EFFECT OF WHEAT STRAW AND PEAT ADDITIVES ON MECHANICAL STRENGTH OF POULTRY MANURE GRANULES

Imants Plume, Aleksandrs Adamovics, Aivars Kakitis, Lauris Plume
Latvia University of Life Sciences and Technologies, Latvia
imants.plume@lbtu.lv, aleksandrs.adamovics@lbtu.lv, aivars.kakitis@lbtu.lv,
plume.lauris@gmail.com

Abstract. Granulation of poultry manure (PM) converts malodorous and logistically challenging waste into a high-value organic fertiliser suitable for precision agriculture. The mechanical durability of granules is essential to ensure reliable handling, transport, and field application. This study assessed the chemical characteristics of raw materials and granules, as well as the mechanical strength of PM granules produced without additives and with wheat straw (WS) or natural peat (NP). Granules were formed from fresh PM (two samples), PM with 2.5% and 7.5% WS, and PM with 7.5% and 15.0% NP. Pre-drying was carried out to 25% moisture either at 24 °C or using a combined regime of 1 h at 70 °C followed by drying at 24 °C. Granulation was performed using a KL200B/C pellet press with 6 mm die openings, and final drying to 10-12% moisture was completed at 24 °C. Laboratory analyses determined total solids, volatile solids, and N, P, and K concentrations. The highest compressive strength (13.6 MPa) was obtained for granules containing 15% NP, while the lowest strength (7.9 MPa) occurred in granules with 5% WS. Pure PM granules pre-dried at 70 °C for 1 h exhibited higher strength (12.8 MPa) than those dried solely at 24 °C (11.9 MPa). Overall, all granule types demonstrated sufficient mechanical integrity for handling and application without risk of structural failure.

Keywords: granules, mechanical strength, poultry manure, wheat straw, peat.

Introduction

The number of poultry was 7.03 million birds at the end of 2025 in Latvia, of which 4.52 million were laying hens and 2.52 million broilers [1]. 97.3% of poultry are kept in large farms with more than 25,000 birds [2]. Poultry manure production, estimated using national normatives on manure output from poultry [3], was 210,000 in 2025. Poultry manure (PM) is mainly composted for organic fertiliser production or used for anaerobic digestion for biomethane and digestate generation [2].

PM can be applied directly to agricultural soils, but the use of fresh manure results in uneven nutrient distribution, excessive nutrient loading near application sites, excessive odours, increased transportation and spreading costs, considerable ammonia volatilisation, nutrient leaching, and soil compaction [3]. Therefore, granulation of PM is recommended to reduce nutrient loss emissions, improve transportation and handling of this organic fertiliser.

Drying is an important step in PM stabilisation, and several temperature-control strategies have been proposed to minimise nutrient losses, energy consumption and drying time. Optimal parameters for the second drying stage have been reported as 57.5 °C, final moisture content of 45-50%, and air velocity of 1.2-1.5 $m \cdot s^{-1}$ [4]. However, the first drying stage often was provided at low-temperature air (≈20 °C) conditions, which does not eliminate pathogens and allows microbial degradation to continue, resulting in nitrogen losses during both drying stages during long drying periods. To accelerate the drying process, it is recommended PM drying with the air velocity 2.04 $m \cdot s^{-1}$ through a layer of material placed on the sieve providing manure moisture reduction from 52.4% to 22.7% after 3 h drying [5].

Granulation elevates the temperature of poultry manure (PM) above 100 °C, a level sufficient to markedly reduce microbial and pathogen loads while simultaneously limiting nutrient losses during subsequent storage [6]. The resulting granulated PM products can be applied as soil fertilisers, soil conditioners, or as partial substitutes for mineral fertilisers. Field studies demonstrate that applying PM granules at a rate of 2 $t\,ha^{-1}$ can increase rapeseed and potato yields by 28.4% and 22.6%, respectively, while also reducing nutrient runoff and contributing to long-term improvements of soil structure and nutrient content [7].

Combined applications of PM granules with reduced mineral fertiliser doses have produced the highest maize yields compared with either fertiliser type alone [8]. Pelletised PM applied at 6 $t\,ha^{-1}$ has also increased melon and cucumber yields [9]. Long-term subsurface banding of pelletised PM has been shown to improve soil physical properties, including reductions in bulk density [10].

For full potential from use of poultry manure granules their mechanical properties, including crush force and compressive strength, should be investigated to provide its safe packing, transportation and distribution on field. Further structural and chemical improvement of granules can be provided by additives, however some additives, e.g. biochar, can lower the mechanical properties of granules [11] whereas other additives, e.g. wood ashes, can improve the mechanical strength of granules from poultry manure [12].

The aim of this study is to determine whether mechanical properties of granules from poultry manure are dependent on drying mode and concentration of wheat straw or natural peat additive in raw mixture.

Materials and methods

Poultry manure (PM) was supplied from the company Alūksnes putnu ferma SIA, natural peat (NP) from the company Latflora SIA, and wheat straw (WS) from an agricultural farm located in Saldus region. Raw materials were stored at + 1 °C until use in the following 7-day period. PM and NP biomasses were composed of relatively small particles (3-15 mm) and were used in the experiment without any pretreatment. Prior to mixing, WS was chopped and sieved through a 5 mm screen.

Raw materials PM, NP, WS are shown in Fig. 1, and granules made from PM or PM mixtures with NP and WS are shown in Fig. 2.

a) b) c)

Fig. 1. **Raw biomass:** a – poultry manure; b – wheat straw; c – natural peat

Eight samples were prepared, each weighing 2 kg. The set comprised two samples of pure PM, three PM–WS mixtures, and three PM + NP mixtures. The PM–WS mixtures were produced using PM : WS ratios of 0.975 : 0.025 (2.5% WS), 0.95 : 0.05 (5.0% WS), and 0.925 : 0.075 (7.5% WS). The PM + NP mixtures were prepared using PM : NP ratios of 0.925 : 0.075 (7.5% NP), 0.85 : 0.15 (15.0% NP), and 0.875 : 0.225 (22.5% NP).Chemical analyses of raw materials and granules were provided in a laboratory, accredited according to LVS EN ISO/IEC 17025:2017. The following methods were used in the laboratory: LVS EN 13040:2008 (Sections 8.1; 9-11) for dry matter; LVS EN 13654-1:2003 for nitrogen; LVS ISO 9964-3:2000 for potassium; LVS ISO 6598:2001 for phosphorus.

Samples were dried to a moisture content of 25–30% using two basic drying regimes:

High-low temperature drying: Fresh PM (moisture $W1_H = 71\%$) was subjected to a pre-drying treatment at 70 ± 0.5 °C in a thermostatic aeration camera (model SNOL 58/350) for 1 h, followed by drying on the aerated sieve at 24 °C until PM moisture was lowered to 25%, stages I and II in Fig 2.

Low-temperature drying: All mixtures and one pure PM sample were put on the sieve in a 3-4 cm thick layer and dried to moisture 25% using heated air with temperature 24 °C directed by a fan upwards through the layer of biomass, stage II in Fig.2. Moisture of biomass during drying stage II was controlled regularly by help of moisture balance MOC-120H.

All dried samples were subsequently granulated using a 7.5 kW KL200B/C granulator equipped with a horizontal die containing 6 mm openings, stage III. The produced granules were then dried to a final moisture content of 8-12% using low temperature 24 °C air directed by the fan upwards through the layer of biomass, zone IV. The granules were mixed gently during the drying process to ensure uniform moisture reduction.

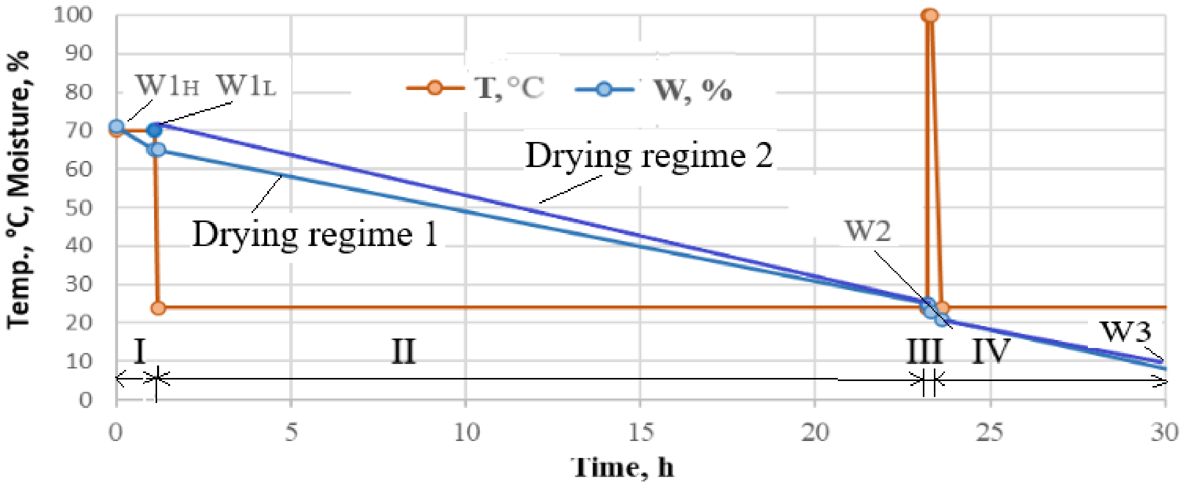

Fig. 2. **Temperature and moisture changes shematic in drying-granulation:** I – high temperature drying stage; I, and IV – low temperature drying stage; III – granulation stage; IV – post-granulation drying stage; W1H – initial moisture in drying regime 1; W1L – initial moisture in drying regime 2; W2 – moisture of biomass before granulation; W3 – moisture of produced granules

Granules made from poultry manure or poultry manure mixtures with wheat straw and natural peat are shown in Fig. 2.

???

a) b) c)

Fig. 2. **Granules produced from:** a – poultry manure; b – poultry manure 92.5% + wheat straw 7.5%; c – poultry manure 77.5% + natural peat 22.5%

The material testing unit INSTRON (accuracy class – 0.5) was used to determine the compressive strength of the granules placed upright on the end surface during testing. Testing of 3 granules from the same sample were provided for calculation of measurement deviation.

For calculation of maximal compression stress the following equation was used [14]:

$$\sigma_{\max} = \frac{F_{\max}}{S} = \frac{F_{\max}}{0.25\pi D^2}, \tag{1}$$

where $\sigma_{\max}$ – maximal compression stress of granule, MPa;
F_{max} – maximal compression strenght of granule, N;
D – diameter of a cylindrical granule, mm.

Statistical calculations, including standard deviation, were provided using standard Excel tools.

Results and discussion

Chemical analysis of raw biomass and granules produced from poultry manure or mixtures of poultry manure (PM) with wheat straw (WS) or natural peat (NP) is presented in Table 1.

There was a slight variation in the average diameters of the produced granules, likely caused by differences in the structure of the raw mixtures and by the gradual reduction of channel openings in the granulator die as a result of particle deposition on the inner channel walls.

The drying–granulation process reduced the moisture content of the granules by approximately threefold compared with the raw PM samples. A decrease in nitrogen content was also observed for all granule types during drying–granulation, with the largest reduction of 1.21% occurring in PM95 + WS5.0 granules and the smallest reduction of 0.32% in PM_70°C granules. The lower nitrogen loss in the latter may be attributed to reduced biodegradation of PM following the pre-heating step, in which the raw PM was held at 70 °C for 1 h during the first stage of the drying process.

Table 1

Average content of nitrogen (N), phosphorus (P), potassium (K) in dry matter, content of dry matter (DM) in biomass, granule diameter (D_{gr}) maximal destruction force (F_{max}) and tensile strength (σ)

Biomass sample	Sample code	N, %	P, %	K, %	DM, %	D_{gr}, mm	F_{max}, N	σ, Pa
PM	R1	4.76	1.44	1.97	28.94	n/a	n/a	n/a
WS	R2	0.50	0.09	1.17	88.41	n/a	n/a	n/a
NP	R3	0.81	0.03	0.03	32.26	n/a	n/a	n/a
PM_24°C	G1	4.03	1.21	1.92	92.80	5.50	263	11.1
PM_70°C	G2	4.44	1.32	2.01	93.00	5.53	305	12.8
PM + WS2.5	G3	4.48	1.22	1.96	94.30	5.27	218	10.3
PM + WS5.0	G4	3.55	1.13	1.86	89.79	4.97	154	7.9
PM + WS7.5	G5	4.16	1.18	1.89	93.71	5.68	283	11.1
PM + NP7.5	G6	4.47	1.32	1.99	93.71	5.68	280	11.0
PM + NP15	G7	4.18	1.23	1.82	93.06	5.60	338	13.6
PM + NP22.5	G8	3.71	1.04	1.58	92.45	5.40	186	8.2
Aver. std. dev.	-	n/a	n/a	n/a	n/a	5.45 ± 0.14	253 ± 35	10.8 ± 2.53

The results of testing the granules with respect to the effect of the mechanical compressive force are shown in Fig. 1.

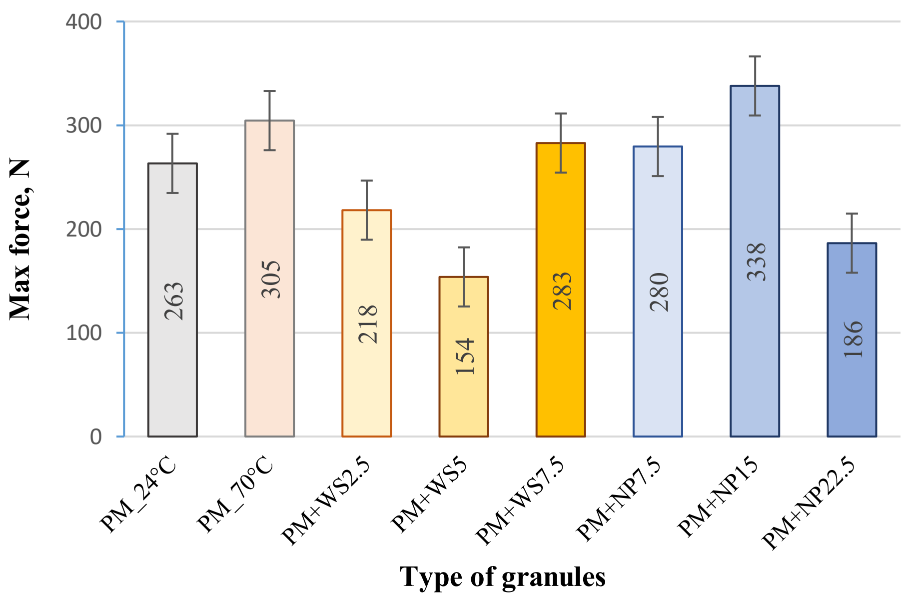

Fig. 3. **Maximum compressive force for granules produced from poultry manure (PM) and PM mixtures with wheat straw (WS) and natural peat (NP)**

As illustrated in Fig. 3, the maximum vertical force that granules can withstand before structural failure varies considerably across the tested formulations. The lowest resistance was observed for granules produced from poultry manure with a 5% wheat straw additive, which failed at 154 N. In contrast, the highest strength was recorded for granules incorporating 15% natural peat, reaching 338 N before breakage.

These findings are broadly consistent with previously reported results for granules produced from poultry-manure-biochar mixtures [11].

The corresponding compressive strength values, calculated according to Equation (1), are presented in Fig. 4.

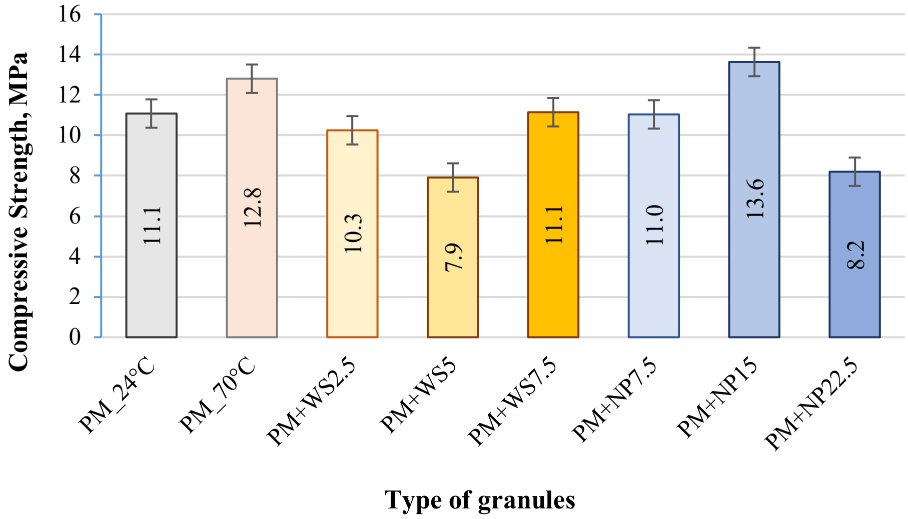

Fig. 4. **Compressive strength of granules produced from poultry manure (PM) and PM mixtures with wheat straw (WS) and natural peat (NP)**

As shown in Figure 4, the compressive strength of the granules ranges from 7.9 MPa for the sample containing 5% wheat straw to 13.6 MPa for granules produced from poultry manure with a 15% natural peat additive. Notably, the compressive strength of granules made from pure poultry manure pre-dried at 70 °C is 13.5% higher than that of granules produced from pure poultry manure dried at 24 °C.

Conclusions

1. Granulation of poultry manure is an effective method for reducing moisture content and increasing the bulk density of poultry-manure-based fertilizer.
2. Pre-drying poultry manure for 1 h at 70 °C (G2) during the initial stage of processing resulted in lower nutrient losses and higher granule compressive strength compared with granules produced from manure dried at 24 °C (G1). This improvement is likely associated with reduced microbial activity resulting inlower biodegradation during the following low-temperature dryingstagein sample G2.
3. The addition of 15% natural peat to poultry manure resulted in the highest mechanical performance, with granules sustaining a maximal vertical force of 338 N and exhibiting a compressive strength of 13.6 MPa, outperforming granules produced from pure poultry manure.
4. Mechanical performance of the granules produced from poultry manure with a 5% wheat-straw additive (G4) was the weakest, withstanding only 154 N of vertical force and exhibiting the lowest compressive strength of 7.9 MPa. This reduced resistance may be associated with the decrease in the granule diameter observed in sample G5, likely caused by sediment accumulation on the inner surface of the pelleting die.
5. Further investigation is required to clarify the trend in mechanical strength when increasing the proportion of straw or peat additives. An expanded range of additive ratios should be examined to determine their precise influence on granule durability.

Acknowledgements

Preparation of this paper is funded by the Latvia University of Life Sciences and Technologies.

Author contributions

Conceptualization, I.P.; methodology, I.P. and A.K.; software, L.P.; validation, A.A. and I.P; formal analysis, A.K and I.P...; investigation, I.P., A.A. and A.K.; data curation, A.K., and I.P.; writing –

original draft preparation, I.P.; writing – review and editing, A.A. and I.P.; visualization, L.P., V.N.; funding acquisition, A.K. and A.A.

All authors have read and agreed to the published version of the manuscript.

References

[1] Statistical database Business sectors Agriculture Livestock LAL090. Number of livestock and poultry at the end of year (thousand heads) 1915-2025. [online] [11.02.2026] Available at: https://data.stat.gov.lv/pxweb/en/OSP_PUB/START__NOZ__LA__LAL/LAL090/

[2] Pilvere I., Krievina A., Upite I., Nipers, A. Manure Production Projections for Latvia: Challenges and Potential for Reducing Greenhouse Gas Emissions. Agriculture 2025, 15, 2080. DOI: 10.3390/agriculture15192080

[3] Cabinet Regulation No. 834. Requirements Regarding the Protection of Water, Soil and Air from Pollution Caused by Agricultural Activity, Annex 2, 23 December 2014, [online] [11.02.2026] Available at: https://likumi.lv/ta/en/en/id/271376

[4] Ijaz M.U., Akbar A., Eman R., Hayat M.F., Naz H., Ashraf A. Mitigating Nutrient Pollution from Livestock Manure: Strategies for Sustainable Management. In: Hussain, N., Hung, CY., Wang, L. (eds) Agricultural Nutrient Pollution and Climate Change. Springer, Cham. 2025. DOI: 10.1007/978-3-031-80912-5_6

[5] Li X., Kang X., Xi L., Dou Q., Shi Z., Liu T. Wang L. Drying Characteristics of Chicken Manure Under a Variable Temperature Process. Appl. Sci. 2025, 15, 4093. DOI: 10.3390/app15084093

[6] Aboltins A., Kic P. Comparison of two methods of poultry manure drying. 13th International Scientific Conference "Engineering for Rural Development", proceedings Publisher: Latvia University of Life Sciences and Technologies, Faculty of Engineering, Jelgava, 2014, pp. 143-148.

[7] Mieldazys R., Jotautiene E., Jasinskas A. Physical mechanical properties evaluation of experimental granulated poultry manure fertilizer. 21st International scientific conference "Engineering for rural development" proceedings, Jelgava, Latvia, 2021, 20, pp. 412-416.

[8] Mažeika R., Arbačiauskas J., Masevičienė, A. et al. Nutrient Dynamics and Plant Response in Soil to Organic Chicken Manure-Based Fertilizers. Waste Biomass Valor 12, 2021, pp. 371-382. DOI: 10.1007/s12649-020-00978-7

[9] Darabi S., Heidari G., Khalesro S., Azizabadi H.J. 2025. Effect of Different Levels of Pelleted Poultry Manure and Chemical Fertilizer on Fodder Quality and Maize (Zea mays L.) Grain Yield. Agroecology, vol. 16, no.1, pp. 129-146. DOI: 10.22067/agry.2023.78185.1122

[10] Sovarel G., Scurtu I., Hogea S.S., Sbîrciog G. 2022. Influence of different doses of organic fertilizer from poultry fertilizer pellets on melon and cucumber crops. XXXI International Horticultural Congress (IHC2022): International Symposium on Plant Nutrition, Fertilization, Soil Management. Article 1375_49, pp. 373-380.

[11] Feng G., Adeli A., Read J., JMcCarty J., JJenkins J. Consequences of pelletized poultry litter applications on soil physical and hydraulic properties in reduced tillage, continuous cotton system, Soil and Tillage Research, vol. 194, 2019, 104309, DOI: 10.1016/j.still.2019.104309

[12] Jotautiene E., Mieldazys R., Gaudutis A., Aboltins A. Granulation of poultry manure and biochar for production of organic fertilizers. 20th International scientific conference "Engineering for Rural Development". Proceedings. Publisher: Latvia University of Life Sciences and Technologies, Faculty of Engineering, Jelgava, 2021, pp. 431-436. DOI: 10.22616/ERDEV.2021.20.TF091

[13] Mieldažys R., Jotautienė E., Jasinskas A. The opportunities of sustainable biomass ashes and poultry manure recycling for granulated fertilizers. Sustainability, vol. 11(16), 4466, 2019. DOI: 10.3390/su11164466

[14] Williams O., Taylor S., Lester E., Kingman S., Giddings D., Eastwick C. Applicability of Mechanical Tests for Biomass Pellet Characterisation for Bioenergy Applications. Materials (Basel). 2018 Jul 31; 11(8):1329. DOI: 10.3390/ma11081329. PMID: 30065239; PMCID: PMC6119871

[15] Williams O., Taylor S., Lester E., Kingman S., Giddings D., Eastwick C. Applicability of Mechanical Tests for Biomass Pellet Characterisation for Bioenergy Applications. Materials (Basel). 2018 Jul 31; 11(8):1329. DOI: 10.3390/ma11081329. PMID: 30065239; PMCID: PMC6119871