https://doi.org/10.17221/41/2020-RAE

Analysis of the physical-mechanical properties of a pelleted chicken litter organic fertiliser

Anna Brunerová[1], *Miroslav Müller*[1], *Gürkan Alp Kağan Gürdil*[2], *Vladimír Šleger*[3], *Milan Brožek*[1]

[1]*Department of Material and Manufacturing Technology, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic*
[2]*Department of Agricultural Machines and Technologies Engineering Faculty of Agriculture, Ondokuz Mayis University, Samsun, Turkey*
[3]*Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic*

**Corresponding author: brunerova@tf.czu.cz*

Citation: Brunerová A., Müller M., Gürdil G.A.K., Šlegr V., Brožek M. (2020): Analysis of the physical-mechanical properties of a pelleted chicken litter organic fertiliser. Res. Agr. Eng., 66: 131–139.

Abstract: Pelleted fertiliser production represents improvements in fertiliser management and ensures several benefits, such as a more accurate dosing (less applications), the slow-release of long-lasting nutrients, the possible application during the whole year, easier storage and transportation and better separation of fertilisers and pesticides. The present research investigated the physical-mechanical properties of a pelleted chicken litter organic fertiliser. The pellet samples' particle density ρ (kg·m^{-3}), mechanical durability *DU* (%), compressive strengths in the cleft σc (N·mm^{-1}) and in simple pressure σp (MPa) were investigated. The last two indicators, σc and σp, demonstrated the pellets' resistance to the compressive stress. The resulting values proved ρ = 1 289.73 kg·m^{-3}, *DU* = 95.5%, σc = 58.61 N·mm^{-1} and σp = 20.02 MPa, while all the results were evaluated positively. The observed level of the *DU* (%) did not achieve the mandatory level for the commercial production of pellets (*DU* = 97.5%), however, such a level is stated for a pellet solid biofuel intended for energy production. Therefore, the achieved level of the *DU* (%) represents a satisfactory result within the investigated pellet samples' mechanical quality. In general, the viability and practicability of chicken litter pellet production was proven, as well as, the suitability of such a feedstock for pellet production. Moreover, the observed results proved a high level of the investigated pellet samples' mechanical quality.

Keywords: compression force; densification process; sustainable technology; poultry manure; pellet strength

Densification technologies work with the application of mechanical pressure to ground feedstock material, whereas the final products are pellets, briquettes or different kinds of moulded materials. In general, pellets are produced from a biomass and represent a solid biofuel intended for energy generation by combustion processes (Werther et al. 2000). However, a densification process can be applied to various materials solely for the purpose of improving their mechanical properties (volume density, moisture content) for better handling, transportation and storage, for example, pellets produced from minerals, metals (Shibata et al. 2009; Poggio-Fraccari et al. 2020), plastics (Holmes et al. 2014), livestock and poultry litter (McMullen et al. 2005; Morriën, Prescott 2018) or organic fertilisers (Alemi et al. 2010; Suppadit et al. 2011).

Suporrted by the Internal Grant Agency of the Faculty of Engineering, Czech University of Life Sciences Prague, Grant No. 2019: 31140/1312/3103.

https://doi.org/10.17221/41/2020-RAE

The production of pelleted fertilisers is gaining in popularity nowadays, namely, organic fertilisers derived from organic sources such as animal matter and excreta, human excreta or vegetable matter. The production of organic fertilisers in the form of pellets reduces the negative issues related to their handling and storage. Moreover, this allows their precise application or eliminates microorganisms and odours (ammonia volatilisation) (Sultana et al. 2010; Lawong et al. 2011). Indeed, the advantage of organic fertilisers in a pelleted form over bulk or liquid forms also lies in their easy mobilisation of the nutrients over time, which makes it a source of mineral nutrients in long-term applications (Sultana et al. 2010). One of commonly used feedstocks for organic fertiliser pellet production is livestock or poultry manure or litter (used bedding); it is a significant source of organic nitrogen improving the physical condition of the soil (Alemi et al. 2010; Reza-Bagheri et al. 2011; Suppadit et al. 2012; Takahashi et al. 2016). As curious as it may seem, pelletising of human faecal sludge in developing countries within the organic fertiliser production has also been extensively investigated with satisfactory results (Nikiema et al. 2013).

The utilisation of poultry litter as a feedstock for organic fertiliser pellets represents an important step in the related waste management. Poultry litter prevalently consists of manures and bedding materials, with certain amounts of feathers and spilled feed (Sultana et al. 2010; Suppadit et al. 2012). The high nutrient content of poultry litter is represented by the presence of nitrogen, potassium and phosphorus (Maliba et al. 2011). A pelletised poultry litter organic fertiliser is more advantageous and preferable when compared with an unprocessed form (Suppadit 2000). The amount of poultry manure production differs regarding the specific poultry types; 1 000 birds produce the following amount of manure per day: layer chickens – 120 kg, meat chickens – 80 kg, turkeys – 200–350 kg and ducks – 150 kg (Collins et al. 1999; Williams et al. 1999). The annual amount of poultry litter is approximately 3 700 tonnes from 1 000 birds; thus, its subsequent sustainable utilisation has a significant impact on the environment and should be a necessary part of a proper waste management system (Suppadit 2000; Alkis, Celen 2009). Consequently, the production of pellets from poultry litter organic fertilisers has high potential, which are enhanced by their satisfactory mechanical quality (McMullen et al. 2005; Singh et al. 2009). Regarding the use of such pellets as a fertiliser, the majority of the available data are focused on their nutrient and chemical parameters, in contrast to their mechanical properties, which, however, are just as important (Hammac et al. 2007).

As was already mentioned, poultry manure and litter belong among high quality organic fertilisers and the viability and practicability of the pellet production from those materials is sustainable and advantageous. However, the available scientific literature about their production and quality is not sufficient or is missing. A pelletising technology can be applied on the mentioned materials to improve their mechanical properties for their better handling and storage; thus, a detailed analysis of the mentioned pellet resistance and strength should be a major investigated point of interest. Consequently, the main aim of the present research was to produce pellets from a chicken litter organic fertiliser and investigate their mechanical properties by experimental measurements with a specific focus on the pellet compression strength.

MATERIAL AND METHODS

The present chapter describes the process of the investigation, whereas the majority of the research activities were practical. Specifically, the feedstock material collection and processing, further, the process of the samples' production (pelletising). In next step, the produced samples (pellets) were subjected to destruction tests to determine their mechanical strength. The obtained data were processed by the related software.

Feedstock material. The chicken litter, which represents the feedstock material used for the sample pellet production, originated from a broiler house with a capacity of 60 000 broiler chickens of the Ross 308 breed. The broiler house is located in Kavak city, Kavak district, Samsun province, Turkey. The feedstock material was collected after 42 days from the application of a new bedding, thus, after one life cycle of broiler chickens. The collected chicken litter was properly processed to achieve the requirements for the pellet feedstock material (moisture content, particle size). After the mechanised collection by a skid-steer loader, the chicken litter was sundried outside the chicken house by solely using solar energy. The determination of the moisture content *Mc* (%) was performed according to the proper technical standard ISO 18134-2 (2017): Solid biofuels – Determination of moisture

https://doi.org/10.17221/41/2020-RAE

content – Oven dry method – Part 2: Total moisture – Simplified method. When the *Mc* decreased to 10%, the dried material was transported for the laboratory treatment. Subsequently, the material was crushed by using a hammer mill (Figure 1A); its working unit was equipped with 8 blades and a sieve with 10 mm diameter holes and the used rotation speed was 2 850 r·min^{-1}.

Pellet production. A laboratory type pelleting mill (Levent Makina, Turkey) (shown in Figure 1) was used to process the chicken litter feedstock densification into the form of pellets. The used pellet mill was equipped with a horizontal rotating 6 mm diameter die matrix on the mould. The feedstock material was loaded manually.

The experimental testing was focused on the mechanical parameters of the investigated pellet samples, which describes their mechanical quality and indicates the efficiency of the densification process and the suitability of the chosen feedstock material. The mechanical quality plays important role in the viability and utility of pelleted products; the primary purpose of pelleting is to improve the mechanical properties of the feedstock material and ensure the easier handling, transportation and storage (Gilvari et al. 2019).

(A)

(B)

Figure 1 The used equipment (A) pelleting mill and (B) pelleting mill pressing unit

The basic investigated parameter was the particle density ρ (kg·m^{-3}) of the produced pellet samples. Experimental measurements were performed in accordance to the related technical standard EN ISO 18847 (2016): Solid biofuels – Determination of particle density of pellets and briquettes. The observed basic mechanical parameters (noted in Table 1.) were used for the further calculation of the samples' particle density ρ (kg·m^{-3}) by using the following formula (Equation 1):

$$\rho = \frac{m}{V} \tag{1}$$

where: ρ – particle density (kg·m^{-3}); m – sample mass (kg); V – sample volume (m^3).

The main indicator of a solid biofuel's mechanical quality is the mechanical durability *DU* (%) for both a pellet and briquette solid biofuel. Within the current research, the *DU* of the produced pellet samples was performed according to the mandatory standard ISO 17831-1 (2015): Solid biofuels – Determination of mechanical durability of pellets and briquettes – Part 1: Pellets. The measurements were performed by using the Pellettester equipment, type PT 500 (Research Institute of Agricultural Engineering, p.r.i., Czech Republic) (Figure 2), while the pellet samples were subjected to controlled impacts in tumbling cans within the monitoring of their abrasion resistance. In practice, the tested samples' material losses in % were measured and calculated after the tumbling by using the related Formula (2):

$$DU = \frac{m_A}{m_E} \times 100 \tag{2}$$

where: DU – mechanical durability (%); m_A – mass of the sieved pellets after the tumbling treatment (g); m_E – mass of the pre-sieved pellets before the tumbling treatment (g).

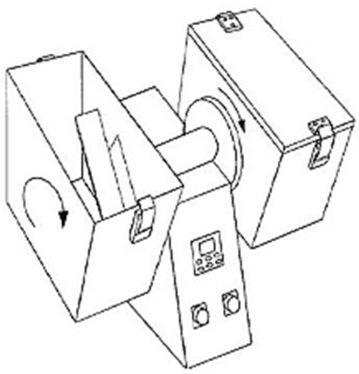
Table 1. Mechanical parameters of the produced pellet samples (on average)

L (mm)	ø (mm)	*m* (g)
33.03 ± 1.73	5.86 ± 0.13	1.15 ± 0.12

L – sample length; ø – sample diameter; *m* – samples mass

https://doi.org/10.17221/41/2020-RAE

(A)



(B)

Figure 2. The used Pellettester tumbling can, type PT 500; (A) schematic and (B) in practice

The used Pellettester tumbling can, type PT 500) (Figure 2) was equipped with two rotation vessels that ensure the required controlled impacts of the investigated pellet samples during its operation. The equipment was constructed, tested and calibrated in accordance with the mentioned standard by the Research Institute of Agricultural Engineering, p.r.i. (Prague, Czech Republic).

The last investigated mechanical quality indicator was the compressive strength *σ*; which describes the resistance of the pellet samples to the compressive stress. Such a stress arises by the weight of the pellet products being stored on top of each other during handling, storage or transportation, thus, this indicator simulates any possible damage in practice and plays an important role in logistics.

The methodology of the compressive strength *σ* measurement is not based on technical standards, but on a previously performed experimental testing and publications of other authors (Rubio et al. 1999; Altuntas, Yildiz 2007; Seifi 2010; Yahya et al. 2013; Okot et al. 2018). The measuring principle counts in observation of a maximum increasing load, which is applied on the pellet sample before it disintegrates. The pellet samples were compressed by a universal testing machine equipped with a force meter with a range of 0–5 000 N, an accuracy of 0.1 and a pressing speed vp of 1 mm·min^{-1}. The used machine was verified and calibrated according to the ISO 7500-1 (2018) standard: Metallic materials – Calibration and verification of static uniaxial testing machines – Part 1: Tension/compression testing machines – Calibration and verification of the force-measuring system. The software Test and Motion, (version 4.2.17) was used for the observed data determination.

In respect to the common practice of pellet handling, two different variants of the measured indicator were investigated. Specifically, the compressive strength in cleft σc (N·mm^{-1}) and the compressive strength in simple pressure σp (MPa). In both cases, the tested samples were horizontally placed between two flat parallel jaws for the determination of the compressive strength in cleft σc (N·mm^{-1}) and vertically for the compressive strength in simple pressure σp (MPa). Primarily, the maximal load $F_{\max}$ (N) was observed when the pellet sample disintegrated. Subsequently, the observed value of the maximal load $F_{\max}$ (N) was used for the calculation of both kinds of compressive strength *σ* by using the following formulas (Equations 3 and 4):

$$\sigma c = \frac{F_{\max}}{L} \tag{3}$$

where: σc – compressive strength in cleft (N·mm^{-1}); F_{max} – maximal load (N); L – sample length (m).

$$\sigma p = \frac{F_{\max}}{A} \tag{4}$$

where: σp – compressive strength in simple pressure (MPa); $F_{\max}$ – maximal load (N); A – cross-sectional area (m^2).

Statistical analysis. The observed data were sorted and cleaned using Microsoft Office Excel software. Furthermore, the processed data were analysed by STATISTICA software, while descriptive statistics and an ANOVA (analysis of variance) analysis (decision criteria of $P > 0.05$) of the pellet samples' mechanical strength were performed.

Additional pellet samples. For the subsequent comparison of the physical-mechanical properties of the investigated pellet samples from the chicken litter, four different waste biomass materials were used for the production of additional pellet samples.

https://doi.org/10.17221/41/2020-RAE

Such feedstock materials were chosen according to their variability as a representative of various biomass types, namely, sorghum husk, tea leaves, peach branches and hazelnut shells. Those additional feedstock materials were processed identically to the investigated chicken litter feedstock. Furthermore, the additional pellet samples were produced and tested under the same conditions as the investigated chicken litter pellet samples.

RESULTS AND DISCUSSION

In general, the first observed result was the success of the performed densification process, thus, the successful production of the subsequently investigated pellet samples (Figure 3).

As is visible from Table 1, the diameter of all the produced pellet samples was under 6 mm, which corresponds to the size of the used die matrix (6 mm). The observed result of the pellet samples' diameter indicated that there was no relaxation in the feedstock material after the densification process, thus, the diameter of the pellet samples did not increase. The relaxation of the feedstock material and the related increase in the densified products is common in practice; however, it is not a positive effect. If the relaxation crosses an acceptable limit, it can cause the deformation and disintegration of the product (Yahya et al. 2013). Therefore, the observed values indicate a positive result, moreover, it positively evaluates the used feedstock material and its preparation. As a consequence, it also proves the suitability of chicken litter as a feedstock material for the pellet production.

Physical-mechanical properties. As a main aim of present research, the pellet samples abrasion and compressive resistance or hardness were investigated. Such quality indicators were stated by the determination of the produced pellet samples' particle density ρ (kg·m^{-3}), mechanical durability *DU* (%) and compressive strengths σ. The observed result values are noted in Table 2, while the compressive strength in the cleft σc (N·mm^{-1}) and compressive strength in the simple pressure σp (MPa) were distinguished.

Figure 3. Produced pelleted organic fertiliser samples from the chicken litter

The achieved level of the particle density ρ (kg·m^{-3}), as noted in Table 2, occurred at a high level, thus, it proved the success of the densification process and the suitability of chicken litter as a feedstock for the pelleting process. The results of other authors published in the available literature with pelleted organic fertilisers provided a comparison, see Table 3. The list of feedstock materials, shown in Table 3, used for the production of pelleted fertilisers indicates the viability, usefulness and attractiveness of the pelleting technology application into agriculture waste management and organic fertiliser production.

The production of pellets for commercial purposes is subject to the related technical standards of a specific country. European standards for solid biofuel specifications define the requirements on a pellet biofuels' mechanical quality and the fuel parameters. Specifically, in EN 17225-6 (2014): Solid biofuels – Fuel specifications and classes – Part 6: Graded non-woody pellets can be applied to the present research and the used feedstock material. Chicken litter is defined as "Biomass blends and mixtures" and the produced pellet samples represents "Graded non-woody pellets". Related to the particle density ρ (kg·m^{-3}), another standard, namely, ÖNORM M 7135 (2000): Compressed wood or compressed bark in natural state – Pellets and briquettes, Requirements and test specifications, states its minimal level ρ ≥ 1 120 kg·m^{-3}. Whereas, standard DIN 51731 (1996): Testing of solid fuels – Compressed untreated wood – Requirements and testing, states a required level of ρ = 1 000 to 1 400 kg·m^{-3}. Considering the requirements of both mentioned standards, the level of the particle density ρ (kg·m^{-3}) of the investigated pellet samples achieved the mandatory requirements on the mechanical

Table 2. Mechanical quality indicators

ρ (kg·m^{-3})	*DU* (%)	σc (N·mm^{-1})	σp (MPa)
1 289.73 ± 62.93	95.5	58.61 ± 5.64	20.02 ± 3.60

ρ – particle density; *DU* – mechanical durability; σc – compressive strength in the cleft; σp – compressive strength in the simple pressure

https://doi.org/10.17221/41/2020-RAE

Table 3. Particle density ρ of various pelletised fertilisers

Pellet feedstock	ρ (kg·m^{-3})	Literature
Quail litter	1 700.0	Suppadit et al. (2012)
Poultry manure	1 642.0	Allaire, Paren (2004)
Cow manure and urea	1 277.0	Alemi et al. (2010)
Cattle manure	1 210.4	Mieldažys et al. (2019)
Cow and chicken manure mixture	745.4	Lawong et al. (2011)
Chicken manure	543.8	Romano et al. (2014)
Swine manure	669.8	Romano et al. (2014)

ρ – particle density

quality. However, it should be noted that mentioned standards are focused on pellet biofuels intended for combustion within energy generation, while the investigated pellet samples represent an organic fertiliser. The *DU* represents the main quality indicator for both a pellet solid biofuel intended for burning and a pelleted organic fertiliser (Pawłowska et al. 2019). In both cases, this indicator describes the pellets strength and resistance towards mechanical impacts causing the abrasion of the pellets, thus, their damage and related material and financial loss. In practice, such harm can be caused by the storage, transportation and handling of the pellets. However, in the case of pelleted organic fertilisers, the mentioned damage is also related to the spreading of the pellets into the soil by a centrifugal fertiliser spreader and/or incorporating the pellets into the soil during sowing (Pocius et al. 2016).

The achieved level of the *DU* = 95.5% of the investigated pellet samples did not correspond to the level stated by the mandatory technical standard ISO 17831-1 (2015): Solid Biofuels–Determination of Mechanical Durability of Pellets and Briquettes – Part 1:

Regarding the commercial production of pellets (*DU* ≥ 97.5%), however, such a level is only stated for a pellet solid biofuel intended for energy production by direct combustion. Therefore, the achieved level of the *DU* represents a satisfactory result within the investigated pellet samples' mechanical quality and material loss (financial loss), thus, proved the suitability of such a production. The comparison of the observed results with the pellets produced from different organic fertilisers is shown in Table 4.

As Table 5 shows, the chicken litter pellet samples exhibited satisfactory results in comparison with

Table 4. Mechanical durability of the pellets from various organic fertilisers

Pellet feedstock	*DU* (%)	Literature
Fermented poultry manure	99.5	Pocius et al. (2016)
Digestate	99.0	Dyjakon, Noszczyk (2019)
Cattle manure compost	92.8–98.1	Pocius et al. (2016)
Cow and chicken manure mixture	91.7	Lawong et al. (2011)
Quail litter	73.3–95.5	Suppadit et al. (2012)

DU – mechanical durability

Table 5. Compression strength of the additional pellet samples

Feedstock	*DU* (%)	σc (N·mm^{-1})	σp (MPa)
Sorghum husk	97.7	75.5 ± 3.9	22.6 ± 4.0
Tea leaves	98.4	56.5 ± 9.1	17.1 ± 2.3
Peach branches	80.7	55.3 ± 11.8	8.9 ± 3.5
Hazelnut shell	93.1	44.6 ± 7.15	13.1 ± 3.6

DU – mechanical durability; σc – compressive strength in cleft; σp – compressive strength in simple pressure

https://doi.org/10.17221/41/2020-RAE

the other tested pellet samples. Only better results could be observed in the case of the Sorghum husk and the Tea leaf pellet samples representing a herbaceous biomass. Related to the densification process and biofuel properties, the wood biomass (represented by peach branch sample in present research) is commonly considered as the best feedstock material regarding its advantageous mechanical properties and high content of lignin. Therefore, the chicken litter pellet samples better results than the peach branch pellet samples proved the high mechanical quality of such a kind of pellet and the suitability of chicken litter for the densification process.

Statistical analysis. The data analysis proved the differences in the observed values of the compressive strength in cleft *σc* ($N\cdot mm^{-1}$) and the compressive strength in simple pressure *σp* (MPa) between all the kinds of tested pellet samples, as seen in Figure 4. The production and testing conditions were constant. It is important to know the maximal compressive strength σ of the pellets with regard to the transportation and handling, in practice; such knowledge is necessary for the elimination of any possible damage to and for the degradation of the pellets.

The diameters ø (mm) of all the kinds of investigated pellet samples did not significantly differ, they ranged from 5.98 ± 0.10 mm up to 6.15 ± 0.04 mm, which indicates a difference of approximately 1.45%. A significant difference was observed in the case of the pellet sample length *L* (mm), i.e., from

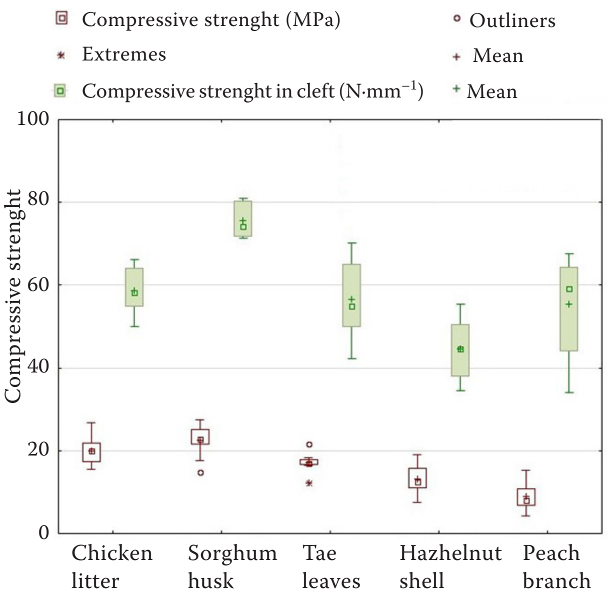


Figure 4. Descriptive statistics of the compressive strength of the tested pellet samples

14.70 ± 0.24 mm up to 21.55 ± 0.34 mm. As a consequence, it is more eloquent for practical application to consider the value of the compressive strength in cleft *σc* ($N\cdot mm^{-1}$).

A statistically significant difference between the different kinds of pellet samples was demonstrated by the ANOVA *F*-test ($P > 0.05$ insignificant difference, $P < 0.05$ significant difference). A statistically significant difference was demonstrated for the compressive strength in simple pressure *σp*, thus, $P = 0.0001$ and the compressive strength in cleft *σc*, thus, $P = 0.0001$ depending on the tested pellet sample kind (shown in Figure 4, the x-axis).

CONCLUSION

Using chicken litter for the production of a pelleted organic fertiliser exhibits the advantage of the used feedstock material. The whole process of the feedstock collection and preparation, pellet samples' production and subsequent testing were performed without any major complications. The ability of the feedstock material to be dried only by using solar energy represents a significant advantage in energy savings within the drying process. The experimental measurements on the physical-mechanical properties of the pelleted chicken litter organic fertiliser provided satisfactory results with regards to the investigated mechanical quality indicators; density $\rho = 1\,289.73\ kg\cdot m^{-3}$, mechanical durability *DU* = 95.5%, compressive strengths in cleft $\sigma c = 58.61\ N\cdot mm^{-1}$ and compressive strength in simple pressure $\sigma p = 20.02$ MPa. The tested indicators were chosen because they simulate the hardness and resistance of the pellets to the compressive stress and impacts, which arise by the weight of the pellets being stored on top of each other, with their transportation or handling. Although the pellet samples did not achieved the mandatory *DU* level for the commercial production of pellets (*DU* ≥ 97.5%), the observed level is the mandatory level for a pellet solid biofuel intended for burning. However, the achieved level of *DU* represented satisfactory result when compared with the other tested pellet samples and previously published research. Consequently, the observed results were positively evaluated, even in comparison with wood biomass pellets, while the wood biomass is commonly considered as the best feedstock for the densification process, thus, for a solid biofuel production. The statistical analysis proved that due to the

https://doi.org/10.17221/41/2020-RAE

undesirable different pellet sample length *L* (mm), it is more desirable for practical applications to consider the value of σ*c* ($N\cdot mm^{-1}$). The combination of the observed high level of the chicken litter pellets' mechanical quality with all the benefits, which pelleted fertilisers represent, it can be concluded that the production of a pelleted organic fertiliser from chicken litter represent an advantageous technology within a proper agriculture waste management system.

REFERENCES

Alemi H., Kianmehr M.H., Borghaee A.M. (2010): Effect of pellet processing of fertilizer on slow-release nitrogen in Soil. Asian Journal of Plant Sciences, 9: 74–80.

Alkis E., Celen M.F. (2009): Effects of alum treatment of two litter materials on growth performance of broiler chicken. African Journal of Agricultural Research, 4: 518–521.

Allaire S.E., Paren L.E. (2004): Physical properties of granular organic-based fertilisers, part 1: Static properties. Biosystems Engineering, 87: 79–87.

Altuntas E., Yildiz M. (2007): Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. Journal of Food Engineering, 78: 174–183.

Collins E.R., Barker J.C., Carr L.E., Brodie H.L., Martin J.H. (1999): Poultry waste management handbook. New York, Natural Resource, Agriculture, and Engineering Service .

Dyjakon A., Noszczyk,T. (2019): The Influence of Freezing Temperature Storage on the Mechanical Durability of Commercial Pellets from Biomass. Energies, 12: 2627.

Gilvari H., Jong W., Schott D.L. (2019): Quality parameters relevant for densification of bio-materials: Measuring methods and affecting factors – a review. Biomass and Bioenergy, 120: 117–134.

Hammac W.A., Wood C.W., Wood B.H., Fasina O.O., Feng Y., Shaw J.N. (2007): Determination of bioavailable nitrogen and phosphorus from pelletized broiler litter. Scientific Research and Essay, 2: 89–94.

Holmes L.A., Turner A., Thompson R.C. (2014): Interactions between trace metals and plastic production pellets under estuarine conditions. Marine Chemistry, 167: 25–32.

Holm-Nielsen J.B., Al Seadi T., Oleskowicz-Popiel P. (2009): The future of anaerobic digestion and biogas utilization. Bioresource Technology, 100: 5478–5484.

Lawong W., Hwangdee P., Thumma S., Lawonga Ch. (2011): Development of two pellet die organic fertilizer compression machine. Procedia Engineering, 8: 266–269.

Maliba B.G., Zobolo A.M., Siebert S.J. (2011): Poultry manure enhances grass establishment at a quarry rehabilitation site in subtropical South Africa. African Journal of Agricultural Research, 6: 46–50.

McMullen J., Fasina O.O., Wood C.W., Feng Y. (2005): Storage and handling characteristics of pellets from poultry litter. Applied Engineering in Agriculture, 21: 645–651.

Mieldažys R., Jotautienė E., Jasinskas A., Pekarskas J., Zinkevičienė R. (2019): Investigation of physical-mechanical properties and impact on soil of granulated manure compost fertilizers. Journal of Environmental Engineering and Landscape Management, 27: 153–162.

Morriën E., Prescott C.E. (2018): Pellets or particles? How can we predict the effect of soil macro-arthropods on litter decomposition? Functional Ecology, 32: 2480–2482.

Nikiema J., Cofie O., Impraim R., Adamtey N. (2013): Processing of fecal sludge to fertilizer pellets using a low-cost technology in Ghana. Environment and Pollution, 2: 70–87.

Okot D.K., Bilsborrow P.E., Phan A.N. (2018): Effects of operating parameters on maize COB briquette quality. Biomass Bioenergy, 112: 61–72.

Pawłowska M., Bielińska J.E., Kasprzycka A. (2019): Influence of storage conditions on a quality of pelletized waste-derived fertilizer. Journal of Ecological Engineering, 20: 226–233.

Pocius A., Jotautiene E., Pekarskas J., Palsauskas M. (2016): Investigation of physical-mechanical properties of experimental organic granular fertilizers. In: Engineering for Rural Development. Jelgava, May 25–27, 2016: 1116–1119.

Poggio-Fraccari E., Bader G., Alemany L., Mariño F. (2020): Pelletized Cu-Ni/CePr5 catalysts for H2 purification via water gas shift reaction. Fuel, 271: 117653.

Reza-Bagheri, Ali-Akbari G., Hossein-Kianmehr M., Sarvastani Z.A.T., Hamzekhanlu M.Y. (2011): The effect of pellet fertilizer application on corn yield and its components. African Journal of Agricultural Research, 6: 2364–2371.

Romano E., Brambilla M., Bisaglia C., Pampuro N., Pedretti E.F., Cavallo E. (2014): Pelletization of composted swine manure solid fraction with different organic co-formulates: effect of pellet physical properties on rotating spreader distribution patterns. International Journal of Recycling of Organic Waste in Agriculture, 3: 101–111.

Rubio B., Izquierdo M.T., Segura E. (1999): Effect of binder addition on the mechanical and physicochemical properties of low rank coal char briquettes. Carbon, 37: 1833–1841.

Seifi M.R. (2010): The moisture content effect on some physical and mechanical properties of corn. The Journal of Agricultural Science, 2: 125–134.

Shibata Y., Suyama J., Kitano M., Nakamura T. (2009): X-ray fluorescence analysis of Cr, As, Se, Cd, Hg, and Pb in soil using pressed powder pellet and loose powder methods. X-ray Spectrometry, 38: 410–416.

Singh K., Risse L.M., Das K.C., Worley J., Thompson S., Mani S. (2009): Studying compaction behavior of fractionated

https://doi.org/10.17221/41/2020-RAE

poultry litter and use of pyrolysis condensate as binder during pelletizing. Transactions of the ASABE, 52: 949–956.

Sultana A., Kumar A., Harfield D. (2010): Development of agri-pellet production cost and optimum size. Bioresource Technology, 101: 5609–5621.

Suppadit T. (2000): Poultry waste pelleting, villager technology. International Journal of Livestock Production, 18: 51–54.

Suppadit T., Sangla L., Udompon L. (2008): Layer chicken parent stock pelleted litter as fertilizer in soybean production. Philippine Journal of Science, 137: 53–60.

Suppadit T., Sangla L., Sunthorn N. (2011): Effects of pelleting on fertilizer quality of quail litter. African Journal of Agricultural Research, 6: 5940–5947.

Suppadit T., Pongpiachan S., Panomsr S. (2012): Effects of moisture content in quail litter on the physical characteristics after pelleting using a Siriwan model machine. Animal Science Journal, 83: 150–357.

Takahashi S., Ihara H., Karasawa T. (2016): Compost in pellet form and compost moisture content affect phosphorus fractions of soil and compost. Soil Science and Plant Nutrition, 62: 399–404.

Werther J., Saenger M., Hartge E.U., Ogada T., Siagi Z. (2000): Combustion of agricultural residues. Progress in Energy and Combustion Science, 26: 1–27.

Williams C.M., Barker J.C., Sims J.T. (1999): Management and utilization of poultry wastes. Reviews of Environmental Contamination and Toxicology, 162: 105–157.

Yahya A., Hamdan K., Ishola T.A., Suryanto H. (2013): Physical and mechanical properties of *Jatropha curcas* L. Fruits from different planting densities. Journal of Applied Sciences, 13: 1004–1012.

Received: June 22, 2020
Accepted: October 1, 2020
Published online: December 30, 2020