brunerova et al., 2020). Also, Brunerova et al. (2020) mentioned durability as the most important aspect of mechanical quality. It means the blocks can withstand the rigours of handling and delivery without breaking. Payne (1997) studied the relationship between the quality of the densified products in terms of briquette or pellet durability and stability. Highly durable and stable briquettes and pellets are not easily broken during handling, transport, and storage. A durability index is determined to simulate the ability of pelleted and cubed material to withstand the impact force and vibration during handling. Stability is the ability of the product to maintain its original size and shape. Tumuluru et al. (2010) suggested that compaction of fodder and straw into large blocks could save storage space and transportation costs and have the same effect as the compaction process.

The utilization of poultry litter represents an important step in the related waste management. Therefore, the object of this paper is to demonstrate the processes and performance of the poultry litter moulding prototype and to produce blocks from poultry litter and investigate their physical-mechanical properties by experimental measurements with a specific focus on the block compression strength. This prototype would contribute to optimizing poultry litter efficiency in terms of storage, transportation cost, and off-site utilization. So, the physical-mechanical characteristics of the poultry litter molds, such as bulk density, particle density, porosity, durability, rupture force, and decomposition, need to be measured in order to quantify the integrity of the molds. Also, the purpose of this paper is to investigate the effect of moisture content in fresh poultry litter on the values of the above characteristics because moisture content is the key factor affecting the moulding process.

2 Materials and methods

2.1 Sample preparation

Samples of fresh poultry litter were obtained from a privet poultry house with a capacity of 2000 broiler chickens (Ross). The broiler house is located 31 º10' 13" N, 31 47' 56" E at Meet- Salseel city, El-Dakahlia Governorate, Egypt. Consisting of a concrete floor and an open house with a stocking density of 10 birds per m^2. At the end of each raising cycle, after harvesting the birds, poultry litter is generally heaped into piles or windrows for mechanized collection by a machine manufactured by the author. Fifty kg per sample was immediately collected, placed in clean bags, and transported to the laboratory.

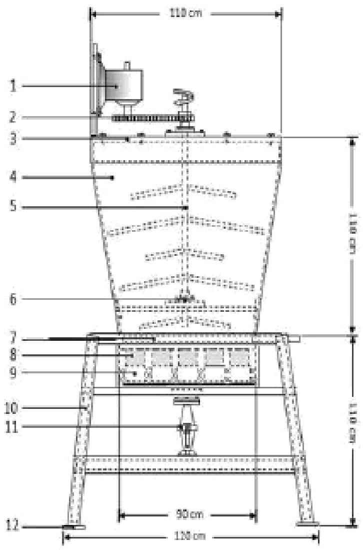
The average chemical composition of fresh poultry litter is presented in Table 1.

Table 1 Shows the nutrient content of fresh poultry litter in kg t^{-1}

N, kg t^{-1}	P, kg t^{-1}	K, kg t^{-1}
13.1	4.5	3.6

2.2 A description of the developed prototype

The developed prototype is composed of three units (a power transmission unit, mixing unit, and formatting unit) as represented in Figure 1.



1-Electric motor; 2- Transmission system (gears and chain); 3-Upper mixer filling gate; 4- The mixer; 5- Mixer shaft; 6-Loading balley; 7- The mixer bottom gate; 8- Top pressure rammers; 9-Bottom formation molds; 10-Chassis leg; 11-Hand pressure lever; 12-Chassis ground stand

Figure 1 Schematic diagram for the developed prototype

2.3 Power transmission unit

A small electric motor (AC Motor 0.56 KW, 190-380 volts at 1400 rpm) was used as a power source. It is connected to a small reduction gearbox to operate the mixing unit. A motion of about 400 rpm is transmitted to the main driven shaft by the mains of two perpendicular gears and a chine as shown in Figure 2.

2.4 Mixing unit

Since the nutrient composition is not constant, the mixing unit consists of a conical container with an upper diameter of 75 cm and a lower diameter of 45 cm. There are eight stirring levers evenly distributed along the main stirring shaft. Each mixing lever is directed downwards in the positive direction of the added mixture to the formation unit.

Figure 2 The developed prototype

2.5 Formatting unit

The formatting unit consists of a rectangular metal box. It is used hollow moulds and rammers to form poultry litter blocks. As shown in Figure 1 (Parts 8 and 9), the moulds are separated with a heating coil (0.57 Kw) to achieve poultry litter blocks free from pathogens. The compaction was applied by a manual lever, which lifts and presses the horizontal free base located at the bottom of the forming mechanism. The whole mould section is designed as a drawer between the mixing and pressing parts to facilitate the removal of the formed blocks. The lower vertical load was applied manually to the samples until the desired force was achieved. Rammers from flat iron with a thickness of 5 mm were used to fit into the compaction moulds for load application. The chassis consists of 4 cm square iron pipes (welded and fabricated locally). The developed prototype has dimensions of 120 cm in length, 120 cm in width, and 220 cm in height, as shown in the schematic diagram Figure 3. After the process, all moulded poultry litter samples were collected into plastic bags to analyze their physical-mechanical properties at the laboratories of El-Serw Agricultural Research Station, Damietta Governorate, and the Faculty of Agricultural Engineering, Al-Azhar University, Cairo Governorate, Egypt.

The advantage of this prototype is that it cannot be influenced by the moisture content of the fresh poultry litter because there is no die that tends to clog if the moisture content is too low, and an electric drill is needed to remove the clogged litter, which adds considerable time for repairs and replacements to the production cost. Also, converting poultry litter into blocks makes it more suitable for long-distance transportation and makes recycling extremely cost-effective. Another advantage is that the compactness of the moulds requires less storage space during the off season and protects against the egg laying of house flies or other insects and unpleasant odors. Finally, poultry litter blocks are uniform in quality and size and can be applied to fish farms without generating any dust.

2.6 In the primary experiment's procedure

Samples of fresh poultry litter with a moisture content of about 47% were collected and let to dry for 1, 2, 3, and 4 days to reach a moisture content of about 34%, 26%, 17%, and 11%, d.b., respectively. The moisture contents were measured by putting 10 g of sample in an air convection oven set at 105℃ for 48 h according to ASAE Standard S269.4 (ASAE Standard, 2002). The moisture content was calculated using the following equation:

$$Mc.,\% = \frac{M_i - M_f}{M_f} \times 100 \qquad (1)$$

Where, M_i= the initial mass of the sample, g

M_f= the final mass of the sample, g

The formatting moulds were tested to select the optimal poultry litter block dimension and the proper compaction force. The dimensions of the mould were 3×12×12 cm, and the cross section was rectangular for handling. One of the hollow moulds of selected dimensions was constructed and filled with the loose mixture to be compressed. An aweigh representative of the actual load was then applied. The optimum pressing force was determined. The chosen optimum force was at the maximum moisture content (47%). The force applied at the maximum moisture content is suitable for the lower levels of moisture content. Mixing time was tested at lower moisture levels (11%). Time required to mix at lower moisture levels suitable for other mixing conditions. Primary experiments showed that the optimum compaction pressure was about 120 kg cm^{-2}, and the suitable mixing time was 2 minutes, while stirring the mixture for about 2 minutes until there was sufficient mix. Moulded blocks were formed by applying pressure for 2.5 minutes to give enough time to blank molds.

2.7 Measurements

The experiments were conducted and replicated three times. The developed prototype was studied to evaluate the excited used prototype under five levels of moisture content (11%, 17%, 26%, 34%, and 47%) to measure the following:

Bulk density:

The bulk density was determined according to modified ASAE Standard S269.4 (ASAE Standards, 2002). The mass of the individual mould was determined in gram by using an electric digital balance with an accuracy of 0.0001 g. The geometrical dimensions of samples were measured with an accuracy of 0.01 mm using a digital micrometer, and volume was estimated. Bulk density was taken as the ratio of the mass to the volume of the sample.

Mechanical durability:

It is determined according to ASAE Standard S269.4 (ASAE Standards, 2002). Some samples were tumbled at 50 rpm for 10 minutes in a dust-tight enclosure. A no. 5 US sieve with an aperture size of 4 mm was used to retain crumbled moulds after tumbling. Durability is expressed by the percent ratio of moulds retained on the sieve after tumbling compared to the mass of moulds before tumbling. Durability is high when the measured value is above 80%, between 70% and 80% is medium, and low when below 70% (Fasina, 2008).

The rupture force, N:

To determine the rupture force of each sample, a proprietary tension/compression testing machine

(Instron Universal Testing Machine/SMT-5) was used; which was equipped with a 500 kg compression load cell and an integrator (Saiedirad et al., 2008). The measurement accuracy was ± 0.001 N in force. The measuring was achieved by placing the samples on a flat plate in their natural position. A flat plate plunger was then pressed onto the sample at a speed of 10 mm/s. The maximum force needed to rupture the pellet was determined from the force-deformation curve recorded by the computer interface with the texture analyzer. So, this indicator is used to demonstrate the block's resistance to compressive stress.

Decomposition:

The decomposition or break down process of each sample was processed according to the procedure of Suppadit (2009). Samples were placed outdoors in the open-air site. After 4 weeks, the samples were oven dried at 65 ℃-70 ℃ for 24 h for dry matter basis determination using a specified drying method (Model Sharp IEC, Tokyo, Japan). The decomposition was calculated using the following equation:

$$De = \frac{dm_b - dm_a}{dm_b} \times 100 \tag{2}$$

Where, dm_b= dry matter as the basis of samples prior to decomposition, g

and dm_a= dry matter as the basis of samples after decomposition, g.

2.8 Statistical analysis

All statistical analyses were performed with the Costat Program (Oida, 1997). Linear regression analysis was used to investigate the possible utility of moisture content as an estimator of physical and mechanical properties. To evaluate the linear correlations between parameters and characteristics, Pearson's coefficients were calculated.

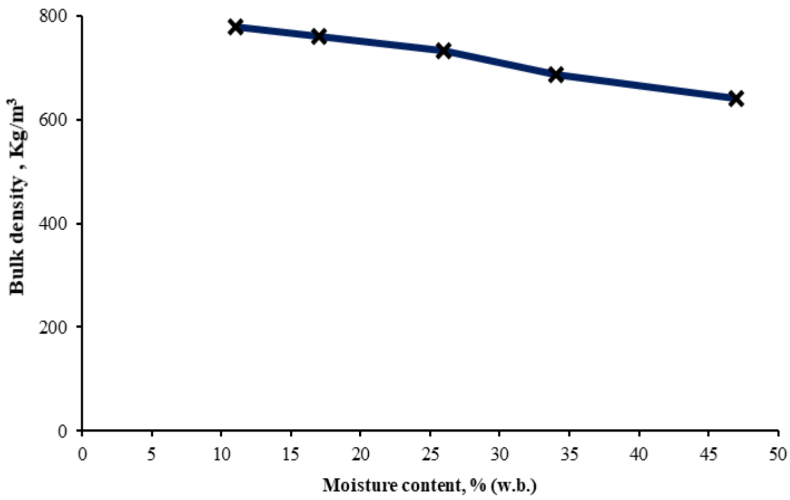


Figure 3 Effect of moisture content on bulk density

3 Results and discussion

3.1 Effect of moisture content on some physical-mechanical properties

3.1.1 Bulk density

The bulk density of poultry litter blocks ranged from 642 kg m^{-3} at 47% moisture content to 778 kg m^{-3} at 11% moisture content (Figure 3). While the bulk density of the fresh poultry litter was 185 kg m^{-3}. Therefore, the compaction of poultry litter into blocks can reduce the amount of space required to store poultry litter by more than four times. Bulk density decreased linearly as the moisture of poultry litter increased. The reduction in the values of bulk density was due to the expansion of the block size, which led to an increase in particle volume with moisture content (Fasina, 2008). So, the storage space required per unit mass of material will increase with the increase of water content. Similar results were obtained from moisture content effects on the bulk density of poultry litter pellets (McMullen et al., 2005). The obtained regression equation used to relate the bulk density (ρ_d, kg m^{-3}) of the blocks to moisture content (Mc,%) was in the form of:

ρ_d = -3.8896 M_c + 825.42 (R^2= 0.9897).

3.1.2 Mechanical durability

Durability of poultry litter blocks varied from 69.6% to 94.8% (Figure 4). There was a linear decrease in durability as the moisture content increased. At moisture contents greater than critical value, the forces compacting the particles together are less than the forces compacting the particles due to volume expansion of the blocks. This is similar to the reported trend of poultry litter pellets (McMullen et al., 2005). The following equation was used to relate block durability (Du,%) to moisture content.

D_u = -0.7153 M_c + 102.95 (R^2= 0.9978).

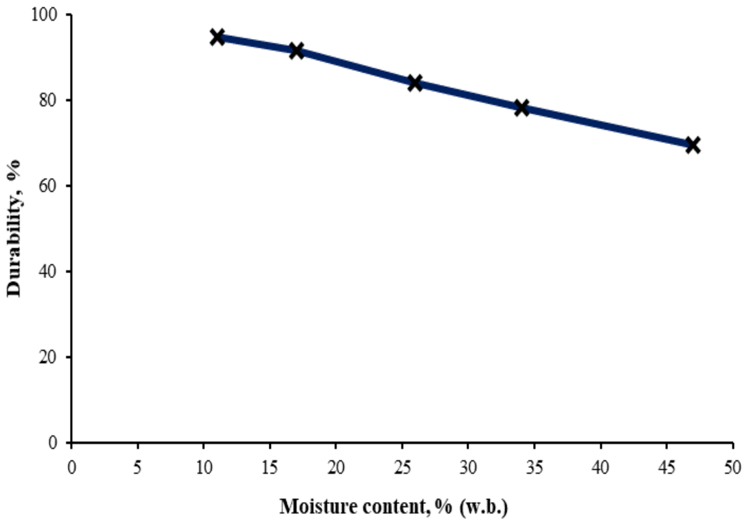


Figure 4 Effect of moisture content on durability

3.1.3 Rupture force

The rupture force of poultry litter blocks varied from 92 to 343 N (Figure 5). It was more sensitive to moisture variations than durable. A linear decrease in rupture force occurred as the moisture content of poultry litter increased. So, the samples offered less resistance to static compression load with increasing moisture content. Moisture decreased the strength of the bonds that hold the particles together, making the particles more friable. This is similar to the trend of poultry litter pellets that has been reported by McMullen et al. (2005). The equation used to relate the rupture force (R_f, N) to moisture content was as follows:

R_f = -7.0608 Mc + 397.44 (R^2= 0.9294).

3.1.4 Decomposition

Decomposition of poultry litter blocks varied from 55.35 to 86.87% based on DM (Figure 6). The breakdown of samples increased with the increasing moisture content of fresh poultry litter. This is in contrast to its durability. In general, when the moisture of the biomass increased, the sample solidity and compactness decreased. Slowly, nutrient decomposition can reduce leaching and nutrient loss, improve fertilizer utilization in upland soils (Alemi et al., 2010). The following equation was used to relate the decomposition (De,%) of the sample to its moisture content.

De = 0.8786 M.C. + 48.067 (R^2= 0.9656).

3.2 Statistical analysis of some poultry litter physical-mechanical properties

As shown in Table 2, ANOVA analysis revealed highly significant differences between treatments (p<0.05).

Analysis of Pearson correlations:

Pearson correlations of moisture content, bulk density, durability, rupture force, and decomposition of poultry litter are shown in Table 3. A Pearson correlation analysis of moisture content, bulk density, durability, rupture force, and decomposition of poultry litter was carried out in order to measure the relationship between five individual physical-mechanical parameters, as illustrated in Table 3. All correlation coefficients (r) were of sufficient magnitude to ensure that the correlations between two physical-mechanical parameters were statistically significant at $p<0.05$. As illustrated in Table 3, strong positive correlations were observed in the combinations of decomposition-moisture content (r = 0.933), durability-bulk density (r = 0.925), rupture force-bulk density (r = 0. 918), and rupture force-durability (r = 0. 883). Obviously, moisture content plays an important role in decomposition. To achieve a high quality of pelleting, it is therefore necessary to intensify efforts to reduce the water content in poultry litter.

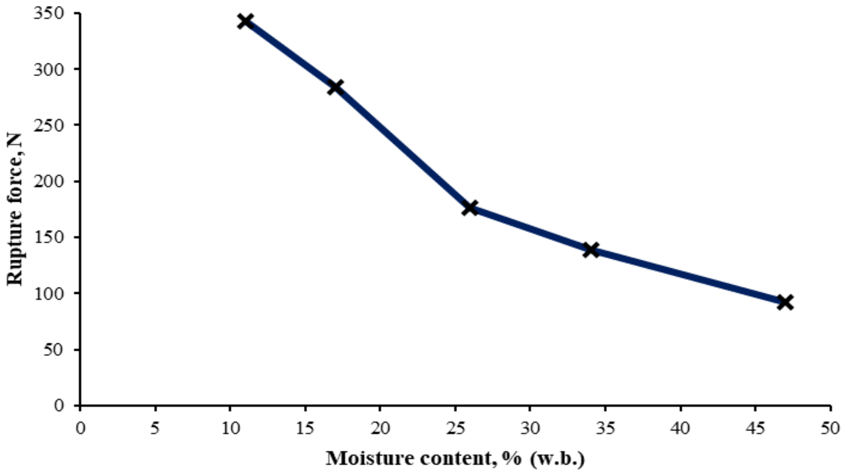


Figure 5 Effect of moisture content on rupture force

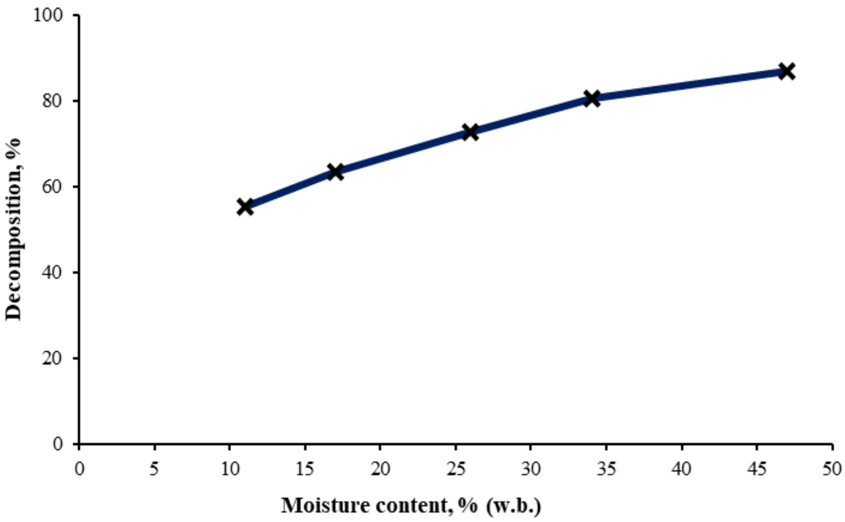


Figure 6 Effect of moisture content on decomposition

Table 2 Means and standard error for bulk density, durability, rupture force, and decomposition as influenced by the factor under consideration

Factor		Bulk density, kg m^{-3}	Durability,%	Rupture force, N	Decomposition,%
Moisture content,%	M_1	778±6.93	94.8±0.90	343±3.61	55.35±4.94
	M_2	761±2.65	91.5±0.80	284±7.94	63.45±5.50
	M_3	733±3.46	84.1±2.23	176±8.89	72.76±7.18
	M_4	688±12.17	78.2±1.54	139±15.13	80.52±3.87
	M_5	642±12.49	69.6±0.44	92±10.15	86.87±4.13
	p-value	0.0001	0.0001	0.0001	0.0001

Table 3 Pearson correlations of moisture content, bulk density, durability, rupture force, and decomposition of poultry litter

Items	Moisture content	Bulk density	Durability	Rupture force	Decomposition
Moisture content	1.00				
Bulk density	-0.987	1.00			
Durability	-0.946	0.925	1.00		
Rupture force	-0.948	0.918	0.883	1.00	
Decomposition	0.933	-0.909	-0.885	-0.939	1.00

4 Conclusions

The physical-mechanical properties of poultry litter blocks depend on their moisture content. Bulk density, durability, and rupture force of blocks decreased, while particle decomposition of blocks increased linearly with an increase in water content. In addition, Pearson's correlation analysis emphasized that moisture content is the most critical physical parameter affecting the quality of poultry litter block samples. Compaction can be used as a method to increase the bulk density of poultry litter for economical transport, reducing leaching losses and improving nutrient uptake by plants. Poultry litter can be used as a raw material for the production of fertilizer, feeders, and energetic blocks. This prototype can be used to compress and form a mixture of shredded corn stalks and winter cow manure in order to prepare a high-quality organic fertilizer.

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