AGRICULTURAL TECHNOLOGY COMMITTEE
OF THE POLISH ACADEMY OF SCIENCES
POLISH SOCIETY OF AGRICULTURAL ENGINEERING

AGRICULTURAL ENGINEERING

VOL. **19** **1**(153)

Kraków 2015

Auspices: Agricultural Technology Committee of the Polish Academy of Sciences

Publisher: Polish Society of Agricultural Engineering

CONTACT DETAILS:
ul. Balicka 116B, 30-149 Kraków
tel./fax. (+48) 12 662-46-99
e-mail: redakcja@ir.ptir.org

ISSN 2083-1587

Scientific quarterly journal

- Published since 1997, an edition of 1(153) – 100 copies
- Electronic version: http://ir.ptir.org
- A journal indexed in BazTech, Index Copernicus, SIGZ, AGRIS, BazEkon, EPNP
- Points granted by the Ministry of Science and Higher Education – 5 points (www.nauka.gov.pl)

Printing and binding by: NOVA SANDEC, ul. Lwowska 143, 33-300 Nowy Sącz
tel. +48 (18) 547-45-45; e-mail: biuro@novasandec.pl; http://www.novasandec.pl
Standard unit of text length 10.50; quire 9.50
Cover design – Piotr Nawara

Contents

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):5-14

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.101

THE INFLUENCE OF MOISTURE CONTENT OF BARLEY ON THE FLAKING PROCESS

Agata Blicharz-Kania[a*], Dariusz Andrejko[a], Beata Ślaska-Grzywna[a], Agnieszka Starek[a], Paweł Szejgiec[a], Paweł Krzaczek[b]

[a] Department of Biological Fundamentals of Food and Feed Technology
University of Life Sciences in Lublin
[b] Department of Power Industry and Vehicles, University of Life Sciences in Lublin
[*] *Contact details: ul. Głęboka 28, 20-612 Lublin, e-mail: agata.kania@up.lublin.pl*

ARTICLE INFO

Article history:
Received: April 2014
Received in the revised form: November 2014
Accepted: December 2014

Keywords:
barley
flaking process
moisture content
grain

ABSTRACT

The paper presents the study, which aimed at determining how moisture content of barley grain and the size of the grain crusher working gap affect changes on the embodied energy during the flaking process and properties of the obtained flakes. Thus, the barley grains of Barke variety were moisturized up to the level of 14, 18, 22 and 26%. Then grains were subjected to flaking, and at the same time the embodied energy was measured. The next step was to evaluate the physical properties of the product such as: angle of repose, chute angle, bulk and shaken density. Also a mesh analysis was applied. Moreover, the absorption coefficient of water has been evaluated for each series of products. As stated, the size of grain crusher working gap significantly affects changes of the embodied energy during the process. The lowest values were registered for 2.0 mm wide gap. As observed, the moisture content of grains affects the physical properties of the product. It should also be noted, that during the flaking process of grain with moisture content of 14%, the significant amount of flour is obtained.

Introduction

Cereal grains are the basic food raw material in the production of food and feed. They have many favourable food properties and contain small amount of water which gives a possibility of easy transport and processing. Due to these properties they are the most popular plant product in the international turnover. Approximately 10% of the global cultivation area of cereals is covered by barley (68-71 mln. ha) (Borek, 2008). This plant has been used by a man for ten thousand years. Barley grain is used mainly for production of groats, flakes, coffee substitute, as a raw material in brewing for production of beer and feed. The most important method of using barley in the food industry is production of malt (Baik and Ullrich, 2008)

The basic structural component of barley grain are carbohydrates (at the average 66% of dry mass of grain), mainly starch. Additionally, plants are rich in proteins. They may amount from 9 to even 15% of dry mass of grain. The content of fats in the barley grain is at the average of 4% but in the naked forms this value may be higher (Dziki and Laskowski, 2004). Moreover, grain is rich in minerals (2.7-3.2%). Spelt forms of barley include more ash than the naked ones. Products from barley are a precious source of vitamins from group B and a vitamin E. A chemical composition of cereal grains is varied. Moreover, particular components are distributed irregularly in a grain, thus the manner of seed processing has a decisive impact on the chemical composition of grain products (Jurga, 1997, Panasiewicz et al., 2005). External layers of a grain are the richest in vitamins and fibre, thus products made of the whole grain e.g. wholemeal flour and bread, groats and cereal flakes have a high nutritive value (Pijanowski, 1996).

Presently, when healthy lifestyle is fashionable, "Fit" products are bought more eagerly. These are, inter alia, cereal flakes including oat and barley flakes. The fact that digestibility of barley starch is considerably lower than other cereals is crucial (Czarnowska-Misztal et al., 2007). Furthermore, in the recent years, a special attention has been paid to consumption of fibre (Nawrolnik, 2013). Cereal grains, in particular barley grains, is very rich in this component (Michalak et al., 2003). High-fibre products with high content of soluble fraction, such as flakes of the wholemeal grain recommended by dietitians may be obtained only from raw material which is high in fibre, such as oat and barley (Muir et al., 2004, Rzedzicki and Wirkijowska, 2008).

Therefore, the objective of the research was to determine how the moisture of barley grain and a range of the working slot of a grain crusher affect the changes of energy consumption of the flaking process and the quality of the obtained flakes. The scope of the research included repeated moistening of grain, then flaking of grain and assessment of the physical properties of products.

Research methodology

Barke variety of spring barley was used in the research. Before moistening the grain moisture was determined (acc. to the standard PN-ISO 712:20002), which was 14%. Then, the raw material was moistened to the moisture content of 18, 22 and 26%. The assumed moisture of grain was obtained by adding to the sample an appropriate amount of distilled water. The amount of water necessary for moistening was calculated from the formula:

$$M_W = \frac{w_2 - w_1}{100 - w_2} \cdot M_N \tag{1}$$

where:

M_W – amount of water required for moistening, (g)
M_N – mass of the moistened cereal, (g)
w_1 – initial moisture, (g)
w_2 – required moisture, (%)

After moistening of grain, samples of the mass of 500 g were closed in hermetic vessels and placed in a cooling chamber in temperature of 4±°C for 24 hours. In order to obtain regular moisture in the whole material, samples were shaken several times during the process of their seasoning. Two hours before flaking, samples were taken out of the cooling chamber in order to obtain the temperature of the surrounding.

Barley grain was flaked with the use of a grain crusher H–750 by MAGROTEX (Poand) company. The device was connected to a computer, the task of which was to register energy required to flake the sample. The flaking process was carried out at the working gap size of a grain crusher which was s_1=0.5 mm; s_2=1.0 mm and s_3=2 mm. Samples with 500 g mass were flaked.

Measurement of physical properties of so prepared flakes was carried out according to the applicable Polish Standards, i.e. angle of repose – PN-74/Z-04002/07, chute angle – PN-74/Z-04002/08, bulk density – PN-ISO 7871-2:1998, shaken density – PN-80/C-04532. Measurement of physical properties was carried out in seven repeats and an arithmetic average was accepted as a result.

Moreover, a screen analysis of flakes was carried out. A laboratory vibrating screen AS 200 by Retsh company (Germany) was used. 100 g of flakes was screened using the vibrations amplitude of 2 mm, the measurement time was 4 minutes and the interval was 20 s. A wire screen with the following dimensions of meshes was used. 0.01; 0.02; 0.05; 0.1; 0.2 and 0.315 mm. Based on the obtained results, an average dimension of particles was calculated using the following relation (2):

$$s = \frac{\frac{l_1 + l_2}{2} \cdot m_1 + \frac{l_2 + l_3}{2} \cdot m_2 + \cdots + \frac{l_n + l_{n+1}}{2} \cdot m_n}{100} \tag{2}$$

where:

- s – average dimension of particles, (mm)
- l – dimension of screen meshes, (mm)
- m – mass of a fraction on the screen, (%)

The last stage of research consisted in determination of the flakes ability to absorb water. The measurement consisted in a cyclic immersing (10 immersions per a minute) of containers filled in with 5 g of flakes in a container with water of 8°C temperature and then placing them on rotational arms of a device. For all samples the measurement time was 5 minutes. Then, containers along with a material were placed in a dryer. After the process, the samples were weighed and the loss of mass of the tested flakes was calculated. Comparing the mass of a sample before immersing in water and afterwards, the amount of water absorbed by flakes was calculated.

The obtained results were statistically anlysed with the use of Statistica 6.0 programme. In order to determine the mathematical relations between the tested parameters and the size of the grain crusher gap and the moisture of the raw material, the analysis of variance and Tukey's test were carried out at the level of significance of α=0.05.

Research results and their analysis

Figures 1-7 present changes of energy consumption of the flaking process and properties of the obtained flakes in relation to the size of the working gap of a grain crusher and the determined moisture of a grain. Various letters presented in plots prove occurrence of statistically significant differences between average sizes.

Figure 1 presents the impact of the grain moisture and the size of the working gap on the flaking energy. It should be stated clearly that the increase of the working gap from 0.5 to 1.0 and 2.0 mm resulted with the decrease of energy inputs necessary for the flaking of grain, independently from the moisture of grain. Moreover, moisture influenced the energy consumption of the process. It was found out that the raw material moisture significantly affects the flaking energy. The highest values of energy were reported at the grain moisture of 18%, whereas the least energy was necessary for flaking of raw material with 26% moisture at the use of a working gap of a grian crusher which is 2 mm.

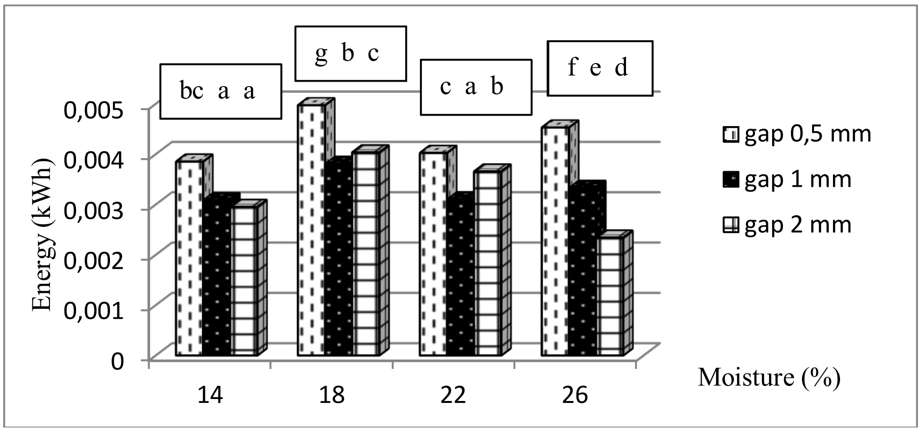


Figure 1. Influence of moisture content of grain and size of the working gap on the flaking energy

Figure 2 presents the impact of the grain moisture and the size of the grain crusher working gap on the angle of repose of flakes. It was assessed that the highest values of the angle of repose of flakes were reported for grain with 26% moisture independently from the used grain crusher working gap.

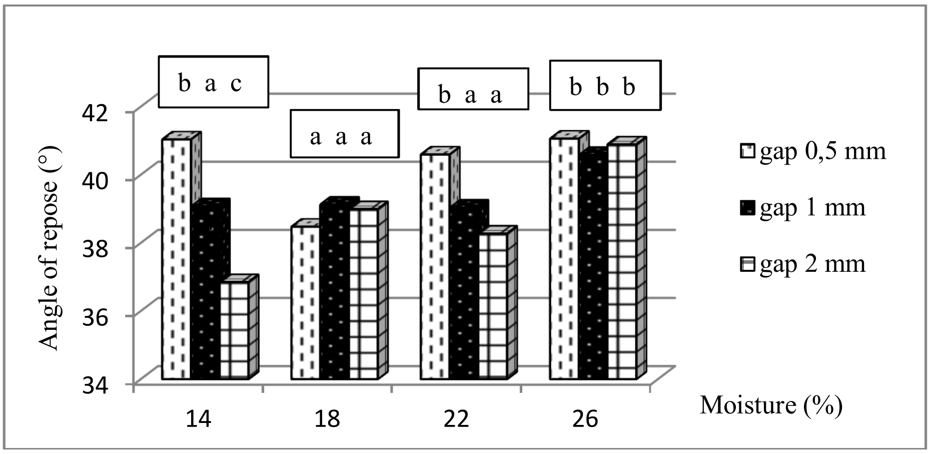


Figure 2. Influence of moisture content of grain and size of the working gap on the angle of repose of barley flakes

Figure 3 presents the impact of the grain moisture and the size of the working gap on the chute angle of flakes. It was reported that at the use of particular working gaps, the value of the chute angle of flakes increased along with the increase of grain moisture. The analysis of the results of Tukey's test of significance of differences presented in figure 3 at the level of significance of α=0.05 allowed determination of the significant impact on the increase of the value of the chute angle of flakes, when grains were moistened from 22% to 26%.

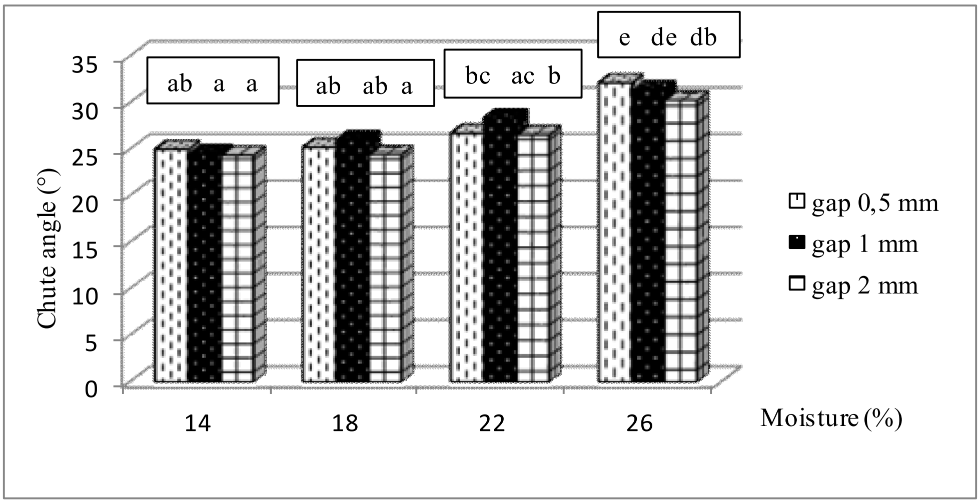


Figure 3. Influence of moisture content of grain and size of the working gap on the chute angle of barley flakes

Figure 4 presents the impact of the moisture content of grains and the size of the working gap on the shaken density of flakes. It was reported that the increase of the barley grains moisture and the increase of the working gaps of the grain crusher directly affect the shaken density of flakes. The lowest values of the shaken density of flakes were reported for a grain with moisture of 14% whereas the highest for moisture of 26%.

Figure 5 presents the impact of the grain moisture content and the size of the grain crusher working gap on the chute angle of flakes. The highest values of the bulk density were reported in the case of flakes obtained from a grain of 22% moisture. Moreover, the increase of the bulk density of flakes along with the increase of the working gap between shafts was visible. After the analysis of the results of Tukey's test of significance of differences, presented in figure 5, at the level of significance α=0.05, it was found out that the moistening grain with the use of a working gap of a grain crusher with 1 and 2 mm width significantly influences the bulk density of flakes.

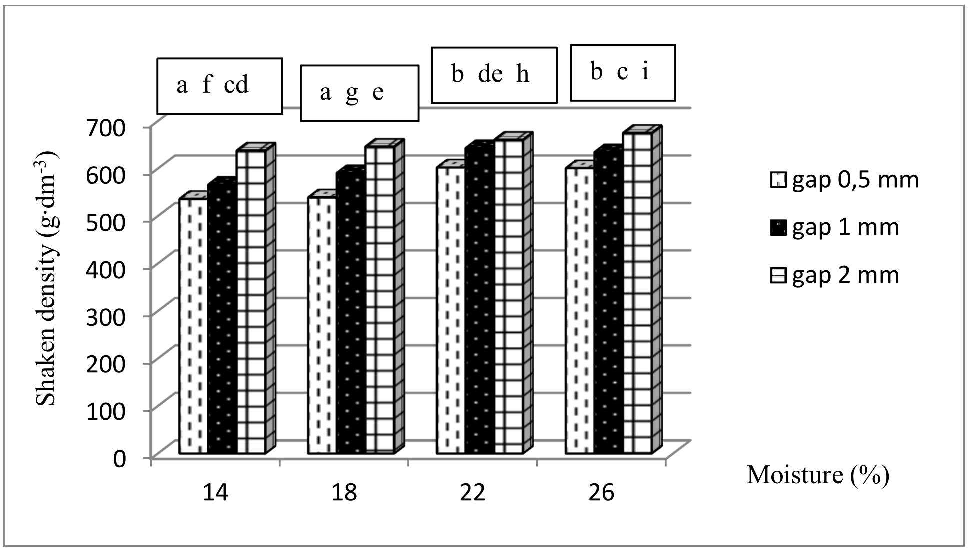


Figure 4. Influence of moisture content of grain and size of the working gap on the shaken density of barley flakes

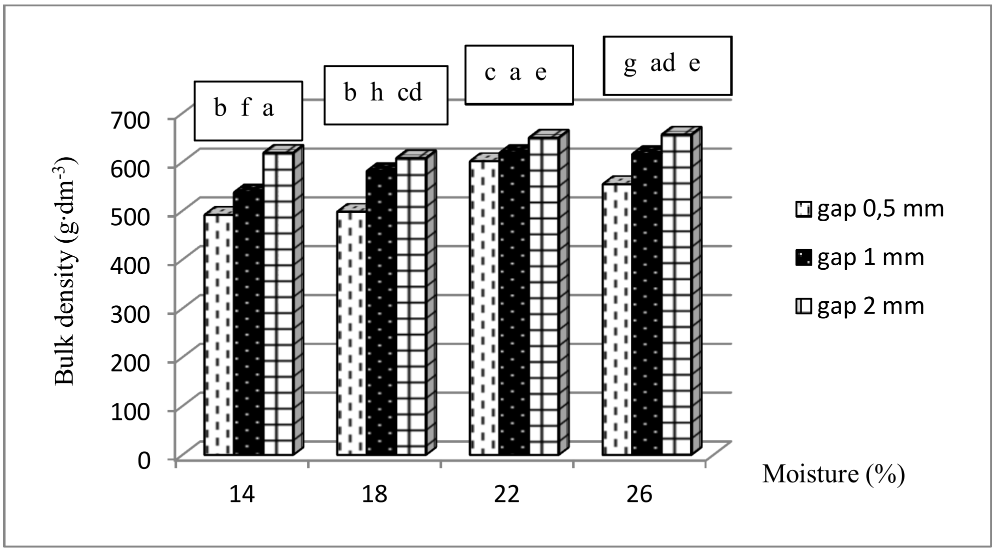


Figure 5. Influence of moisture content of grain and size of the working gap on the bulk density of barley flakes

Table 1 presents the impact of moisture of grains on the participation of fraction of flakes obtained on particular screens. For moisture of grains which was 18%, 22% and 26%, the highest mass of fraction was obtained on a screen with 0.315 mm diameter of meshes. In the case of grain with moisture of 18, 22 and 26% an insignificant (up to 2%) amount of floury fraction was reported, flakes were uniform. Whereas, flakes obtained from seeds with moisture of 14% characterized with a considerable difference of dimensions and the highest content of floury fraction.

Table 1
Percentage of the fraction of the flakes obtained on individual screens

Moisture (%)	Grain crusher gap (mm)	Dimensions of meshes, (mm)						
		0.315	0.2	0.1	0.05	0.02	0.01	bottom
14	0.5	31.070	41.932	21.960	3.395	1.254	0.306	0.083
18		88.520	9.561	1.555	0.158	0.133	0.070	0.003
22		93.430	6.489	0.033	0.005	0.043	0	0
26		92.400	7.537	0.025	0.013	0.025	0	0
14	1.0	40.990	43.030	14.61	0.930	0.315	0.125	0
18		89.230	10.317	0.395	0.035	0.023	0	0
22		88.670	11.302	0.015	0.013	0	0	0
26		89.590	10.405	0.005	0	0	0	0
14	2.0	57.820	38.303	3.759	0.050	0.068	0	0
18		84.117	15.475	0.380	0.028	0	0	0
22		86.085	13.900	0.015	0	0	0	0
26		98.852	0	1.148	0	0	0	0

Figure 6 presents the impact of the grain moisture and the size of the grain crusher working gap on the average dimension of flakes particles. The analysis of the results of Tukey's test of significance of differences presented in figure 6 at the level of significance of α=0.05 allowed determination of the significant impact of the grain moistening of grains from 14% to 18% on the increase of flakes particles dimensions. However, no further increase of the grain moisture on the average dimension of flakes particles was reported. The smallest dimension of particles was obtained from grain with 14% moisture at the 0.5 mm gap, whereas the highest for the grain with 26% moisture at the working gap of 2.0 mm and it was at the level of 0.255 mm.

Figure 7 presents the impact of the grain moisture and the size of a working gap on the flakes ability to absorb water. It was assessed that flakes with 14% moisture absorbed more water than flakes with a higher moisture content. Furthermore, the working gap has an impact on the amount of the absorbed water. The highest values were reported for flakes obtained in the 2.0 mm working gap whereas the lowest for flakes obtained in the 0.5 mm working gap.

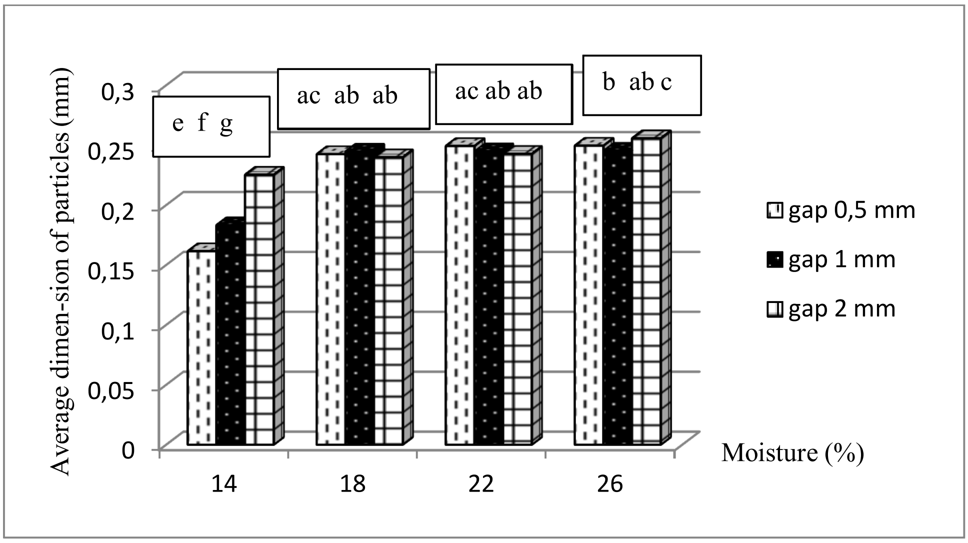


Figure 6. Influence of moisture content of grain and size of the working gap on the medium average size of flakes

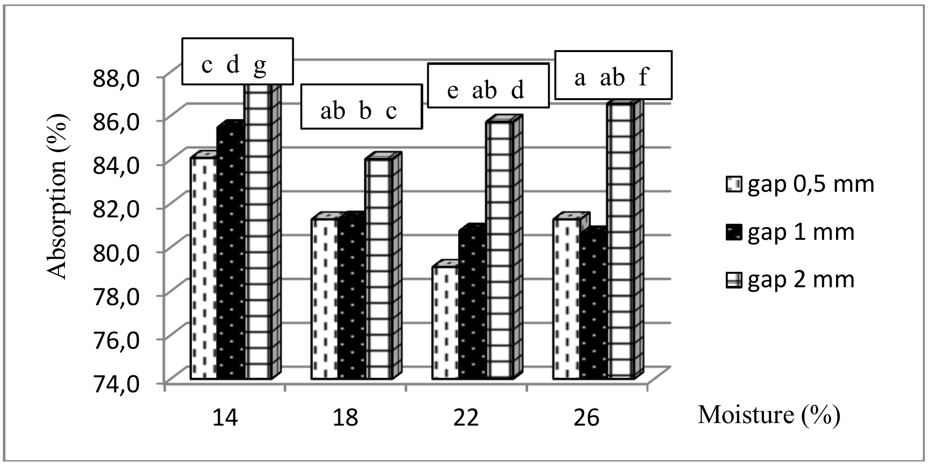


Figure 7. Influence of moisture content of grain and size of the working gap on the ability of flakes to absorb water

The tests, which were carried out, proved that moistening of the barley grain within 14% to 26% caused decrease of energy necessary to flake the raw material. Thus, the tests carried out by other authors, were confirmed. They proved that along with the increase of caryopsis moisture their resistance to mechanical loads decreases (Nadulski et al., 2010). Based on the statistical analysis, it was stated that significant changes of the average size of flakes particles obtained from moistened grain from 14 to 18% took place. However, no impact of barley grain and the working gap on the level of value of the angle of repose and chute angle of flakes was reported. Changes of the shaken density and bulk density of the product depended on the size of the grian crusher working gap; to a lesser extent these values depended on the initial moisture of a grain.

Conclusions

Based on the obtained results of research, the following conclusions were made:

1. The increase of the working gap from 0.5 to 2.0 mm and moistening of grain to the level of 26% significantly causes decrease of energy inputs required for flaking of barley grains.
2. No significant impact of the barley grain moisture and the size of the grain crusher working gap on the angle of repose and chute angle of flakes were reported. The highest values of the mentioned sizes were reported at the highest researched moisture of grain – 26%.
3. Grain moisture and the value of the grain crusher working gap had a significant impact on the granulometric composition of flakes. At the gap of 0.5 mm and the grain moisture of 14% the biggest amount of floury fraction is formed.
4. The amount of water absorbed by flakes depends on the grain moisture and the size of the grain crusher working gap. The biggest amount of water is absorbed by flakes produced from grain with moisture of 14%.

References

Baik, B.K.; Ullrich, S.E. (2008). Barley for food: Characteristics, improvement, and renewed interest. *Journal of Cereal Science, 48*(2), 233-242.

Borek, A. (2008). Analiza zmian w powierzchni zasiewów i plonów na świecie w ostatnich dziesięciu latach. *Przegląd Zbożowo- Młynarski*, *1,* 32- 35.

Czarnowska-Misztal, E.; Kunachowicz, H.; Turlejska, H. (2009). *Zasady żywienia człowieka*. Warszawa, WSiP, ISBN 83-02-09149-9.

Dziki, D.; Laskowski, J. (2004). *Przewodnik do ćwiczeń z przetwórstwa zbożowo-młynarskiego*, Lublin, Wyd. Akademia Rolnicza, ISBN 83-72-59093-1.

Jurga, R. (1997). *Przetwórstwo zbóż, cz. I.* Warszawa, Wyd. WSiP, ISBN 83-02-05448-8.

Michalak, M.; Makarska, E.; Lipiec, A.; Wesołowska-Trojanowska, M. (2003). Wpływ systemu uprawy jęczmienia jarego na zmiany udziału frakcji włókna surowego. *Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin, 228*, 95-103.

Muir, J. G.; Yeow, E. G. W.; Keogh, J.; Pizzey, C.; Bird, A. R.; Sharpe, K.; O'Dea, K.; Macrae, F. A. (2004). Combining wheat bran with resistant starch has more beneficial effects on fecal indexes then does wheat bran alone. *Am. J. Clin. Nutr., 79(6)*, 1020-1028.

Nadulski, R., Kusińska, E., Guz, T., Kobus, Z., Oszczak, Z. 2010. Wpływ wilgotności na wybrane właściwości mechaniczne ziarniaków owsa i jęczmienia. *Inżynieria Rolnicza, 3*(121), 135-141.

Noworolnik, K.; Wirkijowska, A.; Rzedzicki, Z. (2013). Znaczenie błonnika pokarmowego w diecie oraz jego zawartość w ziarnie jęczmienia jarego w zależności od odmian i gęstości siewu. *Fragmenta Agronomica, 30(3)*, 132-139.

Panasiewicz, M., Zawiślak, K., Grochowicz, J., Sobczak, P. (2005). Termiczne preparowanie ziarna pszenicy. *Inżynieria Rolnicza*, *11*(71), 367-374.

Pijanowski, E.; Dłużewski, M.; Dłużewska, A.; Jarczyk, A. (2009). *Ogólna technologia żywności*. Warszawa, WNT, ISBN 978-83-204-3610-5.

Rzedzicki, Z.; Wirkijowska, A. (2008). Charakterystyka składu chemicznego przetworów jęczmiennych ze szczególnym uwzględnieniem składu frakcyjnego błonnika pokarmowego. *Żywność Nauka Technologia Jakość 1*(56), 52-64.

WPŁYW WILGOTNOŚCI ZIARNA JĘCZMIENIA NA PROCES PŁATKOWANIA

Streszczenie. W pracy zaprezentowano badania, które miały na celu określenie, w jaki sposób wilgotność ziarna jęczmienia oraz wielkość szczeliny roboczej gniotownika wpływają na zmiany energochłonności procesu płatkowania oraz właściwości uzyskanych płatków. W tym celu dowilżono ziarno jęczmienia odmiany Barke do poziomu 14, 18, 22 i 26%. Następnie ziarno poddano procesowi płatkowania, w trakcie którego przeprowadzono pomiar energochłonności. Kolejnym etapem było określenie właściwości fizycznych produktu, takich jak: kąt zsypu, kąt usypu, gęstość usypowa oraz gęstość utrzęsiona. Przeprowadzono również analizę sitową płatków. Dodatkowo określono zdolność płatków do pochłaniania wody. Stwierdzono, że wielkość szczeliny roboczej istotnie wpływała na zmiany energochłonności procesu. Najniższe wartości odnotowano dla szczeliny o szerokości 2,0 mm. Zaobserwowano, że wzrost wilgotności ziarna wpływa na właściwości fizyczne produktu. Należy także stwierdzić, że przy 14% wilgotności ziarna w procesie płatkowania powstaje największa ilość frakcji mączystej (ok. 5%) w porównaniu do płatków z ziaren o wyższej wilgotności.

Słowa kluczowe: jęczmień, proces płatkowania, wilgotność, ziarno

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):15-23

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.102

A SIMPLIFIED DETERMINATION OF THE SHAPE OF A SUGAR BEET TAP-ROOT

Zbigniew Błaszkiewicz*, Przemysław Sztukowski

Institute of Biosystems Engineering, Poznań University of Life Sciences

**Contact details: ul. Wojska Polskiego 28, 60-637 Poznań, e-mail: zbigniewblaszkiewicz@up.poznan.pl*

ARTICLE INFO

Article history:
Received: September 2014
Received in the revised form: December 2014
Accepted: January 2015

Keywords:
sugar beet
tap-root
shape
geometric model

ABSTRACT

This work presents theoretical and empirical analysis of the usefulness of the selected geometrical models, for the purpose of determination of the sugar beet root shape, based on the available root parameters: diameter, length and the bulb root height. Analysis covered four models in the form of: a spherical sector, composed of a conic and a half of a sphere, composed of a conic and a spherical cap, composed of a conic and a half of an ellipsoid. Within the scope of the assumption of this paper it was proved, that the shape of a tap-root can approximate the simplified model comprising a conic and a half of an ellipsoid.

Introduction

Sugar beet roots are a valuable raw material used for production of sugar and lately for generation of renewable energy and the object of numerous experimental researches. In numerous experiments, dimensions of a root, indispensable for environmental assessment of a morphological structure are measured very rarely (Byszewski, 1979; Guerif et al., 1986; Gutmański, 1991; Ostrowska et al., 2002; Ostrowska and Artyszak, 2005; Przybył, 1998). The literature informs that the soil properties and yield of sugar beet roots is varied on account of soil and climatic conditions and the cultivation systems with a variable number of treatments and crossings of tractor wheels and agricultural machines (Hanse et al., 2011; Koch et al., 2008; Krauze et al., 2009; Sztukowski and Błaszkiewicz, 2002; Tomanowa et al., 2006). The above factors may lead to differentiation of the sugar beet root system and important technological morphological properties of roots (Błaszkiewicz et al., 2003; Dieckmann et al., 2006, Hoffmann and Jungk, 1996; Gajewnik 2013; Koch et al., 2008; Krauze et al., 2009; Lipiec et al., 2012; Ostrowska et al., 2002; Ostrowska and Artyszak, 2005; Schlinker et al., 2007; Scott et al., 1973). It is confirmed by numerous observations which indicated various shapes and sizes of sugar beet in agricultural practice. The advanced computer techniques applied more frequently in order to support the production management require formalized models of agricultural objects including models of the shape of sugar beet roots. Such models, supported by the shape of root parameters may be crucial in agricultural engineering and may serve for approximated and theoretical estimations of the size of root mass losses which take place during machine harvesting as a result of improper topping or breaking roots or for determination of the cubic capacity of storing and transportation means (Gutmański, 1991; Karwowski, 1982; Przybył, 1998).

Scientific centres keep results of researches carried out during harvesting of sugar beets in the form of basic dimensions of the tap - root: the biggest diameter, the total length of a root and the bulb root height. Thus, a question arises whether one may on this basis carry out determination of the simplified model of the sugar beet roots shape with the use of simple solids and geometrical formulas. Only general definitions of the tap-root shape, which may be found in the subject literature, given in the aspect of technological requirements, e.g. pointed-conical (Byszewski, 1979) or wedge-shaped (Ostrowska and Artyszak, 2005), have more orientative meaning than the scientific and practical ones. Thus, even approximated and general theoretical description of the shape of the sugar beet tap-root seems to be necessary. As a result of the above discussions, the objective of the paper was formulated.

The objective of the paper

The objective of the paper is to determine models of the sugar beet tap-roots shape based on a diameter and the total length of a root and the bulb root height as well as their assessment made based on a comparison of the determined parameters of the model and real solids.

Material and methodology of research

Determination of the sugar beet shape models is based on the idea of simple geometrical solids including available parameters of the morphological structure of roots, such as: length of the bottom part H of a root, height of its bulb root h and the highest diameter D_m (fig.1) obtained from field measurements. It was assumed to consider a root as consisting of two parts: lower conical and upper called a bulb root. Parameters describing these parts of the morphological structure of the tap-root were defined as follows. A cross section of a root in the widest place was assumed in the form of a circle, a diameter of which D_m is made of the average value from at least five measurements. A root part below its highest diameter was called a lower part – conical, length of which H is made of a fragment from the place where conical parts of a root meet to its highest diameter – the place where a root meets a measuring device. A bulb root, the height of which is made of a fragment from its highest part to the diagonal cross section in the place of the highest diameter, constitutes the upper part of a root.

The shape of the sugar beet tap root was described with one or two basic spatial geometrical solids. It was assumed that based on two available parameters D_m and H and for its pointed-conical shape (Byszewski, 1979) or the wedge shape (Ostrowska and Artyszak, 2005) required on account of technological aspects, a conic should reflect the lower part of the sugar beet root. As a root head model, a spherical cap, a half of a sphere and a half of ellipsoid were considered. As a result of the above, four variants of the geometrical model of the tap root of a sugar beet (fig. 1-3) were suggested in the following form:

I – a spherical sector,

II – a cone and a half of a sphere,

III – a cone and a spherical cap,
IV – and a cone as a half of an ellipsoid.

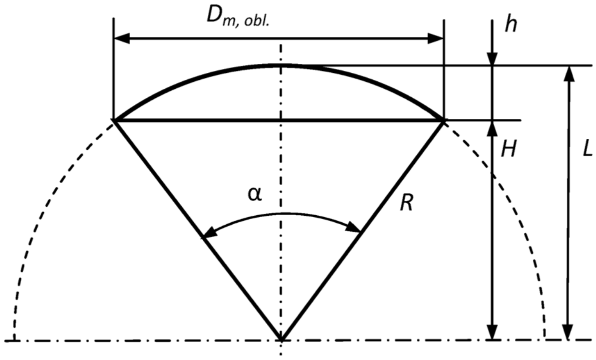


Figure 1. Parameters of sugar beet root model as a spherical sector

Mathematical formulas for determination of the root model volume, for the assumed geometrical solids were presented in table 1. Model I of the root shape in the form of a spherical sector and the describing parameters (where $R = L$) were presented in figure 1. Model II of the sugar beet root shape made of the half of a sphere, which adheres to the base of the reverse conic and the describing parameters were presented in figure 2. In this model, the sugar beet bulb root shape was described with a half of a sphere for the case, when the head height is similar to the half of a diameter of its base ($h \approx ½\, D_m$).

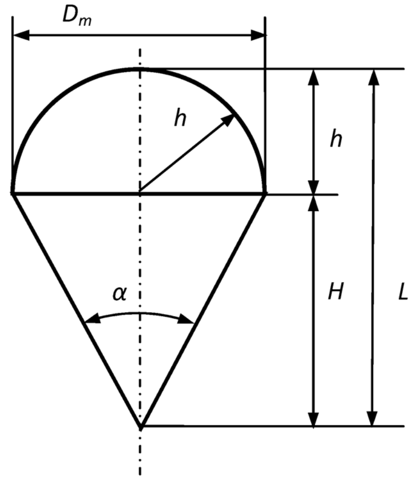


Figure 2. Parameters of sugar beet root model, composed of conic and half of sphere

If two above cases do not take place, the sugar beet shape may be described with a reversed conic and a spherical cap, which adheres to it (model III) or with a reversed conic and a half of ellipsoid which adheres to its base (model IV) (fig. 3).

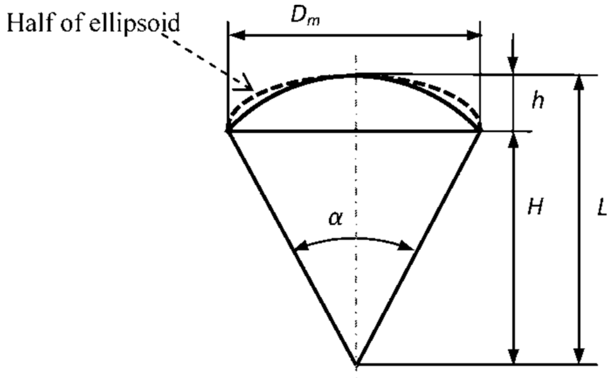


Figure 3. Parameters of sugar beet root model, composed of conic and spherical cap or composed of conic and half of ellipsoid

Evaluation of the usefulness of the suggested models for description of the sugar beet tap root shape was made in the theoretical and empirical analysis of relative errors of approximation determined based on the dimensions of roots obtained from calculations and field research and determined volumes of the model solids of roots.

Table 1
Geometrical formulas for the volume of analyzed geometric solids that form the model of the tap-root of sugar beet

Destination of the tap-root model	Geometric model of the tap-root	Formula for the volume of the conic part of the tap-root	Formula for the volume of the bulb root	Formula for the volume of the tap-root
I	Spherical sector	–	–	$V_c = \frac{2}{3}\Pi h L^2$
II	Conic and half of sphere		$V_g = \frac{2\Pi}{3}h^3$	$V_c = \frac{\Pi}{3}\left(\frac{D_m^2}{4}H + 2h^3\right)$
III	Conic and spherical cap	$V_s = \frac{\Pi}{12}D_m^2 H$	$V_g = \frac{\Pi}{6}h\left(\frac{3}{4}D_m^2 + h^2\right)$	$V_c = \frac{\Pi}{6}\left[\frac{D_m^2}{2}H + h\left(\frac{3}{4}D_m^2 + h^2\right)\right]$
IV	Conic and half of ellipsoid		$V_g = \frac{\Pi}{6}D_m^2 h$	$V_c = \frac{\Pi}{6}D_m^2\left(\frac{H}{2} + h\right)$

As a measure of accuracy, a relative error e_r (w %) of compliance of the root head radius $\frac{D_m}{2}$ and its height h, calculated from formula1:

$$e_r = \left(\frac{D_m}{2} - h\right) 2D_m^{-1} \cdot 100 \tag{1}$$

and a relative error e_D (w %) of compliance of the bulb root diameter obtained from calculations $D_{m,obl.}$ and diameter obtained from empirical tests D_m, calculated from formula 2:

$$e_D = \left(\frac{D_{m,obl.} - D_m}{2}\right) 2D_{m,obl.}^{-1} \cdot 100 \tag{2}$$

A diameter of the bulb root $D_{m,obl.}$, required for calculation 2, was calculated from formula 3 for the spherical sector:

$$D_{m,obl.} = 2\sqrt{(2L - h)h} \tag{3}$$

Parameters h, L and D_m indispensable for validation researches were determined in the research of a 3-year field experiment carried out in light soils – LS loamy sand (acc. to the FAO classification), with a method of random blocks, in four repeats of blocks (I-IV), for traditional technology of sugar beet – Sonia variety cultivation. Sugar beets were cultivated in rows with 0.45 m spacing and distance in the row of 0.18 m. The analysed parameters of roots were measured during harvesting after the removal of leaves with a special measuring device. Results presented in table 2 constitute average values from measurements of 10 roots which were selected at random, made in each block.

Table 2
Results of calculation and empirical investigation of tap-root parameters of sugar beet

Year of investigation	Repetition of empirical research block	Root dimensions (cm) (m)				Relative error e_r, (%)	$\frac{D_{m,obl}}{2}$ [cm]	Relative error e_D, (%)
		D_m	h	H	L			
1	I	10.70	3.33	17.08	20.41	37.8	11.1	70.2
	II	10.40	2.91	17.29	20.20	44.0	10.4	72.2
	III	10.16	2.91	16.58	19.49	43.2	10.2	71.6
	IV	10.50	3.45	17.75	21.20	34.3	11.6	70.2
2	I	11.06	3.91	19.91	23.82	29.3	13.1	70
	II	10.60	3.62	19.49	23.11	31.7	12.4	70.9
	III	11.40	3.88	19.49	23.37	31.9	12.9	69.9
	IV	10.8	3.24	17.95	21.19	40.0	11.3	71.2
3	I	8.16	4.07	24.91	28.98	1.0	14.8	72.5
	II	8.26	4.07	21.79	25.86	1.4	13.9	70.1
	III	8.86	4.13	21.54	25.67	1.5	14.0	70.2
	IV	10.04	3.96	23.84	27.80	21.1	14.3	72.3

Table 2 includes determined values of relative errors e_r and e_D. Whereas, a volume of geometric solids for the analysed models of a root, calculated from formulas presented in table 1, were presented in table 3.

Results of research and their analysis

A lower part of a root was described based on only two parameters D_m and H with the use of a conic, which is compliant to the requirement set forth in literature, that the shape of this part of a root should be conic (an oval shape is assigned to a fodder beet) (Byszewski, 1979; Ostrowska and Artyszak, 2005).

Table 3
Volumes of sugar beet tap-root (in cm^3), calculated from the analyzed geometric formulas

Year of investigation	Research block	Volume of conic shape of tap-root V_s	Model			
			I V_c	II V_c/V_g	III V_c/V_g	IV V_c/V_g
1	I	511.8	2903.8	832.3/320.5	741.5/229.7	711.3/199.5
	II	489.3	2485.6	783.6/294.3	625.7/136.4	654.0/164.7
	III	447.8	2313.9	722.2/274.4	578.6/130.8	605.0/157.2
	IV	512.1	3245.8	815.0/302.9	674.3/162.2	711.2/199.0
2	I	637.3	4644.1	991.3/354.0	844.3/207.0	887.6/250.3
	II	573.0	4047.1	884.6/311.6	757.4/184.4	802.9/229.9
	III	662.8	4435.9	1050.5/387.7	891.3/228.5	926.7/263.9
	IV	547.8	3045.4	877.4/329.6	730.1/182.3	745.6/197.7
3	I	423.4	7155.3	560.4/137.0	562.5/139.1	561.8/138.4
	II	389.0	5697.6	536.5/147.5	532.0/143.0	534.3/145.3
	III	442.4	5696.9	624.4/182.0	606.5/164.1	612.1/169.7
	IV	628.8	6406.5	893.6/264.8	847.6/218.8	837.7/208.9

V_c – volume of tap root
V_g – volume of bulb root

Selected models for imaging the bulb root in the form of a spherical cap, half of a sphere and a half of an ellipsoid. Assessment of precision of models was made for subsequent years of research, which characterize with a considerable variability of the root dimensions. In order to extend the assessment of the usefulness of models, the analysis included diversity of dimensions of roots which occurs in repeats of the field research in blocks. Results of the three-year research included in table 2 show that the ratio of the bulb root height h to its radius of the base is varied, which justifies why various geometric solids for description of the bulb shape were accepted for analysis. In the 3rd year of research (table 2: block I, II and III) the radius and height of the root head are very similar (a determined relative error is lower than 1.5%), whereas in the 1st and 2 nd year of research differences in these parameters are even more than 30%. Moreover, the data presented in table 2 show that in each year of three-year research, the beet head height was lower or at least equal to its base radius, which justifies acceptance of the suggested halves of geometric solids for imaging the root head shape.

In the assessment of model I, it was assumed that the compliance of the empirically determined sugar beet diameter D_m and diameter $D_{m,obl.}$ (table 2) calculated based on parameters L and h of a root (where $L=R;\ R=H+h$) from the formula 3 may decide on the usefulness of the suggested geometric solid in the form of a spherical sector for imaging of the tap-root. A relative error calculated from formula 2 was the basis of analysis. The data presented in this table (col. 3, 8 and 9) prove that the spherical sector very weakly describes the sugar beet root. Differences in the calculated and empirically determined diameter of a beetroot are highly non-compliant, burdened with a relative error which is more than 70%. Moreover, the calculated volume of a root (table 3) decisively diverges from the one calculated for other models. These analyses show clearly that the spherical sector is not useful in imaging the tap-root shape.

In the assessment of model II of the root, verification was carried out which aimed at determination whether a half of a sphere may describe the bulb root, i.e. whether the sugar beet bulb height is similar to the radius of its base $h \approx ½\, D_m$. The analysis of the calculated relative error (table 2, column 7) shows that only in the recent year of research, a quite high compliance of two empirically determined parameters occurs h and $½\, D_m$ (table 2, col. 3 and 4), thus a description of the bulb root with a sphere may be accepted.

In the case of considerable differences of the head height and its radius (table 2: year 1 and 2 of the research, col. 3 and 4) for description of the bulb root, the usefulness of the spherical cap or a half of ellipsoid was considered (table 1: model III and IV). The data included in table 3 (col. 6 and 7) show that differences in the volume of the bulb root calculated with formulas for a spherical cap and a half of an ellipsoid are higher if the bulb root height and a diameter are different, i.e. when the bulb root is more flattened, which can be observed particularly in the 1st and 2nd year of research (table 2, col. 3 and 4). It should be assumed that higher reported values of the calculated half of an ellipsoid are more justified because they result from better approximation of the ellipsoid surface to the bulb root in the place of its highest diameter. Since, the beetroot surface is more rounded in this place than the angular, imaged spherical cap (fig. 3). Description of the root head with a half of an ellipsoid may be improved even by 20% with reference to a spherical cap (tab. 2), which results from the differences of the calculated values of volume for both figures. It may be assumed, within assumptions of this paper, that the suggested simplified model of a root made of a conic and a half of an ellipsoid (model IV) from among the analysed ones, provides the best image of the sugar beet root shape. Model IV replaces also model II when the values D_m and h get close and the shape of a half of an ellipsoid changes into a half of a sphere.

Obtaining models of the sugar beet roots with higher precision makes additional scientific work necessary based on more detailed experimental measurement of the shape and volume. However, for realization of many practical, teaching and general engineering objectives, lower precision of assessment obtained with considerably lower costs of research and analysis may be sufficient.

Conclusion

The paper analysed the sugar beet roots models in the form of one geometrical solid – a spherical sector or comprising two geometrical solids, where a bottom part of the root is imaged by a reversed conic and the head is alternative presented in the form of: a spherical cap, a half of a sphere or a half of ellipsoid. It was assumed that the pointed-conical or wedged shape of the bottom part of the sugar beet root, required on account of technological reasons, should describe a conic. Accepting halves of the suggested geometrical solids for imaging the rood head shape justify results of the root dimensions from a three-year research, which show that the beet head height is lower or at least equal to its radius of the base. The comparative analysis of parameters of the geometrical figures and their values, which were empirically determined, showed within the assumptions of the paper that the spherical sector does not sufficiently describe the shape of the tap-root of sugar beet. The root shape may be described with the use of a model comprising a conic and a half of an ellipsoid which adheres to its base.

For issues which require higher precision of the sugar beet models, further research and analyses carried out based on detailed experimental measurements of the shape parameters and root volume are recommended.

References

Błaszkiewicz, Z.; Kuchenbuch, R.O.; Grzebisz, W. (2003). Badania systemu korzeniowego roślin uprawnych z wykorzystaniem programu komputerowego R.M.S. 2.0.0. *Inżynieria Rolnicza, 12*(54), 15-22.

Byszewski, W. (1979). *Biologia buraka cukrowego*. Warszawa, PWN.

Dieckmann, J.; Miller, H.; Koch, H. J. (2006). Beet growth and soil structure-results from a long term on-farm joint research project (in German). *Sugar Ind. 131*, 642-654.

Gajewnik, B. (2013). *Wybrane aspekty oceny wartości technologicznej buraków cukrowych. Instytut Biotechnologii Przemysłu Rolno-Spożywczego*. Warszawa, Pozyskano z: www.ibprs.pl.

Guerif, J.; Richard, G.; Durr, C.; Boizard, H.; Duvall, Y. (1986). Soil compaction and sugar beet root growth and distribution. *Comptes-Rendes-des Congres de L`Institut International de Recherches Betteravieres*. Belgium, *Vol. 59*, 199-212.

Gutmański, I. (1991). *Produkcja buraka cukrowego*. Warszawa, PWRiL, 704.

Hanse, B.; Vermeulen, G.D.; Tijink, F.G.J.; Koch, H. J.; Marlander, B. (2011). Analysis of soil characteristics, soil management and sugar yield on top and averagely managed farms growing sugar beet (Beta vulgaris L.) in the Netherlands. *Soil & Tillage Research*, *117*, 61-68.

Hoffmann, C.; Jungk, A. (1996). Influence of soil temperature and soil compaction on growth and P uptake of sugar beet. *Z. Pflanzenernähr. Bodenk. 159*, 263-270.

Koch, H. J.; Heuer, H.; Tomanova, O.; Marlander, B. (2008). Cumulative effect of annually repeated passes of heavy agricultural machinery on soil structural properties and sugar beet yield under two tillage systems. *Soil & Tillage Research*, *101*, 69-77.

Karwowski, T. (1982). *Teoria i konstrukcja maszyn rolniczych. Maszyny do zbioru ziemniaków i buraków*. Warszawa, PWRiL, T. 2, Cz. II.

Krause, U.; Koch, H. J.; Maerlaender, B. (2009). Soil properties effecting yield formation in sugar beet under ridge and flat cultivation. *Europ. J. Agronomy, 31*, 20-28.

Lipiec, J.; Horn, R.; Pietrusiewicz, J.; Siczek, A. (2012). Effects of soil compaction on root elongation and anatomy of different cereal plant species. *Soil & Tillage Research, 121,* 74-81.

Ostrowska, D.; Artyszak, A. (2005). Technologia produkcji buraka cukrowego. *Wieś Jutra,* Warszawa.

Ostrowska, D.; Kucińska, K.; Artyszak, A. (2002). Wpływ wielkości masy korzenia buraka cukrowego na wartość technologiczną surowca. *Biul. IHAR, 222*, 149-154.

Przybył, J. (1998). Wpływ technologii uprawy gleby i siewu na jakość plonu buraków cukrowych. *Zesz. Probl. Post. Nauk Roln. 454*(1), 185-191.

Schlinker, G.; Sander, G.; Decker, M.; Kremer-Schillings, W.; Bürcky, K.; Koch, H.J. (2007). Ridge cultivation of sugarbeet-recent experiences and experimental results from Germany (in German). *Sugar Industry, 132,* 920-924.

Scott, R.K.; English, S.D.; Wood, D.W.; Unsworth, M.H. (1973). The yield of sugar beet in relation to weather and length of growing season. *J. Agric. Sci. 81*, 339-347.

Sztukowski, P.; Błaszkiewicz, Z. (2002). Badania zagęszczenia i oporu penetracji gleby w wybranych technologiach uprawy buraka cukrowego. *Biulletin Of Plant Breeding And Aclimatization Institute, 222*, 303-308.

Tomanova, O.; Stockfisch, N.; Koch, H.J. (2006). Impact of continuous ploughless tillage on growth and nutrient supply of sugarbeet during the growing season (in German). *German J. Agron. 10*, 16-25.

UPROSZCZONE WYZNACZANIE KSZTAŁTU KORZENIA PALOWEGO BURAKA CUKROWEGO

Streszczenie. W pracy przedstawiono rezultaty teoretyczno-empirycznej analizy przydatności wybranych modeli geometrycznych do opisu kształtu korzenia palowego buraka cukrowego, wyznaczanych w oparciu o dostępne wymiary korzenia: średnicę i jego długość oraz wysokość główki. Analizowano cztery modele w postaci: wycinka kuli, złożonego ze stożka i połowy kuli, stożka i czaszy kulistej oraz ze stożka i połowy elipsoidy. Wykazano, w zakresie założeń pracy, że stożkowy korzeń palowy może być opisany za pomocą uproszczonego modelu złożonego ze stożka i opartej na jego podstawie połowy elipsoidy.

Słowa kluczowe: burak cukrowy, korzeń palowy, kształt, model geometryczny

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):25-34

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.103

SPECIFIC MECHANICAL ENERGY CONSUMPTION OF EXTRUSION--COOKING OF WHEAT FOAMED PACKAGING MATERIALS

Maciej Combrzyński*, Agnieszka Wójtowicz, Magdalena Klimek, Leszek Mościcki, Tomasz Oniszczuk, Stanisław Juśko

Department of Food Process Engineering, University of Life Sciences in Lublin
*Contact details: ul. Doświadczalna 44, 20-280 Lublin, e-mail: maciej.combrzynski@up.lublin.pl

ARTICLE INFO

Article history:
Received: November 2014
Received in the revised form: December 2014
Accepted: January 2015

Keywords:
foamed material
wheat starch
extrusion-cooking technique
specific mechanical energy consumption
efficiency

ABSTRACT

Extrusion-cooking technique, known from food processing, may be used in production of environmentally friendly foamed materials based on starch. The objective of the paper was to determine the specific mechanical energy consumption of the extrusion-cooking process of foamed materials made of wheat starch at a varied level of moisture of raw materials mixtures and varied participation of foaming components. Functional additives which support the foaming process were applied: PDE foaming agent and polyvinyl alcohol. Specific mechanical energy consumption (SME) was determined according to the moisture content of raw materials and additives used. Energy consumption of the extrusion-cooking process of foamed materials with addition of the foaming agent PDE was increasing along with the increase of moisture and decreased at higher participation of the additive. In case of mixtures with an addition of polyvinyl alcohol the values of SME were getting higher along with the increase of the additive content and moisture of raw materials mixture. The research proved possibility of obtaining starch foamed packaging materials, which may function as a filler in transport packages, at the high efficiency of the process and low energy consumption.

Introduction

Plastics based on petrochemical raw materials, used in the production of packagings are not biodegradable (Borowy and Kubiak, 2008; Żakowska, 2003; 2005). The process of decomposition of plastic may be initialized only as a result of its modification or introduction of additives. Presently, work on the possibility of production of packaging materials, which are environmentally friendly, focuses on searching for alternative raw materials, namely such which both on account of economy and utility will be able to considerably replace synthetic packaging plastics. Available produce, which constitute renewable natural materials, may be used for production of biopolymers (Mościcki, 2008; Roper and Koch, 1990). From among natural raw materials, starch is more frequently used in the research as a renewable organic material. Availability, prices and possibility of complete degradation weigh in its favour. The end of the 20th century is a period of fast increase of the research on new biodegradable plastics and new manufacturing technologies. The extrusion-cooking technique is one of them. It has been linked to the food production so far (Mościcki et al., 2007; Oniszczuk et al., 2012).

Extrusion-cooking of plant raw materials is a process of material processing under high pressure and at high temperature (Mościcki and Mitrus, 2004; Mościcki et al., 2006; Mościcki et al., 2007, Oniszczuk et al., 2006). Significant physical and chemical changes, and thus quality changes take place during thermal and mechanical treatment. Suitably selected parameters of the extrusion-cooking process allow shaping physical, chemical and functional properties of the processed materials.

Foamed materials constitute a group of packagings, which are used mainly in transport of products~~,~~ susceptible to mechanical damages (Bhatnagar and Milford, 1996; Pushpadass et al., 2008). Most frequently produced from plastics constitute an ecological problem in utilization. However, research on the possibility of using starch in production of this type of materials has been carried out. Foamed starch may be obtained with the extrusion-cooking method when a foaming agent is introduced to the gelatinized starch, e.g. water (Sivertsen, 2007; Zhang and Xiuzhi, 2007). Foaming agents allow obtaining air bubbles in a structure. However, nowadays it is difficult to produce foamed materials based on starch with properties similar to synthetic materials (Janssen and Mościcki, 2009; Rejak and Mościcki, 2006).

Materials and methods

The use of various raw materials' mixtures and a varied level of moistening were used to evaluate how efficiency and specific mechanical energy consumption of the extrusion-cooking process of foamed starch packaging materials are changing. During the preliminary research, the impact of mixtures' moisture content on the extrusion-cooking process and the quality of the produced extrudates was reported (fig. 1). Based on the initial measurements, values of 17, 18 and 19% of moisture content were set.

Figure 1. Foamed starch materials produced in the Department of Food Process Engineering

In order to improve the foaming effect, additives in the form of foaming agents: Plastronfoam PDE agent and polyvinyl alcohol (AP) in the amount from 1% to 3%, were used. In the extrusion-cooking process a single-screw extruder-cooker TS-45 o L/D=12 was used (fig. 2). The following range of temperatures in particular sections of an extruder-cooker was applied: 80ºC the first section, 140ºC second section, 120ºC a head and the rotational speed of the extruder-cooker screw 2.16 s^{-1}, which was determined with the use of a tachometer DT-2234 B. The forming die diameter was 3 mm. During the extrusion-cooking the engine load and process efficiency were recorded. The recorded data allowed calculation of specific mechanical energy consumption of the extrusion-cooking process.

Figure 2. Single-screw extruder-cooker TS-45 with L/D=12

Efficiency was calculated according to the formula:

$$Q \equiv \frac{m}{t} (kg \cdot h^{-1}) \tag{1}$$

where:

Q – process efficiency, ($kg \cdot h^{-1}$)
m – mass of extrudate obtained in the measurement, (kg)
t – time of measurement, (h)

Energy consumption was determined with the use of specific mechanical energy consumption (SME) acc. to the formula provided by Ryu and Ng (2001):

$$SME = \frac{n}{n_m} \cdot \frac{O}{100} \cdot \frac{P}{Q} (kWh \cdot kg^{-1}) \tag{2}$$

where:

SME – specific mechanical energy consumption, ($kWh \cdot kg^{-1}$)
n – screw rotations, (s^{-1})
n_m – screw rating rotations, (s^{-1})

O – the engine load in comparison to the maximum, (%)
P – rated power, (kW)
Q – process efficiency, ($kg \cdot h^{-1}$)

The process efficiency was measured in 5 replications assuming an average value as a final result. The results which were obtained during tests were analyzed with the use of ~~a~~ Statistica 6.0 software. The analysis of the response surface methodology with the use of the distance weighted least squares, was applied. Moreover, polynomial regression and determination coefficients were determined.

Results and discussion

The extrusion-cooking process of wheat starch with additive of the foaming agent PDE was characterized with the process efficiency, that is, the amount of the obtained extrudate in the amount of 27.6 $kg \cdot h^{-1}$ to 34.8 $kg \cdot h^{-1}$ in relation to the applied parameters. Changes in efficiency depended on the raw materials' moisture and the content of the functional additive.

The results proved that the increase of the raw materials' moisture with an addition of the foaming agent PDE caused the decrease of the extrusion-cooking process efficiency (fig. 3). This effect was reported in the entire range of the additive use. In case of processing of the raw materials mixtures without PDE agent, a reverse relation was reported, the increase of moisture resulted in the increase of efficiency. Similar relation was presented by Mitrus and Combrzyński (2013) during extrusion-cooking of maize starch.

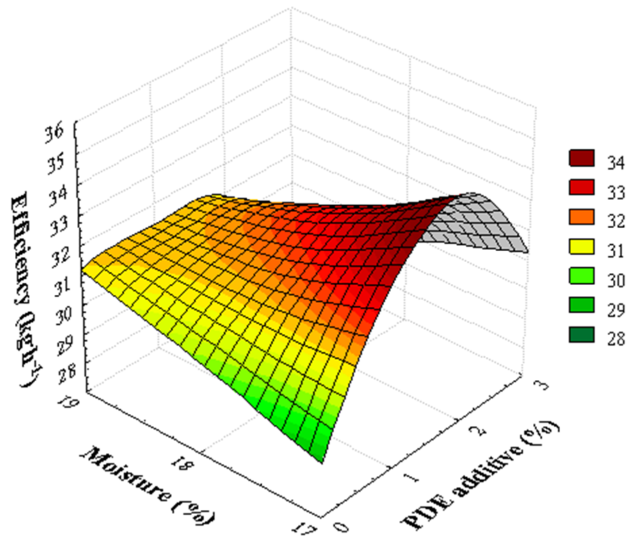


Figure 3. Process efficiency of wheat extrudates with varied addition of the PDE foaming agent

The lowest efficiency of 27.6 kg·h^{-1} was recorded for the raw materials' mixture with 19% of moisture and including 3% of PDE. The highest efficiency was observed during processing of a mixture with 17% of moisture content and 2% of the PDE agent. Increase of the amount of the foaming substance from 2% to 3% caused a considerable decrease of efficiency and disturbance of the wheat starch extrusion-cooking process, which may be proved by negative values of directional coefficients of regression equations (table 1).

The extrusion-cooking of wheat starch with addition of the PDE foaming agent characterized with a very low specific mechanical energy consumption (SME) within 0.073-0.088 kWh·kg^{-1}. The SME values depended equally on–the raw materials' moisture content and the amount of the foaming agent (fig. 4). Along with the increase of the foaming additive participation in the mixture, decrease of the SME value was reported, which may be also observed in the results presented by Mitrus' (2005), where the increase of glycerine additive decreased the SME value of potato starch extrusion-cooking. High values of determination coefficients (0.939-0.985) prove the impact of the PDE additive on the specific mechanical energy consumption (table 1). The opposite relation was observed – the increase of raw materials' moisture increased the SME. The lowest value, which was 0.073 kWh·kg^{-1}, was observed during processing of a mixture with 17% of moisture and at 3% of the foaming agent addition. The highest energy consumption (0.088 kWh·kg^{-1}) was calculated during extrusion-cooking of the mixture with 19% of moisture and 1% of the PDE content.

In case of extrusion-cooking of starch which does not include a functional additive, the SME value increased along with the increase of moisture. Values of the specific mechanical energy consumption were within 0.087-0.099 kWh·kg^{-1}.

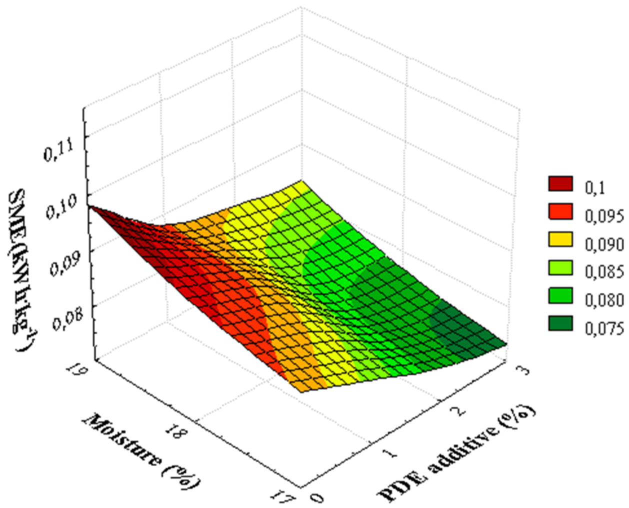


Figure 4. Specific mechanical energy consumption of wheat extrudates with varied addition of the PDE foaming agent

During the extrusion-cooking process of the wheat starch with an addition of the foaming agent in the form of polyvinyl alcohol also similar process efficiency within 28.4-32.2 kg·h^{-1} was reported. The values depended mainly on the raw materials' moisture.

The research showed that along with the increase of raw materials' moisture the efficiency of the extrusion-cooking process increased (fig. 5). This effect was reported in the entire range of the applied additive, as well as in the case of extrusion-cooking of starch without a foaming agent. The lowest efficiency of 28.4 kg·h^{-1} was recorded for the mixture with 17% of moisture and including 3% of the PDE agent. The highest efficiency, (32.4 kg·h^{-1}) was reported for the mixture with 19% of moisture and 2% of the functional additive content. During the analysis of the amount of polyvinyl alcohol, a tendency to decrease the process efficiency at the increasing participation of the additive in a recipe was observed. However, values of determination coefficients were not high (table 1).

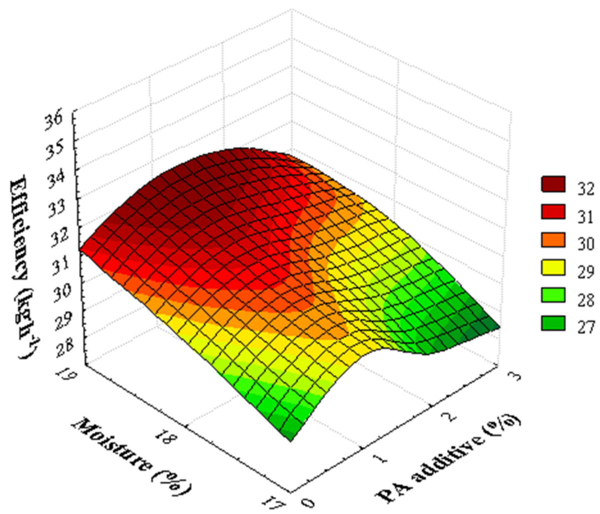


Figure 5. Process efficiency of wheat extrudates with a varied addition of polyvinyl alcohol

The extrusion-cooking process of wheat starch with addition of the foaming agent in the form of polyvinyl alcohol characterized with a higher energy consumption (SME) than in case of the PDE additive. Values within 0.090-0.109 kWh·kg^{-1} were reported. SME values depended on both, the raw material mixture moisture as well as the foaming agent content (fig.4). Along with the increase of polyvinyl alcohol participation in the mixture, the increase of the SME value was reported. A similar relation was noted for the increasing moisture level of raw materials' mixtures. Su (2007) observed a reversed relation, i.e. the SME value decreased during rice flour extrusion-cooking with addition of powdered eggs (the process was carried out with a twin-screw extruder).

The lowest value, which was 0.090 kWh·kg^{-1}, was observed for mixture with moisture of 17% and at 1% of the foaming agent addition. The highest specific mechanical energy consumption (0.109 kWh·kg^{-1}) was noted in case of processing of the mixture with 18% of moisture and 3% of the polyvinyl alcohol content. The increase of the SME and decrease of efficiency during extrusion-cooking of the foamed starch with addition of polyvinyl alcohol could be related to chemical characteristics of the additive, which is defined by the decomposition temperature exceeding 200ºC, whereas for PDE the decomposition temperature was determined as 140ºC (a product data sheet). Too low temperature than the one required for processing of polyvinyl alcohol could influence the change of mass properties in the cylinder of an extruder-cooker and cause impeded flow of material, which was reflected in lower values of the process efficiency and the increase of the specific mechanical energy consumption at the use of 2-3% of the PA additive. This phenomenon was not observed at the use of the PDE additive.

In case of extrusion-cooking of mixtures which do not include a functional additive, the SME values increased along with the increase of moisture. Values of specific mechanical energy consumption of the process were within 0.087-0.099 kWh·kg^{-1}. In the tests carried out by Ruis-Ruiz et al. (2008) a reverse relation was reported where along with the increase of the raw material moisture, the SME value decreased (mixture of corn flour and white beans was subjected to the extrusion-cooking process). For all tested foamed materials produced with addition of polyvinyl alcohol, high values of determination coefficients were obtained (0.793-0.916). They proved a significant impact of the amount of the additive used on the specific mechanical energy consumption during the extrusion-cooking (table 1).

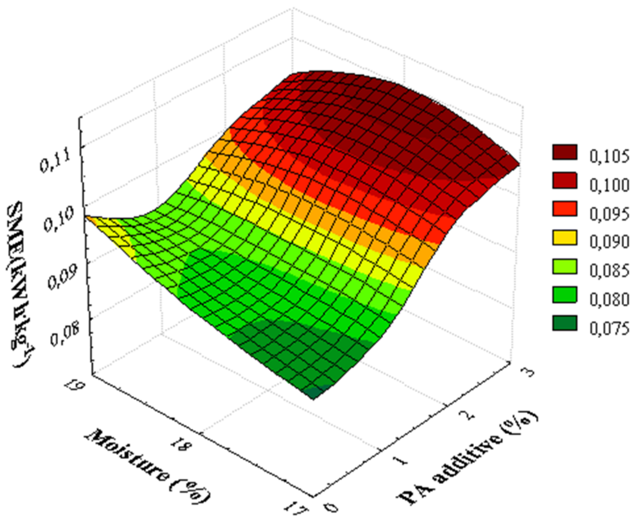


Figure 6. Specific mechanical energy consumption of wheat extrudates with a varied addition of polyvinyl alcohol

Table 1
Second degree equations of regression describing~~e~~ the changes in the efficiency and specific mechanical energy consumption of the extrusion-cooking process in relation to moisture and the amount of the additive used

	Additive	Moisture (%)	Regression equation	R^2
Efficiency	PDE	17	$y = -2.04x^2 + 11.064x + 19.68$	0.991
		18	$y = -1.02x^2 + 5.028x + 26.1$	0.923
		19	$y = -0.84x^2 + 3.096x + 28.8$	0.955
	Polyvinyl alcohol	17	$y = -0.51x^2 + 2.274x + 27.27$	0.564
		18	$y = -0.3x^2 + 1.428x + 29.22$	0.623
		19	$y = -0.66x^2 + 3.132x + 28.74$	0.998
SME	PDE	17	$y = 0.0007x^2 - 0.0084x + 0.0954$	0.985
		18	$y = 0.0008x^2 - 0.0092x + 0.0998$	0.939
		19	$y = 0.0022x^2 - 0.0163x + 0.1127$	0.983
	Polyvinyl alcohol	17	$y = -0.0003x^2 + 0.0082x + 0.0784$	0.893
		18	$y = 0.0009x^2 + 0.0023x + 0.0865$	0.916
		19	$y = 0.003x^2 - 0.0125x + 0.1076$	0.793

Conclusions

1. As a result of increasing moisture of raw materials' mixtures, efficiency and specific mechanical energy consumption of the extrusion-cooking process of foamed materials with no foaming agents increased.
2. The increase of moisture content of raw materials with addition of the PDE foaming agent influenced the decrease of the process efficiency and caused the increase of specific mechanical energy consumption. Along with the increased amount of additive, efficiency and SME decreased.
3. Higher amount of polyvinyl alcohol, influenced higher SME whereas process efficiency dropped. Increase of moisture of raw materials' mixtures with addition of PA influenced the increase of specific mechanical energy consumption.
4. The research showed the possibility of obtaining environmentally friendly foamed packaging materials with high efficiency and low SME of the process. These extrudates, which include the foaming agent PDE and polyvinyl alcohol, may function as fillers in transport packagings.

References

Bhatnagar, S.; Milford, A. H. (1996). Starch-Based Plastic Foams From Various Starch Sources. *Cereal Chemistry*, *5*(73), 601-604.

Borowy, T.; Kubiak, M. S. (2008). Opakowania biodegradowalne alternatywą dla opakowań z tworzyw sztucznych. *Gospodarka Mięsna*, *5*, 18-20.

Janssen, L.P.B.M.; Mościcki, L. (red.) (2009). *Thermoplastic Starch*. Weinheim, Wiley-VCH Verlag GmbH & Co. KGaA., ISBN: 9783527628223.

Mitrus, M. (2005). Changes of specific mechanical energy during extrusion cooking of thermoplastic starch. *TEKA Commission of Motorization and Energetics in Agriculture*, *5,* 152-157.

Mitrus, M.; Combrzyński M. (2013). Energy consumption during corn starch extrusion-cooking. *TEKA Commission of Motorization and Energetics in Agriculture*, *2,* 63-66.

Mościcki, L. (2008). Opakowania biodegradowalne. *Przegląd Zbożowo-Młynarski*, *1*, 28-29.

Mościcki, L. Janssen, L. P. B. M.; Mitrus, M. (2006). Przetwórstwo skrobi termoplastycznej na cele opakowaniowe. *Inżynieria Rolnicza*, *6*(81), 65-72.

Mościcki, L.; Mitrus, M. (2004). Biodegradowalne biopolimery: materiały opakowaniowe. *Inżynieria Rolnicza*, *5*(60), 215-221.

Mościcki, L.; Mitrus, M.; Wójtowicz, A. (2007). *Technika ekstruzji w przemyśle rolno – spożywczym.* Warszawa, PWRiL, ISBN: 9788309010272.

Oniszczuk, T.; Janssen, L. P. B. M.; Mościcki, L. (2006). Wpływ dodatku włókien naturalnych na wybrane właściwości mechaniczne wyprasek biopolimerowych. *Inżynieria Rolnicza, 6*(81), 101-107.

Oniszczuk, T.; Wójtowicz, A.; Mitrus, M.; Mościcki, L.; Combrzyński, M.; Rejak, A.; Gładyszewska, B. (2012). Biodegradation of TPS mouldings enriched with natural fillers. *TEKA Commission of Motorization and Energetics in Agriculture*, *1,*175-180.

Pushpadass, H. A.; Suresh, Babu, S. G.; Weber, R. W.; Milford, A. H. (2008). Extrusion of Starch-based Loose-fill Packaging Foams: Effects of Temperature, Moisture and Talc on Physical Properties. *Packaging Technology and Science*, *21*, 171-183.

Rejak, A.; Mościcki, L. (2006). Biodegradable foil extruded from thermoplastic starch. *TEKA Commision of Motorization and Power Industry in Agriculture*, *6*, 123-130.

Roper, H.; Koch, H. (1990). The role of starch in biodegradable thermoplastic materials. *Starch*, *4,* 42, 123-140.

Ruiz-Ruiz, J.; Martínez-Ayala, A.; Drago, S.; González, R.; Betancur-Ancona, D.; Chel-Guerrero, L. (2008). Extrusion of a hard-to-cook bean (*Phaselous vulgaris* L.) and quality protein maize (*Zea mays* L.) flour blend. *Food Science and* Technology, *41,*1799-1807.

Ryu, G. H.; Ng, P.L. (2001). Effect of selected process parameters on expansion and mechanical properties of wheat flour and whole cornmeal extrudates. *Starch*, *3-4*, 53, 147-154.

Sivertsen, K. (2007). Polymer foams. *3.063 Polymer Physics,1-17.*

Su, Ch.W. (2007). Effects of eggshell powder addition on the extrusion behaviour of rice. *Journal of Food Engineering*, *79* 607-612.

Zhang, J. F.; Xiuzhi, S. (2007). Biodegradable Foams of Poly(lactic acid)/Starch. I. Extrusion Condition and Cellular Size Distribution. *Journal of Applied Polymer Science,* DOI 10.1002/app, 857-862.

Żakowska, H. (2003). Mechanizm biodegradacji. *Opakowania biodegradowalne*, Warszawa Wyd. Centralny Ośrodek Badawczo-Rozwojowy opakowań, 17-20.

Żakowska, H. (2005). *Biodegradacja. Recykling odpadów opakowaniowych*, Warszawa, Wyd. Centralny Ośrodek Badawczo-Rozwojowy Opakowań, 53-54.

ENERGOCHŁONNOŚĆ EKSTRUZJI PSZENNYCH SPIENIONYCH MATERIAŁÓW OPAKOWANIOWYCH

Streszczenie. Technika ekstruzji, znana z przetwórstwa spożywczego, może być stosowana w produkcji przyjaznych dla środowiska materiałów spienionych opartych na skrobi. Celem pracy było określenie energochłonności procesu ekstruzji materiałów spienionych, wytworzonych ze skrobi pszennej przy różnej wilgotności mieszanek surowcowych i różnym udziale komponentów spieniających. Stosowano dodatki funkcjonalne wspomagające proces spieniania: środek spieniający PDE oraz alkohol poliwinylowy. Energochłonność wyznaczano, wykorzystując wskaźnik jednostkowego zapotrzebowania energii mechanicznej (SME). Energochłonność procesu ekstruzji materiałów spienionych z dodatkiem środka spieniającego PDE zwiększała się wraz ze wzrostem wilgotności i obniżała przy większym udziale dodatku. W przypadku mieszanek z dodatkiem alkoholu poliwinylowego wartości SME były wyższe wraz ze wzrostem zawartości dodatku i wilgotności mieszanki surowcowej. Badania wykazały możliwość uzyskania skrobiowych spienionych materiałów opakowaniowych, które mogą pełnić rolę wypełniacza w opakowaniach transportowych, przy wysokiej wydajności procesu oraz niewielkiej energochłonności.

Słowa kluczowe: materiał spieniony, skrobia pszenna, ekstruzja, energochłonność, wydajność

Scientific quarterly journal e-ISNN 2449-5999
Agricultural Engineering
2015: 1(153):35-45
Homepage: http://ir.ptir.org
DOI: http://dx.medra.org/10.14654/ir.2015.153.104

A MODERN METHOD OF OBTAINING ORGANIC SEEDS OF ONION AND RADISH

Marek Domoradzki*, Jacek Szymura, Jan Lamkiewicz, Joanna Kaniewska

Department of Technology and Chemical and Food Industry Apparatus
University of Technology and Life Sciences in Bydgoszcz
**Contact details: ul. Seminaryjna 3, 85-326 Bydgoszcz, e-mail: mdomoradzki@gmail.com*

ARTICLE INFO

Article history:
Received: November 2014
Received in the revised form: January 2015
Accepted: February 2015

Keywords:
organic seeds
seed technology
radish seed
onion seed

ABSTRACT

The paper presents the results of obtaining radish and onion seed on an organic farm and the results of processing seeds after harvesting. The proposed technology of seeds preparation for sowing involves processes of hydraulic separation, washing and leaching, drying, calibration, inoculation and coating. Plants were protected with preparations authorized for organic farming. Obtained organic seed material is consistent with current quality requirements.

Introduction

European Union, which prefers forms of sustainable development of food production, puts pressure on a traditional form of farming in rural areas, funding research and subsidizing production of organic food. Organic food is produced in organic farms with natural methods without the use of chemical crop protection substances and fertilizers. Protection of plantation consists in the use of crop rotation and physical and mechanical methods of crop protection. As a result of such approach to agricultural production, we protect environment and ensure maintenance of correct soil structure and fertility.

Green fertilizers, compost, manure and liming are used in fertilization. The remaining requirements have been included in the Regulation of the Council of Ministers of the European Community no. 834/2007. Crop protection chemicals are virtually banned, except for some natural preparations.

Seeds for organic production must come from organic seed plantations. Thus seed cultivation in chemically unprotected farms is necessary.

Vegetable seeds from commodity plantations must meet requirements for the seed material. This postulate is executed with a method of seed treatment with crop protection chemicals. A current technology of seed extraction comes down to several preventive sprayings of a seed plantation with seed plants crop protection substances, mechanical harvesting of seeds, cleaning of contaminations through sifting and winnowing.

Obtaining seeds from an organic plantation without the use of chemicals is impossible with this method. Two issues need to be solved; the first one concerns preparation of seeds for sowing in order to obtain healthy plants; the second problem relates to decontamination and purifying of the seed crop. The basis for ensuring a high quality of vegetables, which come from organic crops, are healthy seeds with high germination ability.

A need to develop procedures and new technologies for both harvesting as well as preparation of seeds for sowing in organic farms emerged. The state controls the production and economic turnover of organic products. (Act on Organic Agriculture Journal of Laws 116, item 975 as of 26th June 2009, as amended, Journal of Laws, item 55 as of 25th December 2014).

For particular varieties of vegetables, methods of seeds preparation for sowing and after-harvest procedure of seeds processing in order to obtain a high quality of the sowing material should be developed (Domoradzki et al., 2004). Such proceedings as a result come down to developing new operations carried out on seeds and construction of appropriate devices for this purpose (Domoradzki, 2005). These processes are investigated in many countries (Khan, 1992; Parera et al., 1995) and funded in the EU countries.

The objective of the paper

The objective of the paper was to develop procedures for preparing seeds for sowing for an organic plantation and developing an after-harvest organic seeds processing: in case of radish – a one-year plant and in case of onion – a two-year old plant.

For development of procedures and new production methods, the following post-harvest processes of radish and onion seeds processing, which were described by (Domoradzki and Dzieniecki, 2008; Domoradzki, 2011) were selected:

- Classic initial cleaning on screens with windowing of contaminations.
- Hydrostatic separation for onion seeds, which allows removal of a part of a perianth and stems, which contaminate seeds.
- The process of cleaning seeds with water aims at the removal of mineral, microbiological and flotaing contaminations.
- Fast drying after wet operations in order to prevent initialization of germination processes in seeds.
- Seeds calibration on screens in order to select a fraction of the best germinating seeds.

From the pre-sowing seeds processing, a decision was taken to:

- Treat seeds with organic dressings which can be used in organic agriculture.
- Seeds inoculation with fungal spores *Polyversum* and *Trichoderme viryde*
- Seeds coating with peat and mineral materials in order to protect seeds against the attack of pathogens which live in soil, ensuring proper conditions during germination.

The presented proposal of technology aims at obtaining sowing material from organic plantations with quality compliant to seed standards and is subject to experimental verification.

Materials and methods

Radish seeds of Lucynka variety and common onion of Supra variety were used for research. Seeds for sowing on a plantation in an organic farm were prepared by sowing basic seeds from cultivation stations obtained through PNOS [Polish Seed Production, Horticulture and Nursery], in Ożarów Mazowiecki. Seeds for sowing were treated with 1% chitosan relatively to the seeds mass and inoculated with fungal spores in the amount of 10 items per one seed ($1 \cdot 10^6$ $CFU \cdot g^{-1}$) and coated. Detailed methods of seed inoculation and coating were discussed in the paper (Domoradzki, 2011). Plants on the field were protected with Biseptol sprayings.

Experiments were carried out on production fields of organic farms in Kiełpin, Kujawsko-Pomorskie Voivodeship. Experimental cultivations were set on soils belonging to IIIa and IIIb soil classification. Soil reaction was respectfully pH=7.0 and pH=6.6. Low precipitations within 450 mm-550 mm/year, periodical water deficiencies are characteristic for this land. Therefore, sprinkling of experimental fields was maintained. Experimental fields with the area of 200 m^2 were limed and fertilized with a compost

Preparation of seeds for sowing

Initial coating

A layer of peat in the amount of 70 g per 100 g of seeds within 4 hours was placed on seeds in a granulation plate with the use of a 5% dextrin solution (Domoradzki, 2008a). Seeds after coating were dried in a chamber drier with a reversed flow of air (from the top to the bottom) with a maximum temperature of 35ºC. (Domoradzki, 2006)

Seeds coating with fungal spores

Seeds after drying were moistened with water solution of 5% dextrin or 2% polyvinyl alcohol and the peat layer was placed in a granulation plate . The layer was composed of 20 g of peat with fungal spores *Polyversum* and *Trichoderme viride* in the amount of 10 items per one seed. Concentration of spores approximately $1 \cdot 10^6$ $cfu \cdot g^{-1}$. A layer of the dolomite and clay mixture was placed. Seeds after treatment within 4 hours were dried with air in the temperature of 25ºC.

Pot experiments

Numerous experiments, which were to determine the impact of seeds preparation on their germination and growth as well as seedlings health, were carried out. The tests were performed in the climatic chamber of the Department of Phytopathology of the University of Technology and Life Sciences in Bydgoszcz. Experiments were carried out in 5 repeats and one repeat consisted in a pot with 20 seeds. Material for pots consisted in soil from the field in Kiełpin.

Lucynka radish

Table 1

Number and height of radish seedlings in a pot experiment

Facility	1st term of observation			2nd term of observation		
	Average height (mm)	Germination		Average height (mm)	Germination	
		Number of seedlings	(%) for control		Number of seedlings	(%) for control
Control	7.4	84	100.0 a	8.6	94	100.0 a
Polyversum + coat	5.2	46	54.8 b	7.1	61	64.9 b
T. viride + coat	6.4	52	61.9 b	8.1	67	71.3 b
Chitozan + coat	8.3	48	57.1 b	9.7	61	64.9 b
T. viride + chitosan + coat	7.2	50	59.2 b	9.0	64	68.1 b

* the same letters in a column stand for values which do not differ significantly (α=0.05)

Despite generally small differences between particular manners of seeds preparation, a positive impact of 1% chitosan additive on the seeds mass, on an average height of seedlings should be emphasised (table 2). The impact of *Trichoderma viride* on the seedling germination was investigated.

Table 2

Impact of treatment of radish seedlings with preparation which contains gonidia Trichoderma viride and the composition of coat on germinations in the pot experiment

Facility**	Capsule	Number of days after starting the experiment				
		5	6	8	10	13
		Percentage of germinations				
Control	-	72.0 a	77.0 a	80.0 a	80.0 a	80.0 a
Trichoderma viride	-	40.0 b	57.0 ab	65.0 ab	62.0 a	70.0 a
Dust, DX, *Trichoderma viride*	+	3.0 c	30.0 c	50,0 b	60.0 a	65.0 a
Dust, DX, Torf, *Trichoderma viride*	+	45,0 b	62.0 ab	72,0 ab	77.0 a	77.0 a
Dust, APV, *Trichoderma viride*	+	12.0 c	40.0 bc	52.0 b	62.0 a	62.0 a
Dust, APV, Torf, *Trichoderma viride*	+	50.0 ab	67.0 a	82.0 a	82.0 a	85.0 a

* the same letters in a column stand for values which do not differ significantly (α=0.05)

** Dust (peat, dolomite and clay) DX (yellop dextrin), APV (polivynyl alcohol) (+) coated seeds, (-) non-coated seeds

Based on the analysis of results it may be stated that the best results were obtained for the last combination in a table, where in the composition of coat peat and polyvinyl alcohol were used. It is confirmed by the tests on the healthiness of radish seedlings presented in table 3.

Table 3
Impact of treatment of radish seedlings with preparation which contains conidia Trichoderma viride and the composition of coat on germinations in the pot experiment

Facility*	Capsule	Number of germinations of seedlings for 100 seeds	(%) of affected seedlings	IR [fungi infestation ratio of seedlings] W (%)	CFU** on a seed (in a capsule)
Control	-	80	6.2	2.7	-
Trichoderma viride	-	70	7.1	3.4	12.4
Dust, DX, *Trichoderma viride*	+	65	0.0	0.0	24.7
Dust, DX, Muskeg, *Trichoderma viride*	+	77	3.8	1.6	7.9
Dust, APV, *Trichoderma viride*	+	62	4.0	2.2	34.0

* Dust (muskeg, dolomite and clay) DX (yellop dextrin), APV (polivynyl alcohol) (+) coated seeds, (-) non-coated seeds
** CFU – colony forming units

The tests on the impact of the washout treatment on the number of germinations of radish seedlings and their healthiness did not prove any significant differences.

Onion

Table 4 presents the research results on the impact of the washing treatment and onion seeds treatment with a preparation which includes conidia *Trichoderma viride*.

Table 4
The impact of washing and treating onion seeds with preparation which includes conidia Trichoderma viride on the number of seedlings germinations in the pot experiment

Facility	Number of seedlings germinations, (%)	CFU on a seed (in a coat)
Control	93 a	-
Washed	85 ab	-
Washed +coat	77 b	-
Washed, treated *Trichoderma viride* (without a coat)	72 bc	142.9
Washed, treated *Trichoderma viride* + coat	62 c	34.0
Washed, treated *Trichoderma v* + coat+suspension**	58 c	161.9

* values in a column marked with the same letters do not differ significantly (at α=0.05)
** 1% solution of preparation with spores in water

Expected positive impact of the developed combination of onion seeds, including washing treatment on the number of seedlings germinations did not give a higher result than the control sample (table 4).

Field research

Lucynka radish

Experiments on the possibility of obtaining radish seeds in an organic system were carried out in a certified organic farm Kiełpin in a three-year period; they consisted in 5 repeats for 5 combinations. Observations of the growth of plants in a germination stage proved that they were uneven.

Table 5
Germinations of radish seedlings in an organic farm

Facility	% of germinations in relation to control
Control	100.0 a
Chitosan+coat	82.5 b
Chitosan+*T. viride*+coat	77.2 b
T. viride+coat	79.5 b
Polyversum+coat	76.0 b

* the same letters in a column stand for values which do not differ significantly (α=0.05)

Between germination of the coated seeds there were no significant differences during germination. Phytopathologic analysis proved that seedlings from all combinations characterized with good health. Only single plants had symptoms of blights. Plants were developing well. They had favourable weather conditions. Due to a relatively dry and warm vegetation season, diseases did not occur often. The main problem in radish cultivation for seeds constituted pests, which fed before and during flowering.

Based on two-year experiments, it should be stated that radish cultivation for seeds in the organic system, with no zoocide protection is low effective. Collecting insects to traps and using net tunnels is a solution.

Supra onion

Plants in a vegetation period were healthy, regardless the applied biopreparations. In the end of vegetation, pseudo mildew occurred (*Peronospora destructor*). Its intensity was not significant and the applied treatments did not influenced the plants health (table 7).

Plants germinations were at the same level, regardless the applied combinations and were from 58.8 to 63.2%.

Table 6
Germinations and average mass of onion seedlings in the field experiment

Facility (coat)	Number of seedlings germinations		Average mass of a seedling (g)
	At the average per 100 seeds	(%) in comparison to control	
Control	60.0	100.0	0.37
Control + coat	63.0	105.0	0.29
T. viride+coat	58.8	98.0	0.31
Polyversum+coat	59.2	98.7	0.32
Chitosan+coat	63.2	105.3	0.31
LSD $\alpha_{=0.05}$		ns	0.041

* the same letters in a column stand for values which do not differ significantly (α=0.05)

Table 7
Occurrence of pseudo mildew (Peronospora destructor) and the onion crop in relation to the applied treatments

Facility (coat)	Pseudo mildew IR (%)	Crop ($dt \cdot ha^{-1}$)
Control	9.5	111.1 b
Chitosan+coat	5.5	106.7 b*
Chitosan+*T. viride*+coat	6.2	108.9 b
T. viride+coat	7.3	97.8 b
Polyversum+coat	8.2	102.2 b
LSD $\alpha_{=0.05}$	ns	14.47

* the same letters in a column stand for values which do not differ significantly (α=0.05)

In a plantation, researches were carried out on the possibility of limitation of pseudo mildew by spraying onion with Biosept. The obtained results show that spraying with Biosept caused significant reduction of mildew on leaves (table 8). The applied treatments favourably influenced the crop and planting quality of the collected onions.

Table 8
Impact of Biosept application on onion mildew occurrance

Facility	Number of treatments	5 of the affected plants	IR (in %)
Control	-	92.4 a	50.3 a
Biosept	4	45.3 c	15.1 c
LSD $\alpha_{=0,05}$			6.57

* the same letters in a column stand for values which do not differ significantly (α=0.05)

In the following year, material produced in an organic farm, approx. 500 onions were planted. Splendid planting material and a good stand affected the growth and development of plants. No plant with symptoms of primary infection of pseudo mildew was reported.

Harvesting of seeds

For realization of treatment of organic seeds after harvest, apparatus which allows performance of the planned treatment processes was constructed. (Domoradzki, 2005) Seeds after harvesting were cleaned, hydraulically separated, washed, dried, calibrated. Cleaned seeds after harvesting, treatment and the quality research acquire the status of organic seeds.

On experimental fields in an organic farm in Kiełpin, coated radish of Lucynka variety was sowed and the collected Supra onions obtained from the coated organic seeds were also planted. After maturation of seeds, plants were pulled out and arranged in bundles under the roof and inflorescences were dried. Threshed seeds were dried in a winnower of Petkus type with air flow.

Then, seeds were washed in water, contaminations and floating seeds were separated and then dried in a drier with warm air flow. After drying 5.1 kilo of raw seeds of radish and 4.2 kilo of raw seeds of onion were obtained. Cleaning of seeds took place during calibration on screens from 2.0 mm to 3.2 mm every 0.2 mm.

Table 9

Harvesting and cleaning procedure of seeds from an organic plantation

Item	Facility Species Variety	Plantation harvest (kg)	Plantation cleaning (kg)	Washing and floatation (kg)	Drying batch (kg)	Drying losses (kg)	Calibration (kg)	Yield of seeds (%)
4	Lucynka radish	8.00	2.90	5.10	5.00	0.50	4.50	56
5	Supra onion	5.10	0.90	4.20	4.20	0.10	4.10	80

Table 10

Calibration and germination of Lucynka radish seeds

No. of a screen	Fraction (mm)	Diameter av.d (mm)	Mass (kg)	Content (%)	Total (%)	GA acc. to ISTA (%)
1	2.0-2.2	2.10	0.148	3.28	3.28	waste
2	2.2-2.4	2.30	0.495	11.00	14.28	84
3	2.4-2.6	2.50	1.163	25.83	40.11	88
4	2.6-2.8	2.70	1.257	27.92	68.03	89
5	2.8-3.0	2.90	1.002	22.27	90.30	85
6	3.0-3.2	3.10	0.436	9.70	100.00	85
		total	4.500	100.00		

GA – germination ability

Table 11
Calibration and germination of Supra onion seeds

No. of a screen Item	Fraction (mm)	Diameter av.d (mm)	Mass (kg)	Content (%)	Total (%)	GA acc. to ISTA (%)
1	0.0-2.0	1.90	0.170	4.14	4.14	waste
2	2.0-2.2	2.10	0.429	10.46	14.60	87
3	2.2-2.4	2.30	2.206	53.81	68.41	90
4	2.4-2.6	2.50	1.230	30.00	98.41	86
5	2.6-2.8	2.70	0.047	1.15	99.55	62
6	2.8-3.0	2.90	0.018	0.45	100.00	50
			4.100	100.00		

GA – germination ability

Summary of the results of organic seeds processing

Procedure of seeds processing after harvesting consits in fast drying of seeds in order to maintain biological life and guarantees micro-biological cleanness of seeds. Seeds,which were initially dried on a field in sheaves and then under the roof are subject to further cleaning with a floating method and washing seeds in water as well as fast drying in a drier. Seeds after drying are calibrated. Only seeds prepared this way may be tightly packed and stored for further processing. The following treatments proved to be indispensable for processing of organic seeds of radish and onion: drying, floating and washing, drying wet seeds and calibration.

For trading organic seeds a required germination ability of seeds on the minimum level of 80% was assumed. Tables 9,10,11 present the list of the amount of seeds obtained from an organic plantation.

Before sowing, seeds should be treated with organic dressing or inoculated with good microroganisms, admitted for use in organic farming, (Commision regulations (EC) no. 889/2008 as of 5th September 2008 and enclosures), the list of which is extended each year.

Drying of inoculated seeds should take place in the reduced temperature on account of endurance of seeds and survivability of good microorganisms. After coating, seeds acquire protection against pathogens attack. The procedure of obtaining radish and onion seeds, developed in the University of Technology and Life Sciences in Bydgoszcz allows obtaining organic sowing material of good quality.

Conclusions

1. The paper shows that obtaining high quality sowing material from seed organic plantation, which are not chemically protected, is possible.
2. The procedure of processing organic seeds of radish and onion after harvesting was developed. It includes the processes of: cleaning, washing and hydraulic separation, drying and calibration.
3. Presowing processing of seeds affects the healthiness of crops. It consists in inoculation with fungi, coating and treatment with organic dressings.

4. Coating of organic seeds protects seeds against the attack of pathogens included in soil, which creates a coat that protects seeds to the moment of germination.
5. Health of plants on an organic plantation is ensured by useful fungi inoculation *Trichoderma viride* and *Polyversum*, eliminating colonization of pathogenic fungi.
6. After harvesting from weakly organically protected or not chemically protected organic plantations after initial cleaning, the processing of radish and onion seeds is necessary. It consists in washing and hydrostatic separation of seeds and fast drying.
7. Seeds after harvesting were subjected to calibration on screens every 0.2 mm, removing weakly germinating fractions.
8. Sowing material, which meets present quality requirements, which allow admitting sowing material for trade, was obtained.

References

Domoradzki, M.; Sadowski, Cz.; Just, H.; Korpal, W.; Weiner W. (2004). *Technologia wytwarzania nasion warzyw w systemie ekologicznym. Wybrane zagadnienia z nasiennictwa roślin ogrodniczych*. Monografia. ISBN 83-905196-3-1.

Domoradzki, M. (2005). *Aparaty i technologie wspomagające produkcję materiału siewnego. Zmienność genetyczna i jej wykorzystanie w hodowli roślin ogrodniczych.* Monografia. Wydawnictwo Instytutu Sadownictwa i Kwiaciarstwa w Skierniewicach. ISBN 83-88707-86-8.

Domoradzki, M.; Korpal, W. Weiner W. (2006). Badania procesu suszenia nasion warzyw. *Inżynieria Rolnicza, 7*(82), 119-125.

Domoradzki, M.; Dzieniecki, P. (2008) *Technologia przygotowania nasion ekologicznych buraka ćwikłowego do siewu.* Poszukiwanie *nowych rozwiązań w ochronie upraw ekologicznych*. Monografia. Wydawnictwo Instytutu Ochrony Roślin Poznań. ISBN 978-83-89867-31-5

Domoradzki M. Korpal. (2008a). Mieszanina wody, dekstryny i alkoholu poliwinylowego. Do otoczkowania nasion. *Chemik 9*, 456-458.

Domoradzki M. (2011). *Doskonalenie technologii pozbiorowej obróbki nasion ekologicznych na przykładzie roślin baldaszkowatych*. Rozprawa Nr 149. Wydawnictwo UTP w Bydgoszczy. ISSN 0209-0597.

Khan, A. A. (1992). Preplant physiological seed conditioning. *Horticular Reviews, 13*, 131-181.

Parera, C.A.; Cantliffe, D.J. (1995). Presowing seed priming. *Horticular Reviews, 16*, 109-141.

Rozporządzenie Rady (WE) nr 834/2007 z dnia 28 czerwca 2007 r. w sprawie produkcji ekologicznej i znakowania produktów ekologicznych.

Rozporządzenie Komisji (WE) nr 889/2008 z dnia 5 września 2008 r. ustanawiające szczegółowe zasady wdrażania rozporządzenia Rady (WE) nr 834/2007 w sprawie produkcji ekologicznej i znakowania produktów ekologicznych w odniesieniu do produkcji ekologicznej, znakowania i kontroli.

Ustawa z dnia 25 czerwca 2009 r. O rolnictwie ekologicznym. DzU 116 poz. 975

Ustawa z dnia 25 grudnia 2014 r. *O zmianach ustawy o rolnictwie ekologicznym*. DzU 1 poz. 55

ISTA Handbook on Seedling Evaluation 2009. *Metody i zdolność kiełkowania nasion*.

NOWOCZESNA METODA POZYSKIWANIA NASION EKOLOGICZNYCH CEBULI I RZODKIEWKI

Streszczenie. Opracowano technologię przygotowania nasion do siewu na plantacje ekologiczne i wybrano metody obróbki po zbiorze nasion rzodkiewki i cebuli zwyczajnej. Celem pracy było opracowanie procedury pozyskania materiału siewnego tych nasion o wysokiej jakości, zgodnej z normami nasiennymi. Opracowane procesy obejmują: separację hydrauliczną, mycie, suszenie oraz kalibrację. Przed siewem należy wykonać otoczkowanie nasion ekologicznych. Podczas otoczkowania nasion inokulowano powierzchnię nasion zarodnikami grzyba *Polyversum i Trichoderme viride* w ilości 10 szt. zarodników na nasiono lub zaprawiano chitosanem w ilości 1% do masy nasion. Suszenie nasion inokulowanych powinno odbywać się w temperaturze obniżonej do 35°C, co wynikało z badań nad przeżywalnością mikroorganizmów. Uzyskano ekologiczny materiał nasienny zgodny z obowiązującymi wymaganiami jakościowymi, który skierowano do handlu.

Słowa kluczowe: nasiona ekologiczne, obróbka nasion, rzodkiewka, cebula zwyczajna

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):47-55

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.105

A PRELIMINARY ASSESSMENT OF USING THE OPERATING HEAD WITH OVAL NOZZLES FOR IMPINGEMENT FLUIDIZATION OF VEGETABLES

Dariusz Góral[*], Franciszek Kluza, Katarzyna Kozłowicz, Marek Domin

Department of Refrigeration and Food Industry Energetics, University of Life Sciences in Lublin

[*]*Contact details: ul. Doświadczalna 44, 20-280 Lublin, e-mail: dariusz.goral@up.lublin.pl*

ARTICLE INFO

Article history:
Received: November 2014
Received in the revised form: November 2014
Accepted: December 2014

Keywords:
impingement fluidization
air distribution
jet nozzles
oval cross section

ABSTRACT

The operating system of cooling and freezing by impingement and impingement fluidization techniques was modified using oval cross-sectional air jet nozzles at three different configurations of air distribution. The air jet exit velocity at different preset values of 30-50 $m \cdot s^{-1}$ as well as the velocity of air rebound from the operating chamber bottom were measured by applying three heads with oval nozzles and one with classical nozzles for comparative purposes. All of the nozzles had the same cross section. Freezing tests of French fries were performed in these conditions. An analysis of the rebound air velocity fields indicated that both an oval nozzle design and air velocity at the nozzle outlet determine the rebound air velocity. It was found that the limited use of oval nozzles at the impingement fluidization freezing process is possible and that 40 $m \cdot s^{-1}$ was the most appropriate velocity for air jets leaving the nozzles.

Introduction

The efficiency of the impingement freezing method is associated with high heat transfer coefficients in the product surrounding and, therefore, jet impingement is a high performance technique for heating, cooling and drying processes in many industrial applications (Ovadia and Walker, 1998; Lee&Lee, 2000). It consists in directing high velocity impingement air jets leaving vertically arranged nozzles to flow around the product.

The impingement method is used in combination with classical fluidization freezing in thermal treatment, and there are two technical possibilities of conducting the impingement method in fluidization. In the first technical possibility, the thermally treated air jets are directed into the product bed through nozzles from below, i.e. upward to induce fluidized bed boiling. This is a specific modification of classical fluidization and the technical problems that occur in both cases are similar (Ovadia and Walker, 1998).

In the second technical possibility, product fluidization is done by directing the air jets leaving the nozzles from above, i.e. downward into the product placed on a solid base. As a consequence of air jet impingement on and through the product bed and its rebound of air against the base, the particles are carried upward, the bed expands and specific fluidized boiling of the bed starts. Unlike devices using the impingement system, a combination of the fluidization process and impingement effect, called impingement fluidization, is still under experimental studies (Góral and Kluza, 2004).

In order to induce such a fluidization process, a fountain must be created due to interactions between the air jets. Air pressure in the fountain core should be high enough to overweigh the forces of gravitation and to product adhesion to the bottom (fig. 1).

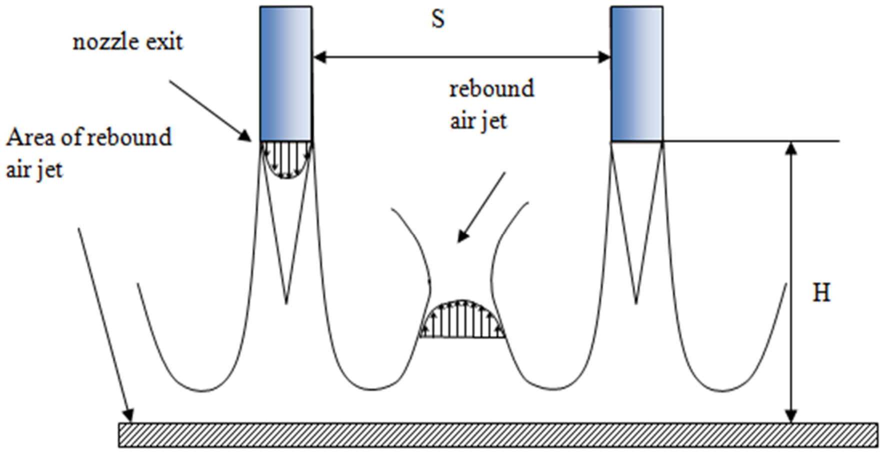


Figure 1. Interaction between air jets

At the minimum fluidization velocity the buoyancy imposes a product upward from the fountain base towards its top. Interactions between bed particles entrain a single particle to the fountain top edge to be later pushed to the lower pressure zone or to get under the air jet leaving the nozzle. Then the particles fall down rapidly onto the working chamber bottom and recirculation starts (Kluza and Stadnik, 2009; Góral and Kluza, 2012).

The feasibility of applying impingement fluidization to fruit and vegetable cooling or freezing in industrial conditions depends on how the physical properties essential for the formation of stable fluidized beds are designed. This is connected with the necessity of achieving a uniform distribution of fountains in the whole working chamber of the installation as well as suitable pressure of the air rebound from the chamber bottom. The studies conducted so far have focused primarily on characteristics of the impingement system, especially on the effect of nozzle spacing as well as the distance between the nozzle exit and the chamber bottom on the heat transfer coefficient between the product and air (Downs and James, 1987; Jambunathan, Lai, Moss and Button, 1992; Huber and Viskanta, 1994a; Huber and Viskanta, 1994b). Besides, the influence of nozzle spacing and configuration on heat transfer was evaluated and a numerical analysis of the nozzle arrangement with two turbulence models was made (Zuckerman and Lior, 2006). The only paper discussing the impact of the nozzle design and spacing on the potential formation of a fluidized bed using the impingement fluidization technique is the research work of Stadnik

(2010). This work indicates that nozzle spacing (S) to its diameter (D) ratio should be found in a range from 1.8 to 4; values above 4 contributed to the creation of a dead zone (no fluidization observed). The optimal nozzle length ranges are within the limits of $6<S/D<20$. The author confirmed a direct relationship between the type of the applied head and uniformity of the temperature fields obtained with it.

Due to the lack of studies on the application of working heads with nozzles of different non-round, cross-sectional shapes for impingement fluidization freezing, we analysed heads with nozzles of an oval cross-section. The aim of the investigations was to find the characteristics of the influence of the nozzle configuration in the head on the rebound air velocity field and to assess the mean values of rebound air jet velocities in relation to the velocity of the air jet at the nozzle exit.

Material and methods

The studies were carried out at the Department of Refrigeration and Food Industry Energetics, University of Life Sciences in Lublin, on a test stand used for impingement fluidization freezing within a temperature range from -30ºC to 0ºC. The process conditions were provided by the installation of 3.9 kW cooling capacity fitted with a centrifugal fan (Nyborg-Mawent type WP-20/1.5) of 0.6 $m^3 \cdot s^{-1}$ air capacity at 2.6 kPa pressure with an inverter LG SV0751G52 for smooth regulation of fan capacity.

Working heads of dimensions 410x360x18 mm (fig. 2) were fitted with nozzles made from round copper tubes 20 mm in inner diameter and 270 mm in length.

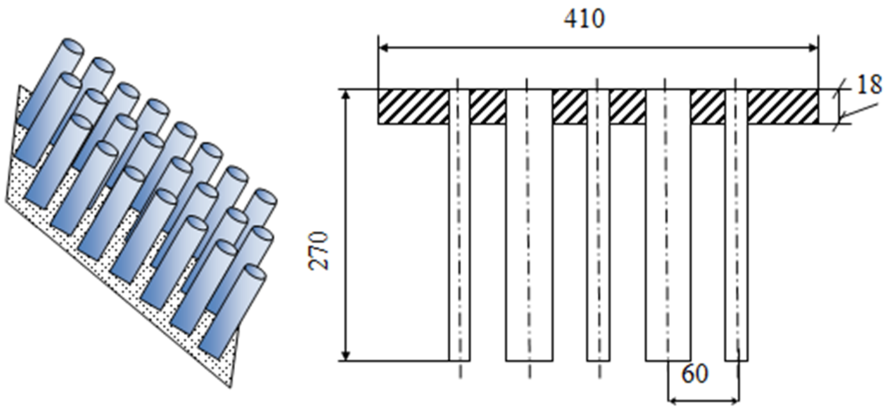


Figure 2. Scheme of head with nozzles

The tubes, at a distance of 230 mm from the nozzle outlet, were formed on a hydraulic press to obtain an oval cross-section of dimensions 10x25 mm. The nozzles were arranged in a parallel, staggered and mixed staggered configuration with a constant nozzle number and distance between the nozzle centres (fig. 3).

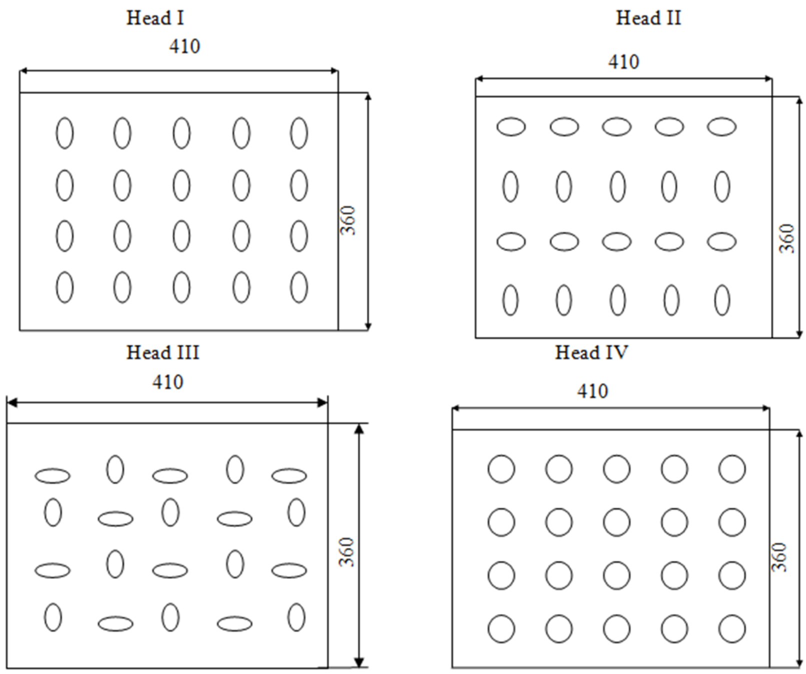


Figure 3. Scheme of head with oval nozzles in the configuration: parallel (head I), staggered (head II), mixed staggered (head III) and classical nozzles (head IV).

A container for the product bed 135 mm in height was used during the studies. The distance between the nozzles and the container bottom was constant – 125 mm.

The aerodynamic values obtained from the tests with the working heads with oval nozzles were compared to the results depicting the head with classical nozzles (nozzle number – 20, inner diameter – 20 mm, nozzle spacing – 50 mm).

Measurement of the rebound air jet velocity was performed by a micromanometer MP 120 (KIMO Instruments) with a Pitot tube type L 3 mm in diameter (fig. 4).

The direction of the Pitot tube tip was perpendicular to the container bottom and parallel to the working head nozzles. The distance between the Pitot tube end and the container bottom was equal to 110 mm each time.

The Pitot tube, as a standard measuring device, was positioned in the working space of each nozzle at measuring points according to the scheme presented in figure 4.

For the purpose of confirming the usability of oval cross-sectional nozzles for a real freezing process, fluidization freezing of French fries and green beans was conducted. French fries were prepared from disease-free potatoes of the same firmness and equal size. The initial treatment involved removal of the outer layer, rinsing under cold tap water and drying on filter paper to take out any excess water. This raw material was cut into cube-shaped fries of a 10x10 mm cross section and little varying length.

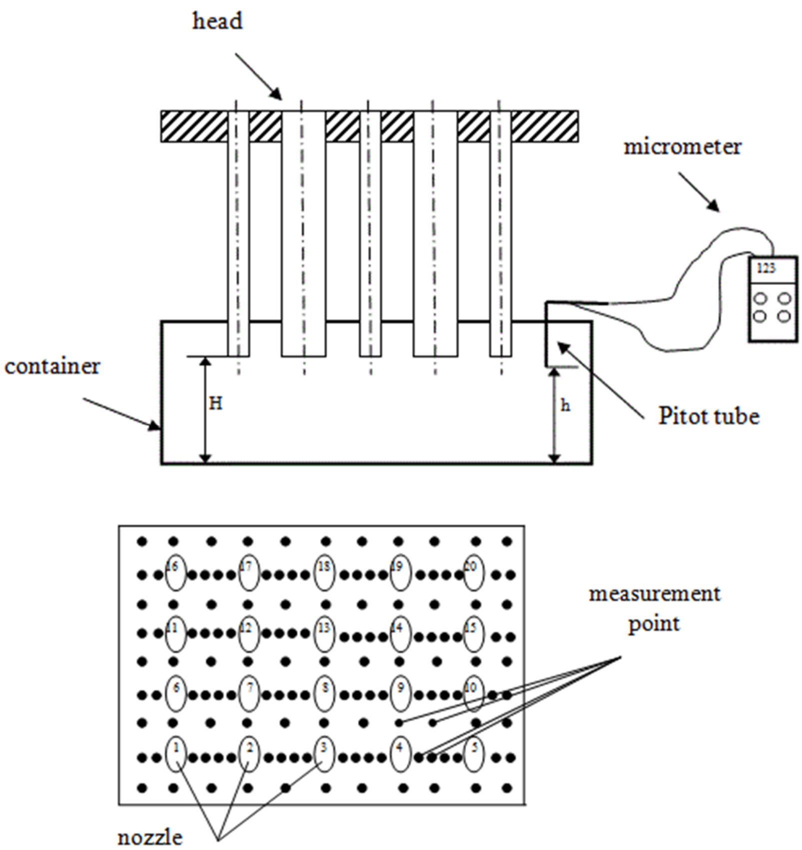


Figure 4. Scheme of measurements of rebound air velocity

Raw material prepared in this way was poured into a container so that it formed an even layer. Then when the fan rotation speed (RPM) was changed over the set range, the velocity of air jet at the nozzle outlet was also changed. Our observations aimed to determine the velocity of air jets leaving the nozzle at which product boiling was obtained and to establish the maximum velocity of air jets at the nozzle exit at which the pneumatic conveying of material did not operate yet.

Results and discussion

A comparative analysis of the rebound air velocity values obtained with four head types at 30, 35, 40, 45, 50 $m \cdot s^{-1}$ velocity of the air jets at the nozzle exit showed a relationship between velocity value, nozzle shape and configuration of nozzle arrangement in the head (fig. 5).

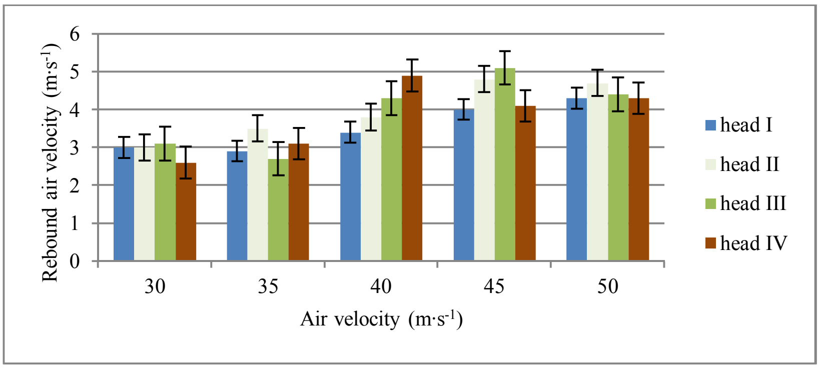


Figure 5. Comparison of mean values of velocity rebound air jets

At 30 m·s^{-1} velocity of air jets leaving the nozzle outlet the heads with oval cross-sectional nozzles (I, II, III) did not bring any significant differentiation in the rebound air jet velocity value, whereas the head with round nozzles (IV) was characterized by a lower mean value of velocity. In the case of 35 m·s^{-1} velocity of air jets at the nozzle exit, marked differences in the mean value of the rebound air velocity were determined in heads II and IV. Application of other head types did not give rise to any significant differences in the mean value of the rebound air jet velocity. A velocity of rebound air jets at the nozzle outlet increased up to 40 m·s^{-1} caused a notable scattering of velocity values, the most intensive was observed for head IV (from 3.4 up to 4.9 m·s^{-1}). When the velocity at the nozzle exit reached 45 m·s^{-1}, the highest rebound air jet velocity (5.1 m·s^{-1}) was recorded for head III. The use of head I and IV provided mean values that were considerably lower as compared to the application of head II and III. Finally, at 50 m·s^{-1} velocity of air jets at the nozzle exit lower mean values of rebound air velocity were noted than at 45 m·s^{-1} velocity of air jets leaving the nozzle. This was most likely the result of some disturbances of the air jet flow due to too high operation pressure in the container under the nozzles of the tested heads.

Views of rebound air jet velocity fields at 30 m·s^{-1} velocity of air jets at the nozzle exit are presented in figures 6.

When analyzing the measurement results for heads with oval nozzles at 30 m·s^{-1} velocity at the air outlet it was found that in all four cases the highest rebound air velocity was recorded at the head edge. Heads with oval cross-sectional nozzles showed a non-uniform distribution of rebound air velocity. A comparison of the present results with those obtained for the head with round nozzles indicated a completely different character of these fields. The fields of rebound air velocity were distributed uniformly, whereas the velocities of air rebound at the application of all four heads were close and ranged between 2 m·s^{-1} and 5.6 m·s^{-1}.

It was also established that changing the nozzle arrangement from parallel to staggered or mixed staggered in the working head did not affect the rebound air jet velocity fields. These velocity fields achieved at 35 m·s^{-1} velocity of air jets leaving the nozzles showed higher levels of distribution uniformity for all of the tested heads. However, as was in the case of 30 m·s^{-1} air jet velocity at nozzle outlet, higher values of rebound air velocities were measured for the edge-mounted nozzles. As was expected, increasing the velocity of air leaving the nozzles caused a growth of the mean velocity of rebound air. The highest air velocities were obtained for a working head with a staggered configuration and in a head with round nozzles, i.e. 7.3 m·s^{-1} and 7 m·s^{-1}, respectively.

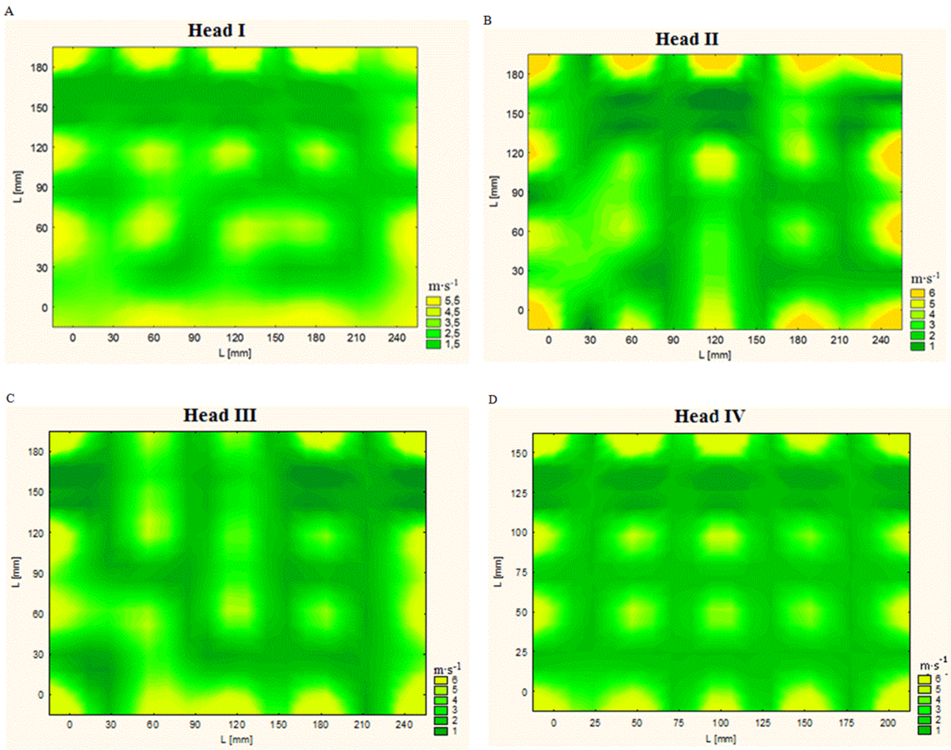


Figure 6. Fields of rebound air velocity at 30 m·s^{-1}

An analysis of air velocity fields at 40 m·s^{-1} showed that, similarly to 30 m·s^{-1}, the obtained fields were characterized by great non-uniformity, except for the uniform distribution of velocity for the head in the parallel arrangement. Besides, in comparison to heads with oval nozzles, a marked elevation of rebound air jet velocity for the head with round nozzles was reported. The maximal velocity value of rebound air oscillated from 6.1 up to 7.7 for heads with oval nozzles and 10 m·s^{-1} for a head with round nozzles. A statistical comparison of the rebound air velocity values indicated no significant differences in the case of the head with oval nozzles arranged parallelly at 35 m·s^{-1} and 40 m·s^{-1} outlet velocity.

Studies on the distribution of the velocity of air jet rebound against the chamber bottom at 45 m·s^{-1} air nozzle velocity showed that the distribution displayed a similar uniformity in the case of the head with oval nozzles and the head with round nozzles. As for the other heads, a markedly more uniform distribution was reported.

When analyzing the velocity field of air jet rebound at 45 m·s^{-1} air nozzle velocity, their non-uniform distribution was found. The increased velocity of air leaving the nozzles did not cause a notable increase of the rebound air velocity only in the case of the head with oval nozzles in the parallel arrangement. In the other cases its growth up to the maximum of 10 $m \cdot s^{-1}$ was recorded.

The effect of an oval cross-section of the nozzles on the possibility of bed boiling was estimated during green beans and French Fries impingement fluidization freezing. It was established that the boiling fluidized bed was obtained for heads with oval nozzles in a parallel and mixed staggered configuration and an air outlet velocity of 40 $m \cdot s^{-1}$. In other cases under investigation neither a boiling fluidized bed nor pneumatic transport of raw material was obtained.

Conclusion

The following conclusions were formulated on the basis of the research and analysis of the measurement results:

1. The increased velocity of air leaving the nozzles and the arrangement of oval nozzles in the head affect the velocity of air jet rebound from the working chamber bottom.
2. In the case of air nozzle velocity above 45 $m \cdot s^{-1}$, the mean rebound air velocity decreases due to overpressure in the working chamber.
3. Studies exploring obtaining a fluidized bed of French fried potatoes and green beans using heads with oval nozzles indicated the possibility of applying this head type in the freezing treatment. The most suitable air nozzle velocity proved to be 40 $m \cdot s^{-1}$.

References

Downs, S.J.; James, E.H. (1987). *Jet impingement heat transfer – a literature survey*, ASME paper No. 87-Ht-35, ASME, New York, NY.

Góral, D.; Kluza, F. (2004). Experimental identification of refrigeration impingement system work. *Inżynieria Rolnicza, 5*(60), 117-124.

Góral, D.; Kluza, F. (2012). Heat transfer coefficient in impingement fluidization freezing of vegetables and its prediction. *International Journal of Refrigeration*, *35*, 871-879.

Huber, A.M.; Viskanta, R. (1994a). Effect of jet-jet spacing on convective heat transfer to confined, impinging arrays of axisymmetric air jets. *International Journal of Heat* and *Mass Transfer, 37*(18), 2859-2869.

Huber, A.M.; Viskanta, R. (1994b). Impingement heat transfer with a single rosette nozzle. *Experimental Thermal* and *Fluid Science*, *9*(3), 320-329.

Jambunathan, K.; Lai, E.; Moss, M.A.; Button, B.L. (1992). A review of heat transfer data for single circular jet impingement. *International Journal of Heat* and *Fluid Flow*, *13*(2), 106-115.

Kluza, F.; Stadnik, Ł. (2009). Experimental formation of bed under jet tube fluidization conditions used for food cooling and freezing. *Electronic Journal of Polish Agricultural Universities, 12*(3), 07.

Lee, J.; Lee, S.J. (2000). The effect of nozzle configuration on stagnation region heat transfer enhancement of axisymmetric jet impingement. *International Journal of Heat* and *Mass Transfer, 43*, 3497-3509.

Ovadia, D.Z.; Walker (Chuck),. C.E. (1998). Impingement in food processing. *Food Technology, 52*(4), 46-50.

Stadnik, Ł. (2010). *Effect of food freezing conditions realized by impingement fluidization*. PhD Thesis, Uniwersytet Przyrodniczy w Lublinie, Lublin.

Zuckerman, N.; Lior, N. (2006). Jet Impingement Heat Transfer: Physics, Correlations, and Numerical Modeling. *Advances in Heat Transfer, 39*, 565-631.

WSTĘPNA OCENA ZASTOSOWANIA GŁOWICY ROBOCZEJ Z OWALNYMI DYSZAMI DO ZAMRAŻANIA METODĄ ODWRÓCONEJ FLUIDYZACJI WYBRANYCH WARZYW

Streszczenie. Układ roboczy urządzenia do chłodzenia i zamrażania metodami impingement i odwróconej fluidyzacji zmodyfikowano, stosując do rozprowadzania powietrza dysze o przekroju owalnym w trzech konfiguracjach ustawienia względem siebie. Pomiary prędkości powietrza wypływającego z dysz przy założonych zróżnicowanych ich wartościach 30-50 $m \cdot s^{-1}$ i prędkości powietrza odbitego od dna komory roboczej przeprowadzono, wykorzystując trzy głowice z dyszami owalnymi i porównawczo jedną z dyszami klasycznymi. Przekrój poprzeczny wszystkich dysz był identyczny. Wykonano próby zamrażania frytek ziemniaczanych w tych warunkach. Analiza pól prędkości powietrza odbitego wykazała, że układ dysz owalnych oraz prędkość wypływającego z nich powietrza decydują o prędkości powietrza odbitego. Stwierdzono, że możliwe jest ograniczone zastosowanie dysz owalnych w obróbce zamrażalniczej metodą odwróconej fluidyzacji, a najodpowiedniejszą prędkością powietrza wypływającego z dysz było 40 $m \cdot s^{-1}$.

Słowa kluczowe: odwrócona fluidyzacja, rozprowadzenie powietrza, dysze, przekrój owalny

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):57-66

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.106

INNOVATIONS IN THE STRUCTURE OF PLANT MATERIAL PELLETIZERS[1]

Roman Hejft, Sławomir Obidziński*

Division of Agri-Food and Forestry Engineering, University of Technology in Bialystok

*Contact details: ul. Wiejska 45E, 15-351 Białystok, e-mail: s.obidzinski@pb.edu.pl

ARTICLE INFO

Article history:
Received: November 2014
Received in the revised form: November 2014
Accepted: December 2014

Keywords:
mixing
non-pressure compensation
powdery material

ABSTRACT

The article presents an innovative mixing-densifying-dosing system of a pelletizer, which feeds plant material to the densifying system. The structure of the system allows simultaneous realization of the mixing operation as well as non-pressure compression of powdery fractions of the processed material. The paper also sets forth results of the presented system. The tests included determination of the rotational speed of the internal cylinder of the system (25, 40, 55 rot·min^{-1}) and mass intensification of the densified raw material flow (4, 8 and 12 kg·h^{-1}) on the amount of the pelletized fraction. Fine-grained waste of nettle from Herbapol plants in Białystok was used as a research material. The tests which were carried out allowed determination of the mixing-densifying -dosing system for initial densification of the fine-grained plant material (nettle waste) before feeding it to the working system of the pelletizer and allowing elimination of the finest fractions of the crumbled plant material by its non-pressure compression during mixing.

Introduction

The process of pressure agglomeration of plant materials (pelletizing, briquetting) is commonly used both in production of fodder and solid organic fuels (often from waste) (Szpryngiel et al., 2011; Skonecki and Laskowski, 2006). In the process, loose plant material (including various compositions of mixtures) acquires a solid form, which brings numerous utility advantages. Variability of plant materials, including physical, chemical, biological properties, which change also during the process (Kaliyan and Morey, 2009; Shaw, 2008), high condensing pressures (60-150 MPa), high temperature in the working system (80-90ºC) causes that this field of science and technique constantly requires many significant innovative supplements (Chłopek et al., 2012; Hejft and Obidziński, 2012; Hejft and Obidziński, 2013).

Pelletizing, briquetting are twin processes. The difference consists mainly in the size of the obtained product (pellet is in the form of rolls with diameter from approx. 2 mm to 10-15 mm, whereas a briquette is often a roll, a cylinder or a prism with the cross-sectional

[1] The article was written as a part of the statute work S/WBiIS/2/2015

area from 3 cm^2 to approx. 50 cm^2). The length of products depends on designation and is from several to dozen or so times bigger than its diagonal dimensions (Hejft, 2002).

Figure 1 presents a prototype pelletizing and briquetting system made as a part of realization of the research paper Ministry of Science and Higher Educatio No. N N504 488239 titled "Testing the working system of the plant materials pelletizer" funded from the budget funds for 2010-2013 (Hejft and Obidziński, 2013a).

Figure 1. A prototype pelletizing system (Hejft and Obidziński, 2013a): 1 – mixing- densifying-dosing system, 2 – drive of the mixing-densifying-dosing device, electric engine MS7124 with a reducer PM50, 0.37 kW, 1370 rot·min^{-1}, 3 – raw material feeding hopper, 4 – mounting support, 5 – feeding hopper for raw material which was initially condensed, 6 – working system, 7 – discharge, 8 – electric engine YX3-180L-4B3IE2, 22kW, 1470 rot·min^{-1}, 9 – embodied torque measuring device Mi20, 10 – control box, 11 – toothed gear ratio 1:6,8, 12 – base

Material subjected to pelleting is fed by the feeding hopper 3 to the mixing-densifying-dosing system 1. Drive 2 of the mixing-densifying-dosing system is carried out through an electric engine with a reducer and a chain transmission. The support 4 allows regulation of the level of location of the mixing-denisfying-dosing system. After the material leaves the mixing-densifying-dosing system it is fed through the feeding hopper 5 to the working system 6 which consists of the material separator, a working system with a flat immovable matrix and pelleting shafts. Produced pellets (briquettes) are taken by the discharge 7. Drive of the pelleting shafts system is carried out from the electric engine through the measuring torque 9 and the reducer 11.

The mixing and densifying system of the pelletizer

Figure 2 presents an innovative mixing-densifying-dosing system before feeding it to the dosing system. The structure of the system allows simultaneous realization of the mixing operation as well as a non-pressure compression of powdery fractions of the processed material (Hejft and Obidziński, 2012a; Hejft, 2013).

The mixing-densifying-dosing system for the working system of the pelletizer may co-operate with both the working system "flat matrix – densifying rolls", as well as "ring matrix- densifying rolls".

Two units have been known so far in the structural solutions of granulating devices (pelleting): mixing and dosing (with a possibility of conditioning material through providing steam). Most frequently these are structures which consist of an immovable cylinder (pipe), inside of which a shaft is turning with a helix reeled on or blades mounted on the helix and of a drive (with an electric engine) (Hejft and Obidziński, 2012a).

The mixing-densifying-dosing system was presented in figure 2, equipped with a rotational cylinder 5, which has openings 5a in the front part, supplying material to the inside. Inside the cylinder there are exchangeable plates 4 mounted with screws to the cylinder (arranged in a helix on its length) with a possibility of regulation of the angle of their arrangement. Drive from the engine 1 is conveyed through a transmission e.g. a belt one onto a movable shield 3, which is mounted on a driven, curved shaft 4. The shield 3 has a cylinder 5 mounted on it, which plays a role of the working mixing-densifying-dosing system and blades 6, which provide raw material inside the cylinder 5.

Making shaft 4 as a curved shaft allows supply of liquid (which may serve as a binder) or another liquid additive or water steam (in relation to demand) through an opening to the cylinder 5.

The rotating cylinder 5 is shielded by the immovable cylinder 8 mounted to the immovable shield 9 through the shield 10 to the casing 11, bearings 12 and is closed with a demountable cover 13. The feeding hopper for raw material 14 and on its end the discharge 15 are mounted to the immovable cylinder 8 over the openings 5a of the cylinder 5. Material fractions introduced to the rotating cylinder 5 through openings 5a and the steering wheel 6 move on the surface of the rotating cylinder 5 which causes partial pelletization (non-pressure) of powdery fraction particles included in material. The structure of the system allows regulation of the tilt angle of the device in relation to the working system of the pelletizer through loosening the screw cap 16 and the change of the arm arrangement 17.

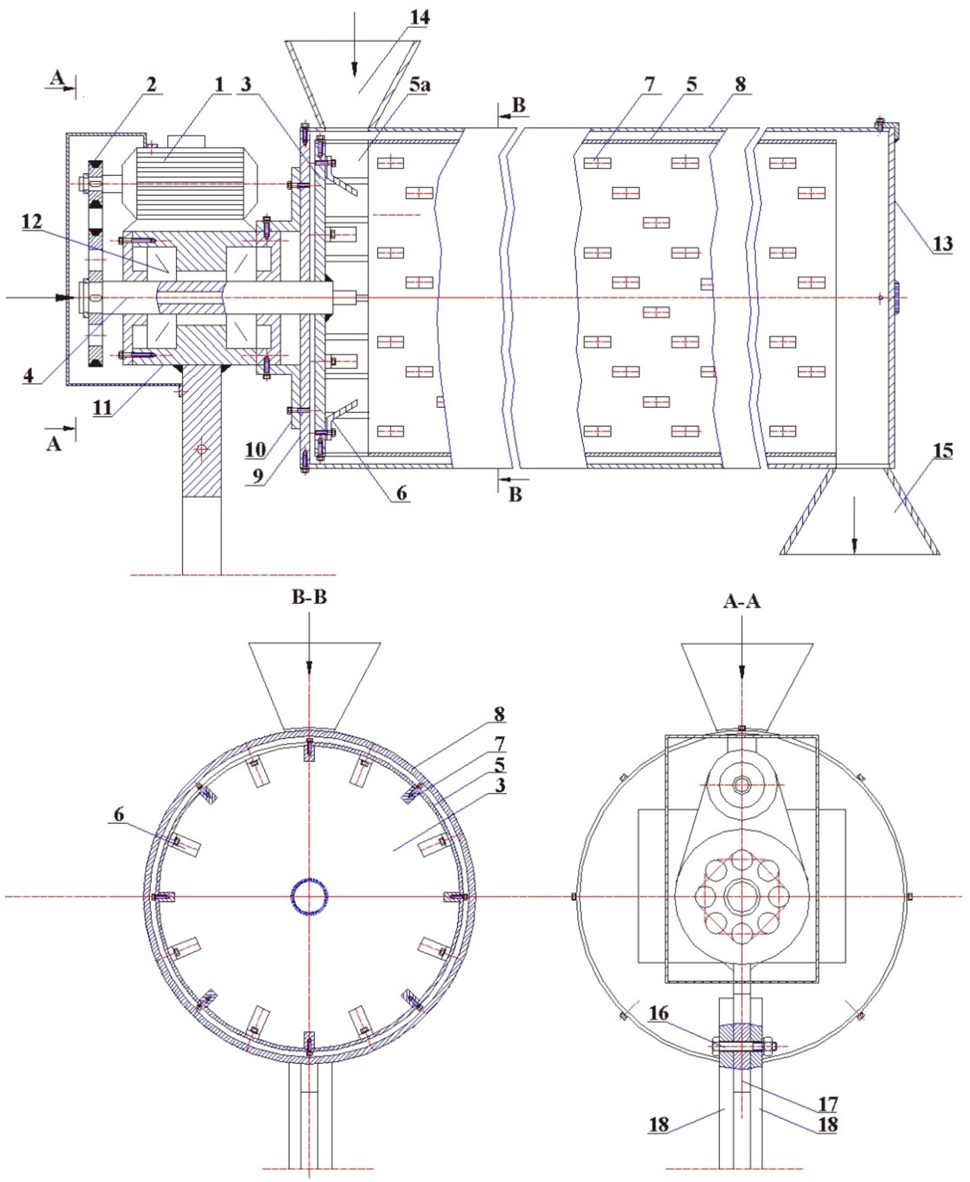


Figure 2. Schematic representation of the mixing-densifying-dosing system (Hejft and Obidziński, 2012a; Hejft and Obidziński, 2013): 1 – electric engine, 2 – belt transmission, 3 – moving shield, 4 – curved shaft, 5 – rotating cylinder, 5a – supplying openings, 6 – blades, 7 – tiles, 8 – immovable cylinder, 9 – immovable shield, 10 – shield, 11 – bearings casing 12 – bearings, 13 – cover, 14 – raw material feeding hopper, 16 – screw cap, 17 – arm, 18 – arms

Figure 3 presents the mixing-densifying-dosing system.

a) b)

c)

Figure 3. *View of the units of the mixing-densifying – dosing system: a) from the feeding hooper, b) from the discharge, c) from the inside*

The objective of the paper

The objective of the paper is to present a structural solution for the mixing-densifying-dosing prototype pelletizing device with a working system "flat immovable matrix- densifying rolls", which allow initial compression of the powdery and fine-grained fraction of material which is pelletized, its mixing and dosing to the working system of the pelletizer and presentation of the initial research of this system.

Methodology of research

The paper includes tests of the non-pressure agglomeration process with the use of the mixing, densifying and dosing system presented in figures 2 and 3.

Fine-grained waste from nettle which came from plants of Herbapol in Białystok and which constituted remaining after processing of these plants during refining and final sorting before drying and during sorting and packing dried herbs were used as the research material.

The initial tests included the rotational speed of the internal cylinder of the mixing-desnifying-dosing system (25, 40, 55 rot·min^{-1}) and mass intensification of the compressed raw material flow (4, 8 and 12 kg·h^{-1}) as variable parameters.

Determination of the impact of the rotational speed of the internal cylinder of the mixing-densifying-dosing system was made at the mass intensification of the compressed raw material flow which is 8 kg·h^{-1}, and the impact of the mass intensity of the compressed material flow was determined at the rotational speed of the internal cylinder of the mixing-densifying-dosing system equal to 40 rot·min^{-1}. These tests were carried out at the 20% participation of binder referred to the amount of the agglomerated material. The content of starch in water solution was 10%.

During the process of agglomeration, binder was supplied into the cylinder through a sprayer nozzle. After the agglomeration process, the obtained product was placed in a separate vessel and dried in the room temperature (approx. 23ºC) for 48 hours and afterwards a screen analysis of each sample was carried out in order to determine the mass participation and the granulometric distribution of the pelletized fraction. Particles which exceed 0.5 mm in size have been assumed as a pelletized fraction.

Determination of the granulometric composition of the fine-grained nettle waste and the pelletized fraction division from the non-pelletized one was made with a shaker LPz-2e by Multiverw Morek company pursuant to the standard PN-EN 932-1. During determination, a previously weighed 50 g -sample of nettle waste was poured onto the upper screen of the screen analysis set. The set of 5 screens with the following dimensions of the square mesh side was applied: 0.5 mm; 0.25 mm; 0.125 mm; 0.063 mm; 0.040 mm. The time of operation of the shaker was 5 minutes at the assumed vibrations amplitude of 80%. After the process of screening, each fraction on the screen was weighed and the obtained result of weighing constitutes a percentage content of a given fraction.

For division of the pelletized and dried fraction the set of 6 screens of the following dimensions of the square mesh side was applied: 0.5 mm; 1.0 mm; 2.0 mm; 4.0 mm; 6.0 mm and 8.0 mm. Division of particular fractions was made by means of its screening within 30 seconds. Results of the obtained measurements were developed in Microsoft Excel.

Results of the research

The screen analysis allowed a statement that in the investigated nettle waste the lowest percentage participation consists of the fraction of 0.5 mm size, the participation of which is 0.13%. The highest percentage participation is in case of a fraction with the size of 0.125 mm, the percentage participation of which is 44.4%, fraction with the size of 0.25 mm amounts to 28.2%. However, waste includes a big amount of fraction with the size of 0.063 mm (19.83%) and fraction with the particle size of 0.040 mm (6.26%). From the point of view of usefulness for pressure compression, this type of granulometric distribution i.e. a considerable participation in powdery fraction waste causes great problems and increases the demand for the power of pelletizing devices. Thus, this type of waste should be mixed before condensation with waste of bigger size of particles or subjected to non-pressure agglomeration before the process of pressure agglomeration.

Based on the obtained research results (fig. 4) a significant impact of the rotational speed of the internal cylinder of the mixing-densifying-dosing pelletizer on the amount of the pelletized fraction of the nettle waste condensed without pressure was determined. Along with the increase of the rotational speed of the cylinder from 20 to 55 rot·min^{-1} a decrease of the amount of the pelletized fraction from 19.29 to 17.48% took place.

The decrease of the mass participation of the pelletized fraction along with the increase of the rotational speed of the cylinder is considerably related to the reduction of time in which the nettle waste stay in a compression drum, which reduces possibility of formation of new agglomerates from the compressed waste, and the time of the increase of the previously formed agglomerates shortens and as a result participation of the pelletized fraction gets lower.

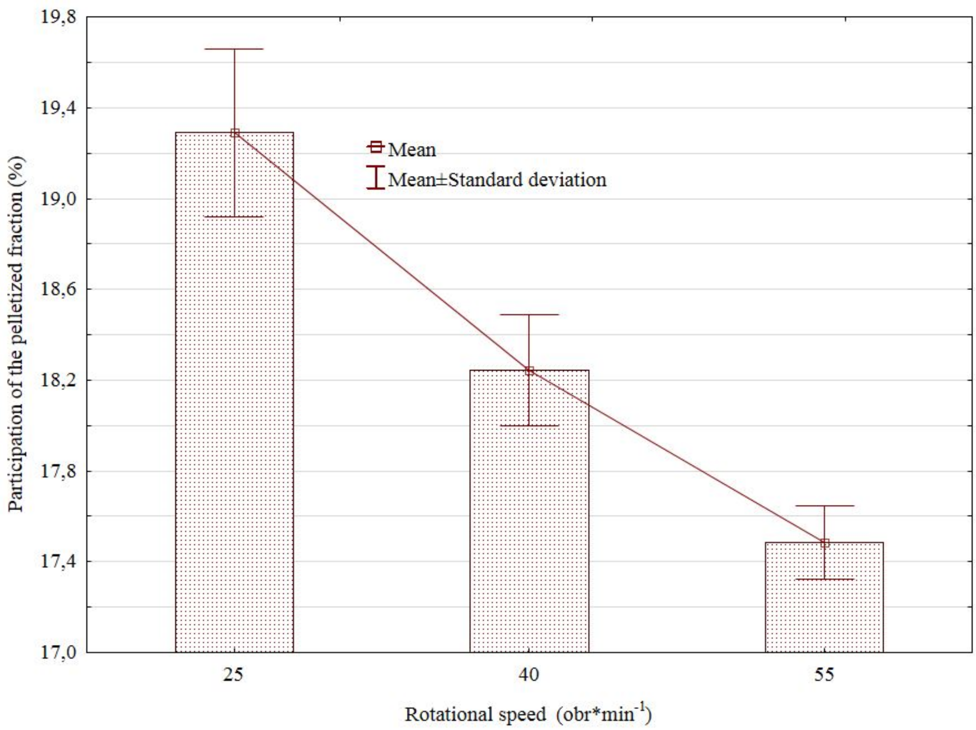


Figure 4. Impact of the rotational speed of the cylinder on the amount of pelletized fraction of the nettle waste

A one-factor analysis of variance (one-dimensional test of significance by Kołmogorow-Smirnow) at the level of significance p=0.05, allowed determination of significant differences between values of the compressed fraction participation, obtained at the increasing rotational speed of the cylinder of the pelletizer.

Figure 5 presents the relation of the amount of the pelletized fraction of nettle waste compressed without pressure to the mass intensification of flow of fine-grained nettle waste.

Increase of the mass intensity of flow of nettle waste from 4 to 12 $kg \cdot h^{-1}$ influenced a slight increase of the amount of the pelletized fraction from 17.45 to 21.18%.

The raise of the mass participation of the pelletized fraction along with the raise of the mass intensity of flow of the compressed waste through the system cylinder is related to the growth of the amount of raw material (nettle waste) in the compression drum, which may simultaneously create new agglomerates from the compressed waste or increase previously formed agglomerates which as a result increases the pelletized fraction participation.

A one-factor analysis of variance (one-dimensional test of significance by Kołmogorow-Smirnow) at the level of significance p=0.05, allowed determination of significant differences between values of the compressed fraction participation, obtained at the increasing rotational speed of the pelletizer cylinder.

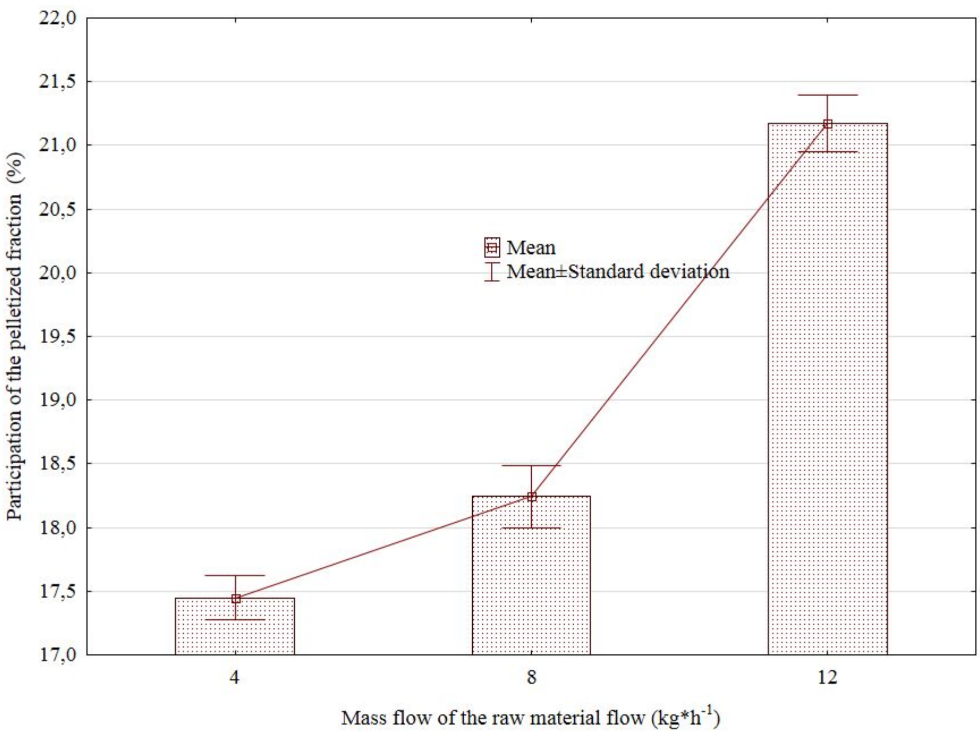


Figure 5. Impact of the mass intensity of flow of raw material on the amount of pelletized fraction of nettle waste

Conclusions

1. The tests which were carried out allowed determination of the usefulness of the mixing-desnifying-dosing system for initial compression of the fine-grained plant material (nettle waste) before feeding it to the working system of the pelletizer and allowing elimination of the finest fractions of the crumbled plant material (pelletized) by its non-pressure compression during mixing.
2. Along with the increase of the rotational speed of the cylinder from 20 to 55 $rot \cdot min^{-1}$ a decrease of the amount of the pelletized fraction from 19.29 to 17.48% took place.
3. The increase of the mass intensity of flow of nettle waste from 4 to 12 $kg \cdot h^{-1}$ influenced the increase of the amount of the pelletized fraction from 17.45 to 21.18%.
4. The one-factor analysis of variance, which was carried out allowed determination of significant differences between the values of the compressed fraction participation, obtained at the growing intensity of flow of the compressed nettle waste and at the growing rotaitonal speed of the pelletizer cylinder.

References

Chłopek, M.; Dzik, T.; Hryniewicz, M. (2012). Metoda doboru elementów układu roboczego granulatora z płaska matrycą. *Chemik, 66, 5,* 493-500.

Hejft, R. (2002). *Ciśnieniowa aglomeracja materiałów roślinnych.* Biblioteka Problemów Eksploatacji, ITE, ISBN 83-7204-251-9.

Hejft, R.; Obidziński, S. (2012). Ciśnieniowa aglomeracja materiałów roślinnych – innowacje technologiczno-techniczne. Część I. *Journal of Research and Applications in Agricultural Engineering, 1,* 63-65.

Hejft, R.; Obidziński, S. (2012a). Urządzenie mieszająco-granulująco-dozujące do układu roboczego granulatora. *Zgłoszenie patentowe P.397754 z dnia 09.01.2012r.* Urząd Patentowy Rzeczypospolitej Polskiej.

Hejft, R.; Obidziński, S. (2013). Ciśnieniowa aglomeracja materiałów roślinnych- innowacje techniczno-technologiczne. Część II. Układ dozujący, mieszająco-granulujący. *Journal of Research and Applications in Agricultural Engineering, Vol. 58*(1), 60-63.

Hejft R. (2013). Innowacje w rozwiązaniach konstrukcyjnych urządzeń do granulowania materiałów roślinnych. *Czysta Energia, 6,* 40-41.

Hejft R., Obidziński S. (2013a). Praca badawcza MNiSzW Nr N N504 488239 pt. „*Badania układu roboczego granulatora do materiałów pochodzenia roślinnego*" finansowana ze środków budżetowych na lata 2010-2013.

Kaliyan, N.; Morey, R.V. (2009). Factors affecting strength and durability of densified biomass products, *Biomass Bioenerg, 3,* 337-359.

PN-EN 932-1. *Badania podstawowych właściwości kruszyw. Metody pobierania próbek.*

Shaw, M. (2008). *Feedstock and process variables influencing biomass densification.* A Thesis. Department of Agricultural and Bioresource Engineering, University of Saskatchewan. Saskatoon, Saskatchewan, Canada.

Skonecki, S.; Laskowski, J. (2006). Wpływ średnicy komory i masy próbki na zagęszczanie poekstrakcyjnej śruty rzepakowej. *Inżynieria Rolnicza, 6*(81), 15-23.

Szpryngiel, M.; Kraszkiewicz, A.; Kachel-Jakubowska, M.; Niedziólka, I. (2011). Ocena gęstości usypowej i energochłonności produkcji peletów w peleciarce z dwustronną matrycą płaską. *Inżynieria Rolnicza, 6*(131), 215-222.

Roman Hejft, Sławomir Obidziński

INNOWACJE W KONSTRUKCJI GRANULATORÓW DO MATERIAŁÓW ROŚLINNYCH

Streszczenie. W artykule przedstawiono nowatorski układ mieszająco-granulująco-dozujacy granulatora, podający materiał roślinny do układu zagęszczającego. Budowa układu pozwala na jednoczesną realizację zarówno operacji mieszania, jak i bezciśnieniowego granulowania pylistych frakcji przetwarzanego materiału. W pracy przedstawiono także wyniki zaprezentowanego układu. W badaniach określono wpływ prędkości obrotowej cylindra wewnętrznego układu (25, 40, 55 obr$\cdot$min^{-1}) oraz masowe natężenie przepływu zagęszczanego surowca (4, 8 i 12 kg$\cdot$h^{-1}) na ilość frakcji zgranulowanej. Jako materiał badawczy wykorzystano drobnoziarniste odpady z pokrzywy pochodzące z zakładów Herbapol w Białymstoku. Przeprowadzane badania pozwoliły stwierdzić przydatność układu mieszająco-granulująco-dozującego do wstępnego zagęszczania drobno-ziarnistego materiału roślinnego (odpadów pokrzywy) przed podaniem do układu roboczego granulatora i pozwalającego na eliminację najdrobniejszych frakcji rozdrobnionego materiału roślinnego przez jego bezciśnieniowe granulowanie w trakcie mieszania.

Słowa kluczowe: mieszanie, bezciśnieniowe granulowanie, materiał pylisty

Scientific quarterly journal e-ISNN 2449-5999
Agricultural Engineering
2015: 1(153):67-76
Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.107

RELATION BETWEEN THE CONTENT OF SIMPLE SUGARS IN A POTATO TUBER AND ITS RESISTANCE TO MECHANICAL LOAD

Tomasz Jakubowski*, Norbert Marks, Beata Maciewicz

Institute of Machinery Management, Ergonomics and Production Processes
University of Agriculture in Kraków
*Contact details: ul. Balicka 116B, 30-149 Kraków, e-mail: tomasz.jakubowski@ur.krakow.pl

ARTICLE INFO

Article history:
Received: August 2014
Received in the revised form: September 2014
Accepted: December 2014

Keywords:
potato
sugar
damage

ABSTRACT

The objective of the paper was to find a relation of the content of simple sugars in a potato tuber and its resistance to mechanical loads. The following potato tuber varieties were investigated: Kuras, Gala, Agata, Ditta, Arrow, Roko and Raja. A force damaging periderm, external and internal damages ratios and mass damages determined potato tubers susceptibility to mechanical damages. Measurement of the sugar content in the potato tubers was carried out with a refractometer. A statistically significant relation, measured with the value of the coefficient of correlation, between the content of simple sugars and susceptibility to internal damages was determined only in potato tubers of Kuras and Raja varieties.

Symbols:

C_{pr} – content of simple sugars, (°Brixa)
F – force which caused damage to periderm of the potato tuber on the border of its biological strength, (N)
W_{zew} – ratio of external damage to potato tuber, (%)
W_{wew} – ratio of internal damage to potato tuber, (%)
W_{mas} – ratio of mass damages to potato tuber, (%)
L – mass of tubers with slight damage – to 1.7 mm of depth, (%)
$Ś$ – mass of tubers with average damage – from 1.7 to 5.1 mm of depth, (%)
C – mass of tubers with heavy damage – more than 5.1 mm of depth, (%)

Introduction

One of many criteria which qualify potato tubers for further use (direct consumption, storing or processing) is their susceptibility to damage both internal and external. According to Marks (2009) potato tuber resistance to mechanical damage is a resultant of many factors: potato variety, growth environment, tuber development and agro-technology of plant cultivation. Factors related to potato plant which determine susceptibility of a plant to damage are mainly: variety, dimensions and tuber maturity as well as its internal structure and chemical composition (McGarry et al., 1996; Marks, 2009; Laerke et al., 2002). Relations between the above mentioned factors and their impact on a mechanical damage were described, inter alia, in the papers by Marks et al., 2000, Krzysztofik and Nawary 2003, Ganczarz et al. 2005 and Jakubowksi 2009. However, in the available subject literature (Molema, 1999; Konstankiewicz et al., 2001; Marks, 2009) there is a small amount of information concerning relations between the chemical composition of a potato tuber and a degree of its susceptibility to mechanical loads (such researches were carried out on account of the selected cells of the pulp tissue of a potato tuber (Hejtmánková et al., 2013) or damages to starch particles (Yue et al., 2012). Particularly noticeable in literature is absence of researches on the relation of simple sugars content in a potato tuber and its resistance to mechanical damage. In the potato bulb (Solanum tuberosum L.) there are carbohydrates which belong to monosaccharides (aldose and ketose) as well as to oligosaccharides (saccharosis) and such that do not show reductive properties of polisaccharides (starch). Simple sugars (monosaccharides) with reductive properties, are represented in a potato tuber mainly by glucose (which contains aldehyde group – CHO) and fructose (which contains ketonic group =C=O). It should be mentioned that a tuber includes also simple sugars (ribose, deoxyribose, arabinose, rhamnose, galactose or galacturnoci acid) which do not occur in the free state but mainly incorporated in nuclein acids of a potato. A separate group consists of metabolites (0.2-4.5% of dry mass of a potato tuber) in the transfer of sugars (phosphatic esters of sugars as e.g.: glucose-6-phosphate, fructose-6 phosphate, triose-3 phosphate) (Wieczer and Gonczarik, 1977).

The issue related to presence of various forms of carbohydrates (and their impact on mechanical damages) in a potato tuber is significant, because the sugar content in relation to the factors which act on a plant may be variable. Dynamics of these changes depends on e.g. the applied agrotechnology or conditions in which bulbs are stored. Research by Wojdyła et al. (2009), shows that sprinkling the potato plantation influences decrease or increase of the sugar content in tubers. According to Shock et al. (1993) after periods of deficiency of precipitation, a potato tuber contains more dry mass and simple sugars and less starch. Starch, as a reserve material is broken down to simple sugars necessary to intensify the plant growth (number of reducing sugars in tubers grows, which limits their technological usefulness). Higher concentration of some carbohydrates (mainly glucose and fructose) influences also the intensity of the Maillard reaction course (Zgórska and Frydecka-Mazurczyk, 2000; 2002).

The objective of the paper was to find the relation of the content of simple sugars in a potato tuber and its resistance to mechanical loads.

The scope of paper and the methodology of research

Tests were carried out at the turn of 2011-2012 in laboratory conditions. Potato tubers of the following varieties were used: Kuras, Gala, Agata, Ditta, Arrow, Roko, Raja. Material for research (in the full technical maturity stage) came from own field experiment, located on the podzoil soil during which correct principles of agrotechnologies for the potato plant were used. Two types of fertilization were used: multicomponent fertilizer *Hydrokompleks Yara Mila* (12% N, 11% P, 18% K) in the amount of 60: 60: 90 $kg \cdot ha^{-1}$ and *Ekolist Standard* with urea – 3 $l \cdot ha^{-1}$ in two doses. Collection of tubers was carried out in the second half of September after 116 days of vegetation. In the aspect of the used methodology of experiment tubers without visible disease symptoms were qualified for tests. 30 tubers were used in an experiment (with a unit mass 35-45g) for each variety. Tests on the potato tubers resistance to mechanical loads were carried out in laboratory conditions (tests covered determination of resistance to static and dynamic damages). A force damaging periderm, external and internal damages ratios and mass damages determined potato tubers susceptibility to mechanical damages. In order to make a static damage, a single potato tuber was loaded with the use of a static and spring penetrometer to the moment of its damage caused by a roll bolt pressed inside the pulp. Pressure on the sample was transferred by a spring, diffraction of which was proportional to the pressure made. The tuber was damaged in its central part along the direction of thickness measurement (smaller dimension of the biggest cross-section). The measure of the tuber resistance to mechanical damage took a form of the force which caused damage of the potato periderm on the border of its biological strength (force of piercing and pressing the bolt into the tuber pulp). In order to cause a dynamic damage, a device (Jakubowski, 2010), which enabled leaving the potato tuber within the height up to 200 cm, was used. The device was equipped with a trap door, the task of which was to limit the rotational movement of the left tuber and reduction of the initial acceleration, which could be formed if the tuber was manually dropped. Tubers were dropped from the height of 100 cm onto a metal plate with the surface area of 0.5 m^2. The surface, which directly adjusted to the plate edges, was secured in order to avoid secondary damages of a tuber, which could occur in case it got bounced from the ground. Tubers, after damage were stored in a freezer in sisal bags for 3 days. The assessment of the damage size caused to a tuber was made with the use of a fissure knife (fissure width 1.7 mm) by removing the skin (Roztropowicz, 1999). Potato tubers were qualified as: non-damaged (which do not have any external and internal damages), damaged externally (abrasion, periderm crackings, damage to pulp) and internal damages (which do not have visible external damages, however which may have blackspot bruisers visible after the removal of periderm). Tubers with external and internal damages were classified (assuming depth of damage as a criterion) as: slightly damaged (depth of damage to 1.7 mm inclusively); at the average (depth of damage 1.71-5.1 mm inclusively) and very damaged (depth of damage exceeds 5.1 mm). For each size of damages, number of tubers and mass was provided. Then mass index of tuber damages was calculated (W_{mass}) according to the formula 1 (where lower indexes: ext., int. and mass respectively: external damages, internal and mass damages).

$$W_{mas} = 0.1L_{wew} + 0.3Ś_{zew,} + 1C_{zew} + 0.1L_{wew} + 0.3Ś_{wew} + 1C_{wew}\ (\%) \qquad (1)$$

Measurement of the sugar content was carried out with the use of refractometer (precision 0.2%) on the prism of which tested potato bulb was placed. This device, equipped with two prisms, using the phenomenon of the total internal reflection (Snellius law), measures the coefficient of refraction of light of the tested substance. The measurement system of the refractometer is lighted with a light beam. In relation to the angle of refraction of this beam, it goes through the border surface to the second prism and then to a spyglass. The field seen in a spyglass is divided into two parts: light and dark. The division line is clear and its location depends on the border angle of the investigated substance. The coefficient of light refraction is proportional to the concentration of the investigated substance. The measurement result is obtained in °Brix scale.

The obtained results were subjected to statistical analysis with the use of STATISTICA 10 at the level of significance of α=0.05. The research included determination of the correlation relations between the content of simple sugars in potato tubers and their resistance to mechanical damage. Moreover, similarities between the potato varieties, accepted for the research were analysed on account of susceptibility of tubers to mechanical damages and the content of simple sugars. Correlation relations were determined with the use of Pearson coefficient and varietal similarities were invetsigated through a one-factor analysis of variance. For statistically significant correlation compounds, with the method of the smallest squares, curves and equations of regression were determined. Varietal differences between the statistically significant averages were investigated with Tukey's test of multiple comparisons. The analysis of variance was carried out with the test on the regularity of distribution in samples (Kolmogorov-Smirnov test) and on the uniformity of variance (Lavene's test). The obtained research results (values expressed in %) for statistical developments were transformed according to the formula $y=arcsin\ \sqrt{x}$ (where x is a researched dependable variable). After the statistical calculations were made, the values were retransformed to the original form.

Table 1 presents the calculated values of Pearson correlation coefficients for linear relations between the content of simple sugars in potato tubers and their susceptibility to mechanical damage. It should be emphasised that interdependence of features determines mutual relations between the selected variables not only through force of the investigated relation but also through its direction. All coefficients of correlation, calculated for the relation C_{pr} – W_{zew}, W_{wew} and W_{mas} are additional values, which proves that along with the increase of the simple sugars content in potato tubers also average values of dynamic damages indexes increase. It should be also included that in the presented research results (table 1) only coefficients of correlation calculated for the relation C_{pr} – W_{zew} and W_{wew} (on account of the analysis method and the nature of the analysed variables) express a simple correlation. Relation $C_{pr} - W_{mas}$ is a multiple correlation, thus informing on the relation of one feature (C_{pr}) with several presented together (W_{zew} and W_{wew}) – thus values for $C_{pr} - W_{mas}$ may be reduced. Statistically significant values of the coefficient of correlation were reported only in case of two varieties of potato (Kuras and Raja) or the relation between the simple sugars content and the index of internal damages of a potato tuber.

Table 1
Coefficients of Pearson correlation between the content of simple sugars in a potato tubers and their susceptibility to mechanical damage

Variety	Value of the coefficient of correlation for the relation			
	$C_{pr} - F$	$C_{pr} - W_{zew}$	$C_{pr} - W_{wew}$	$C_{pr} - W_{mas}$
Kuras	0.16	0.15	0.79*	0.41
Gala	0.15	nrd	0.51	0.51
Agata	-0.36	0.23	nrd	0.23
Ditta	-0.28	0.26	0.53	0.51
Arrow	0.16	0.12	0.52	0.40
Roko	-0.15	0.21	0.57	0.41
Raja	-0.3	0.19	0,72*	0.42

* statistically significant correlation (α=0.05), nrd – no reported damages

The above mentioned varieties differ on account of both their utility and belonging to the group of earliness; also morphology of tuber alone is varied. In principle, the only common feature which joins those two varieties is a higher content of starch, in comparison to the remaining varieties accepted in the experiment. Varieties Gala, Ditta, Arrow and Roko are early (or very early) edible varieties with the starch content of 11.8-13%. Kuras is a late starch variety (19.35 of starch) and Raja is a middle-early edible variety with the content starch of 15.6% *[Characteristics of the national register of potato varieties]* – IHAR [*Plant Breeding and Acclimatization Institute*] 2011). Simple sugars are formed as a result of the reserve material decomposition, which in a potato tuber occurs in the form of starch. Therefore, a hypothesis, that the relation between the internal damages of a tuber and the content of simple sugars shall be determined with the amount of starch in a potato, may be right. Equations of regression (table 2, figure 1) which describe the above mentioned relation ($W_{wew}- C_{pr}$) had low values of coefficients of determination of the trend line (regression models explain only in 52% in case of Raja variety and in 62% in case of Kuras variety, the impact of the simple sugars content on the formation of internal damages of potato tubers).

Table 2
Equations of regression for statistically significant correlations between factors $W_{wew}- C_{pr}$

Potato variety	Regression of equations	Value of coefficient of determination
Kuras	$y = 12.67x + 18.8$	$R^2 = 0.62$
Raja	$y = 9.19x + 9.81$	$R^2 = 0.52$

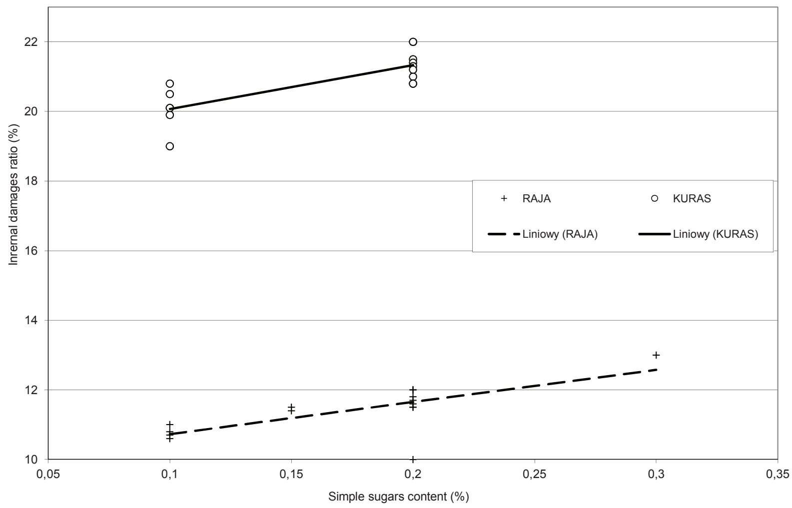


Figure 1. Relation between the content of simple sugars and the content of the ratio of damages to potato tubers of Raja and Kuras variety

Table 3

Results of one-factor analysis of variance - impact of the investigated dependent variables on the differences between the potato varieties accepted in the experiment.

Variable	Sums of squares	Mean sums of squares	Error of the sum of squares	Error of the mean sum of squares	Value of F test	Level p
C_{pr}	0.1069	0.018	0.305	0.003	5.732	0.000
F	92.545	15.424	76.58	0.782	19.738	0.000
W_{zew}	1534.2	255.7	23.8	0.243	1054.8	0.000
W_{wew}	6998.2	1166.4	46.5	0.474	2460.8	0.000
W_{mas}	5411.2	901.9	74.2	0.757	1191.5	0,000

Results of the analysis of variance (table 3) indicate the occurrence of significant differences between the potato varieties accepted in the experiment. Significant value of Snedecor F-test was a premise to carry out multiple comparisons in order to select uniform groups of dependable variables. The post-hoc tests which were carried out (table 4-8) showed existence of 3 homogeneous groups in case of the simple sugars content in tubers of the investigated potato varieties, 4 groups in case of the force value which caused damage to periderm of a tuber on the border of its biological strength and 7 homogeneous groups in case of susceptibility of varieties to both external, internal and mass damages. The structure of homogeneous groups which includes the content if simple sugars in tubers is probably dictated by the similarity of varieties on account of their starch content; Raja and Kuras respectively 15.6 and 19.3%; Ditta, Arrow, Agata and Gala approx. 13% and

Roko 12%. Diversity of the investigated varieties on account of susceptibility of tubers to mechanical damages was the expected result. Potato tubers, used in the experiment may be included to varieties, in relation to a variety, to highly resistant as well as to very susceptible to mechanical damages (3-9 w 9º of IHAR scale). Some discrepancies with regard to the values of ratios of damages obtained in tests referred to ratios included in *Charakterystyce krajowego rejestru odmian ziemniaka IHAR* [*IHAR's Characteristics of the national register of potato varieties]* may be dictated by the fact, that in the presented experiment, all varieties were harvested in one term in order to obtain material in the stage of full technical maturity. In case of tests on the mechanical damages resistance, IHAR collects material according to the date of harvesting predicted for a given earliness of a variety. In such case, it may happen that the collected potato tubers do not have fully shaped periderm and thus their susceptibility to damages will be higher.

Table 4

Tukey's test result for multiple comparisons – differences between the simple sugars content damages in relation to the potato variety

Potato variety	C_{pr} (°Brix scale)	1	2	3
KURAS	0.16	***		
RAJA	0.17	***		
DITTA	0.23		***	
ARROW	0.23		***	
AGATA	0.23		***	
GALA	0.23		***	
ROKO	0.25			***

Table 5

Tukey's test result for multiple comparisons – differences between the values of the force which damages the bulb periderm in relation to the potato variety

Potato variety	F (N)	1	2	3	4
ARROW	8.71	****			
RAJA	9.35		****		
ROKO	9.37		****		
DITTA	10.16			****	
GALA	10.19			****	
AGATA	10.55			****	
KURAS	11.83				****

Table 6

Tukey's test result for multiple comparisons – differences between the value of the tuber internal damages ratio in relation to the potato variety

Potato variety	W_{wew} (%)	1	2	3	4	5	6	7
AGATA	0.00	****						
ARROW	3.92		****					
GALA	8.14			****				
RAJA	11.53				****			
DITTA	19.63					****		
KURAS	20.83						****	
ROKO	22.33							****

Table 7

Tukey's test result for multiple comparisons – differences between the value of the tuber external damages ratio in relation to the potato variety

Potato variety	W_{zew} (%)	1	2	3	4	5	6	7
GALA	0.00	****						
DITTA	1.44		****					
KURAS	4.46			****				
ROKO	6.36				****			
RAJA	7.25					****		
AGATA	9.65						****	
ARROW	11.33							****

Table 8

Tukey's test result for multiple comparisons – differences between the value of the tuber mass damages ratio in relation to the potato variety

Potato variety	W_{mass} (%)	1	2	3	4	5	6	7
GALA	8.08	****						
AGATA	9.64		****					
ARROW	14.96			****				
RAJA	19.12				****			
DITTA	20.67					****		
KURAS	25.33						****	
ROKO	29.01							****

Conclusions

1. A statistically significant relation, measured with the value of the coefficient of correlation, between the simple sugars content and susceptibility to internal damages was determined only in potato tubers of Kuras and Raja varieties.
2. All dependent variables (content of simple sugars, value of the force that damages periderm and indexes of external, internal and mass damages) significantly differentiated potato varieties accepted for the experiment.

References

Gancarz, M.; Konstankiewicz, K.; Pawlak, K. (2005). Variability of parameters of cellular structure in potato tubers. *Acta Agrophysica, 6*(3), 625-638.

Hejtmánková, K.; Kotíková, Z.; Hamouz, K.; Pivec, V.; Vacek, J.; Lachman, J. (2013). Influence of flesh colour, year and growing area on carotenoid and anthocyanin content in potato tubers. *Journal of Food Composition and Analysis, 32*(1), 20-27.

Jakubowski, T. (2009). Wytrzymałość biologiczna skórki bulw ziemniaka napromieniowanych mikrofalami. *Acta Agrophysica, 13*(3), 685-693.

Konstankiewicz, K.; Pawlak, K.; Zdunek, A. (2001). *Influence of structural parameters of potato tuber cells on their mechanical properties. International Agrophysics, 4*, 243-246.

Krzysztofik, B.; Nawara P. (2003). Zmiany właściwości bulw ziemniaka wynikające z czynników agrotechnicznych. *Acta Agrophysica, 2*(4), 777-786.

Lærke, P.; Christiansen, J.; Veierskov, B. (2002). Colour of blackspot bruises in potato tubers during growth and storage compared to their discolouration potential. *Postharvest Biology and Technology, 26*(1), 99-111.

Marks, N. (2009). *Mechaniczne uszkodzenia bulw ziemniaka*. Kraków, PTIR, ISBN 83-917053-7-4.

Marks, N.; Krzysztofik, B.; Sobol, Z. (2000). Wpływ obciążenia bulw w masie na jej odporność mechaniczną. *Inżynieria Rolnicza, 8*(19), 141-147.

McGarry, A.; Hole, C.; Drew, R.; Parsons, N. (1996). Internal damage in potato tubers. *Postharvest Biology and Technology, 8*(4), 239-258.

Molema, G.J. (1999). Mechanical force and subcutaneous tissue discolouration in potato. PhD thesis, Wageningen University, Netherlands, 1-117.

Roztropowicz, S. (1999). Metodyka obserwacji, pomiarów i pobierania prób w agrotechnicznych doświadczeniach z ziemniakiem. *Instytut Hodowli i Aklimatyzacji Roślin Oddział Jadwisin*, 5-50.

Shock, C.; Holmes, Z.; Stieber, T.; Eldredge, E.; Zhang, P. (1993). The effect of timed water stress on quality, total solids and reducing sugar content of potaoes. *American Potato Journal, 70*(3), 227-241.

Wieczer, A.; Gonczarik, M. (1977). *Fizjologia i biochemia ziemniaka.* Warszawa, PWRiL, ISBN 633.491:581.1.

Wojdyła, T.; Pińska, M.; Rolbiecki, S.; Rolbiecki, R. (2009). Wpływ mikronawodnień na zawartość skrobi i cukrów w bulwach wybranych odmian ziemniaków po zbiorach i przechowywaniu. *Infrastruktura i Ekologia Terenów Wiejskich,6*, 293-302.

Yue, Z.; Hébraud, P.; Hemar, Y.; Ashokkumar, M. (2012). Quantification of high-power ultrasound induced damage on potato starch granules using light microscopy. *Ultrasonics Sonochemistry, 19*(3), 421-426.

Zgórska, K.; Frydecka-Mazurczyk, A. (2000). Wpływ warunków w czasie wegetacji oraz temperatury przechowywania na cechy, jakości ziemniaków przeznaczonych do przetwórstwa. *Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin, 213*, 239-252.

Zgórska, K.; Frydecka-Mazurczyk, A. (2002). *Rozmieszczenie suchej masy i sacharydów w różnych częściach bulw ziemniaka. Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin, 489*, 327-334.
Charakterystyka krajowego rejestru odmian ziemniaka. Jadwisin, Instytut Hodowli I Aklimatyzacji Roślin, 2011. Obtained from: http://www.ihar.edu.pl/ziemniak.php.

ZALEŻNOŚĆ MIĘDZY ZAWARTOŚCIĄ CUKRÓW PROSTYCH W BULWIE ZIEMNIAKA A JEJ WYTRZYMAŁOŚCIĄ NA OBCIĄŻENIA MECHANICZNE

Streszczenie. W pracy poszukiwano zależności między zawartością cukrów prostych w bulwie ziemniaka a jej wytrzymałością na obciążenia mechaniczne. Badano bulwy ziemniaka odmian: Kuras, Gala, Agata, Ditta, Arrow, Roko i Raja. Wyznacznikiem podatności bulwy ziemniaka na uszkodzenia mechaniczne były: siła uszkadzająca perydermę, wskaźniki uszkodzeń zewnętrznych i wewnętrznych oraz uszkodzeń masowych. Pomiar zawartości cukru w bulwie ziemniaka wykonano przy użyciu refraktometru. Statystycznie istotną zależność, mierzoną wartością współczynnika korelacji, między zawartością cukrów prostych a podatnością na uszkodzenia wewnętrzne stwierdzono wyłącznie w bulwach ziemniaka odmian Kuras i Raja.

Słowa kluczowe: ziemniak, cukier, uszkodzenie

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):77-84

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.108

COMPARISON OF ECONOMIC EFFICIENCY OF MAIZE CULTIVATION FOR GRAIN IN FARMS, WHICH USE VARIOUS FIELD CULTIVATION TECHNOLOGIES

Paweł Kołosowski*, Tomasz K. Dobek, Patrycja Sałagan

Department of Construction and Use of Technical Devices
West Pomeranian University of Technology in Szczecin
*Contact details: ul. Papieża Pawła VI/3, 71-459 Szczecin, e-mail: Pawel.Kolosowski@zut.edu.pl

ARTICLE INFO

Article history:
Received: October 2014
Received in the revised form: December 2014
Accepted: February 2015

Keywords:
glyphosate
production costs
traditional technology
simplified technology
economic efficiency ratio

ABSTRACT

The increasing crop production costs force to search for alternative cultivation methods of particular crop species, which would reduce production costs and obtain higher income at similar yield. The objective of the research was to evaluate the economic efficiency of maize production for grain. The scope of research covered a simplified and traditional technology of maize cultivation for grain. Maize production costs and costs of fuel, human work, materials and raw materials as well as operation of machines and tools used in the investigated technologies, were calculated. Revenue and income from maize production in the investigated farms were determined. The research, which was carried out, shows that a higher value of the economic efficiency ratio was obtained in the simplified technology of production, where it was at the average of 2.06. Whereas, in the traditional technology, average value of the evaluated ratio was 1.91.

Introduction

Maize is a thermophilic plant, which due to biological progress may be successfully cultivated at a more extended area of the country. Its early varieties with low value of FAO index are recommended for cultivation in the furthest north regions of our country. It concerns not only silage varieties but also varieties cultivated for grain. It is a plant which is comprehensively use in agriculture, which is fine on weaker stands and with periodical water deficiencies (Jasińska and Kotecki, 2003; http://piorin.gov.pl). Therefore, since 2009 area of its cultivation has systematically risen in Poland (Main Statistical Office, 2013).

Maize is a plant, which bears well simplification in soil cultivation. In extreme cases, cultivation treatments may be entirely eliminated or may be limited to cultivation of a narrow area around rows (Banasiak et al., 1999; Piechota, 2011). In some conditions reduction of the number of treatments may result in the increase of the obtained maize crop. However, it is related to intensification of pressure from weeds, which are not destroyed in mechanical soil cultivation (Sekutowski and Rola, 2010; Blecharczyk et al., 2004). Furthermore, giving up treatments limits the scope of available herbicides for foliar fertilization because substances applied to soil are designed for use in well cultivated soil. Weeds developing on the surface of a field, not damaged during a fall ploughing and slightly limited during spring cultivation treatments, have considerably prevail over maize. It mainly concerns perennial weeds such as couch grass. A low rate of growth of maize in its initial growth stages makes undesired plants effective competitors for the cultivated plant, limiting as a result the obtained crop. One of the methods of eliminating weeds after sowing but before maize germination is the use of total herbicides. This treatment is very effective, cheap and does not obstruct the cultivated plant. Glyphosate *(N-phosphonomethyl glycine)* is currently one of the most popular active total herbicide substances (Kołosowski et al., 2013; Woźnica and Waniorek, 2008). Presently, 5 preparations which include active substance, designed for pre-germination combating of weeds in maize, are registered in Poland (www.ior.poznań.pl). Their use combined with simplifications in soil cultivation may prove to be a good solution for many agricultural farms, which cultivate or are going to cultivate maize. A simplified maize cultivation technology combined with the use of glyphosate allows not only reduction of the incurred costs but also enables more efficient organization of field works and allows limitation of selective herbicides.

Objective, scope of work and methodology of research

The objective of the research was evaluation of the economic effectiveness of maize production for grain. The scope of research covered two farms with a simplified and traditional technology of maize cultivation for grain. The paper deals with analysis of economic profitability of maize production. The analysis included calculation of costs incurred for particular treatments (cultivation of field, fertilization, sowing, protection and harvesting) as well as costs related directly to maize production and provision of: costs of human work, fuel, exploitation of machines and tools and costs incurred for purchase of materials and raw materials indispensable for maize production. Costs were calculated based on the methodology developed by IBMER [Institute for Construction, Mechanization and Electrification in Agriculture] (Muzalewski, 2010). Moreover, revenue from sale of the produced grains within 2011 and 2013 was calculated. The lists were used for calculation of the income from production and index of economic effectiveness, understood as a relation of the production value to the incurred costs per one hectare. Tests were carried out in two agricultural farms located in Zachodniopomorskie Voivodeship, which uses different technologies of field cultivation in production of maize for grains. The tests were carried out within 2011-2013. The first agricultural farm (marked as A) used a simplified technology of field cultivation with a pre-germination use of glyphosate, the second farm (marked as B) a traditional technology with fall ploughing (table 1). These farms carry out maize cultivation in similar soil conditions and have a similar machinery park (table 2).

The investigated agricultural farms farm on weaker stands from IVb, V and VI of soil classification. The farm A has acreage of 48 ha and maize within three years of research was cultivated on the area from 12 to 14 ha. The farm B has 54 ha and maize cultivation took 15 ha in each year. In both farms, cereals were a forecrop. The investigated agricultural farms sowed mixed varieties with FAO up to 240, used selective herbicides with a similar composition and applied comparable doses of mineral fertilizers and doses of foliar fertilization. The farm A, using a simplified technology in the research period carried out a pre-sowing manure fertilization in the dose of 30 $m^3 \cdot ha^{-1}$ whereas farm B in its traditional technology applied manure only in the season of 2013 also in the dose of 30 $m^3 \cdot ha^{-1}$. The applied manure came from the same animal farm, which allows presumption that the used natural fertilization had similar parameters. Harvest of maize grains was carried out in the full maturity stage at the moisture of approx. 30%.

Table 1
Comparison of technologies used in investigated farms

Simplified technology – farm A		Traditional technology – farm B	
Date of treatment	Treatment	Date of treatment	Treatment
VIII/2	Disc harrowing	XI/3	Winter ploughing
IV/2	Manure fertilization	III/3	Harrowing
IV/2	Spring cultivation	IV/2	Manure fertilization (only 2013)
IV/3	Sowing with chaff riddle of fertilizers	IV/2	Spring cultivation
V/1	Treatment with total herbicide	IV/3	Sowing with chaff riddle of fertilizers
V/2	Treatment with selective herbicide	V/2	Treatment with selective herbicide
V/2	Top dressing N	V/2-V/3	Foliar fertilizing
V/2 – VI/2	Foliar fertilizing	V/3	Top dressing
X/2 – XI/3	Harvest	X/3-XI/1	Harvest

Table 2
Aggregates used in maize production for grain technologies in investigated farms

Treatment	Farm A	Farm B
Field cultivation	Ursus 1002 + aggregate Unia Ares 3.0 TL (2011)* New Holland T 6.165 + aggregate Unia Ares 3.0 TL (2012 and 2013)*	New Holland T 5.115 + Unia Ibis XL New Holland TD 85 + aggregate Unia Ares 3.0 TL
Manure fertilization	Ursus 1614 + waste removal vehicle 12.6 m^3 (2011)* New Holland T 6.165 + waste removal vehicle 12.6 m^3 (2012 and 2013)*	New Holland T 5.115 + waste removal vehicle 12.6 m^3
Mineral fertilization	Ursus 1002 + spreader Unia MX 1200	New Holland TD 85 + spreader Unia MX 1200
Sowing	New Holland T 6.165 + seeder Maschio Gaspardo SP 4 -row	New Holland TD 85 + seeder Maschio Gaspardo SP 4-row
Protective treatments	Ursus C 330 + sprayer Skotarek P 124	New Holland TD 85 + sprayer Krukowiak 600
Harvest	Case Axial 1629 (service)	Case Axial 1629

* season, when the provided units were used

Results

The most important element in the structure of operation costs of machines in the simplified technology (farm A) were costs related to natural and mineral fertilization, which was related to the use of organic manure fertilization which was carried out in each year. These costs were at the average of 615.30 PLN·ha^{-1} (table 3). Whereas in traditional technology (farm B) the costs of harvesting (except for season 2013) constituted the highest value in the structure of costs of machines and tools operation. Special attention should be paid to approximately 5 times higher average costs of field cultivation in a traditional technology than the costs of field cultivation in a simplified technology (fig. 1), which resulted from fall ploughing in this farm.

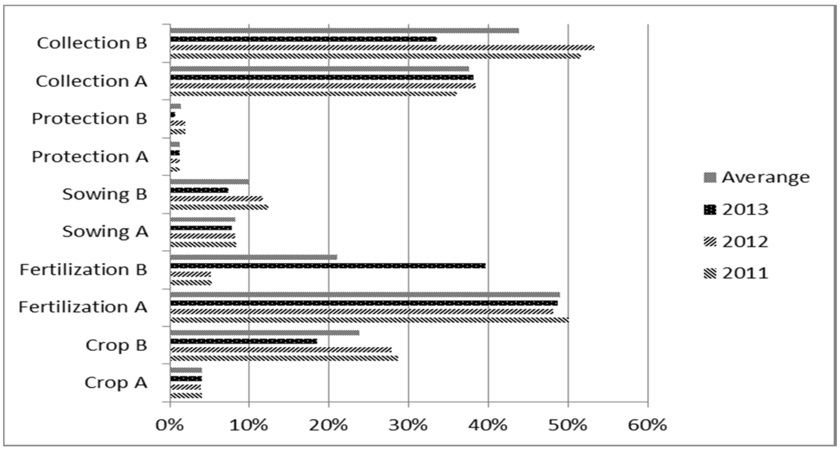


Figure 1. Operation costs of machines used for maize production in farms, which use simplified technology (A) and traditional one (B) divided into treatment groups

Table 3
Costs of treatments in corn production for grain in analysed technologies

Year	Farm	Unit	2011	2012	2013	Average
Cultivation	A		47.37	51.58	52.80	50.58
	B		238.19	266.97	280.51	261.89
Fertilization	A		584.13	628.34	633.42	615.30
	B		43.89	49.00	599.52	230.80
Sowing	A	(PLN·ha^{-1})	98.05	106.73	102.16	102.31
	B		103.51	112.28	112.23	109.34
Protection	A		14.91	16.38	15.77	15.69
	B		16.32	18.14	10.27	14.91
Harvest	A		420.00	500.00	495.00	471.67
	B		429.15	511.20	507.32	482.56

Costs of materials and raw materials for production in the structure of direct costs in both farms constituted the most important element in the structure of direct costs in both farms, which at the average in three years of research amounted to 1258.97 PLN·ha^{-1} in the farm which used a traditional technology and 1281.23 PLN·ha^{-1} in the farm with a simplified technology (table 3). Costs of operation of machines and tools in the farm A were by approx. 22% higher than in the farm B. Also fuel costs were higher there by 12% (table 4). Whereas, costs of human work in both farms were at a similar level.

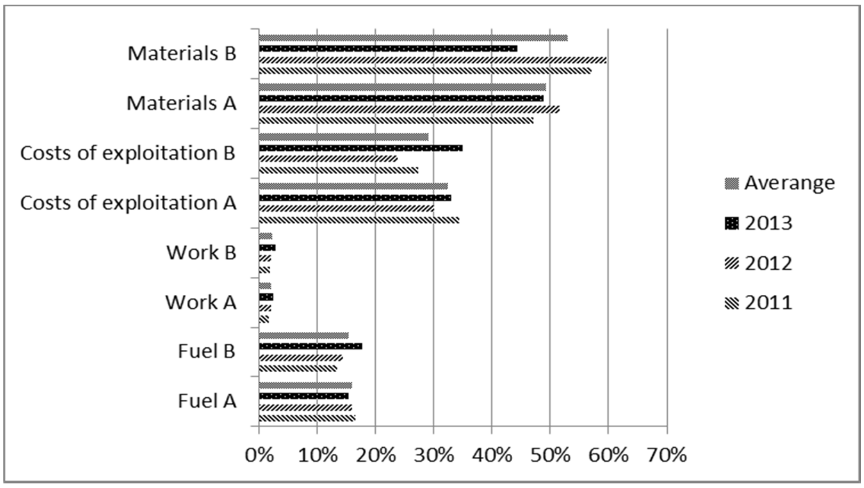


Figure 2. Costs of direct maize production in farm with simplified technology (A) and traditional one (B)

Table 4
Direct costs of corn production for grain in the analysed technology

Year	Farm	Unit	2011	2012	2013	Average
Costs of fuel	A		378.94	451.08	412.24	414.09
	B		275.82	341.50	482.83	366.71
Costs of human work	A		41.46	63.03	69.33	57.94
	B	(PLN·ha^{-1})	39.55	49.21	78.25	55.67
Operation costs of machines and tools*	A		785.52	851.96	886.92	841.47
	B		555.23	566.88	948.79	690.30
Costs of materials and raw materials	A		1077.03	1460.38	1306.28	1281.23
	B		1158.63	1412.20	1206.08	1258.97

* with no costs of fuel and human work

Average costs of maize production per one hectare of crop were higher in the farm A with a simplified technology. They amounted to 2595 PLN·ha^{-1} and were higher by 223 PLN·ha^{-1} than the costs incurred by the farm B with a traditional technology. Higher costs incurred in the farm A are caused by expensive manure fertilization, which they use every year. In the season 2013, when also the farm B fertilized plantations with natural fertilizers, the costs incurred by both farms were at a similar level. Within three years, the farm which uses a simplified technology obtained higher crops of grain. It had greater effect on the revenue from production. Average revenue obtained from the farm A was 5248 PLN·ha^{-1} and was by 15% higher than in the farm B. The smallest difference in revenues from production was obtained in 2013 and it was 266 PLN·ha^{-1}. Considerably higher revenue from production was developed by the farm A with a simplified technology, it resulted in a higher revenue obtained by them. Average income from production of this farm was by 586 PLN·ha^{-1} higher. What is interesting, in all years of research both farms reported a considerable majority of revenue from sale of grains over the incurred costs. It resulted in obtaining the index of economic efficiency above the value of 1, which constitutes the threshold of profitability. Average index of economic efficiency was higher in farms, which use a technology based on the total herbicide treatment and simplified field cultivation and was 2.06. This index reached the maximum value of 2.64 in 2011, whereas the lowest value was obtained for 2013 – 1.72. In the farm B with a traditional technology, this value was 1.91 (table 4) and was from 2.43 in 2011 to 1.60 in 2013.

Table 4
Economic effectiveness of maize production in farms with simplified technology (A) and traditional one (B)

Year	Cost of production (PLN·ha^{-1})		Revenue from production (PLN·ha^{-1})		Income from production (PLN·ha^{-1})		Index of economic effectiveness	
	A	B	A	B	A	B	A	B
2011	2283	2029	6016	4935	3733	2906	2.64	2.43
2012	2826	2370	5130	4050	2304	1680	1.81	1.71
2013	2675	2716	4598	4332	1923	1616	1.72	1.60
Average	2595	2372	5248	4439	2653	2067	2.06	1.91

Manure fertilization was significant for the obtained yield. It is particularly visible in 2011 and 2012 seasons, when a farm with a simplified technology obtained considerably higher incomes. It complies with the research carried out by Sulewska et al. (2007), which proved a positive impact of manure fertilization on the obtained yield of grain and maize silage.

Conclusions

In both analysed farms, costs of materials and raw materials were the most important element of maize production costs structure. While, the lower costs relate to human work costs. The highest costs in the farm A, which used a simplified technology, were related to manure organic fertilization and mineral fertilization; those costs were at the average of 615.30 PLN·ha^{-1}. Whereas, in the farm B, with a traditional technology, the most expensive treatment was harvest with the average of 489 PLN·ha^{-1}.

In both farms (A and B) the lowest costs were related to plant protection chemicals, with the average of 15 PLN·ha^{-1}.

Due to higher yield in a farm with the simplified technology in this farm, a considerably higher value of production was obtained, at the average by 809 PLN·ha^{-1}. It was crucial in the evaluation of the production profitability. In the analysed conditions, a simplified technology proved to be more profitable, which was proved by a higher value of the economic effectiveness of maize production for grain.

References

Banasiak, J. (red). (1999). *Agrotechnologia.* Warszawa-Wrocław. Wyd. Naukowe PWN, ISBN 83-01-12697-3.

Blecharczyk, A.; Małecka, I.; Skrzypczak, G. (2004). Wpływ uproszczonej uprawy roli na plonowanie i zachwaszczenie kukurydzy oraz na właściwości gleby. *Acta Sci. Pol., Agricultura, 3*(1), 157-163.

GUS. (2013). Wyniki produkcji roślinnej w 2012 r. Warszawa, ISSN 1507-9678. Obtained from: *http://www.stat.gov.pl.*

Jasińska, Z.; Kotecki, A. (red). (2003). *Szczegółowa uprawa roślin.* T.1, Wyd. AR we Wrocławiu, ISBN 83-89189-16-X.

Kołosowski, P.; Dobek, T.; Sałagan, P. (2013). Analiza efektywności ekonomicznej alternatywnej technologii uprawy kukurydzy na ziarno z wykorzystaniem glifosatu. *Inżynieria Rolnicza 4*(147), T.1,121-128.

Metodyka integrowanej produkcji kukurydzy. (2009). Państwowa Inspekcja Ochrony Roślin i Nasiennictwa – Główny Inspektorat Warszawa. Obtained from: *http://piorin.gov.pl*.

Muzalewski, A. (2010). *Koszty eksploatacji maszyn*. Wyd. ITP Falenty-Warszawa.

Piechota, T. (2011). Wpływ międzyplonu na zachwaszczenie kukurydzy w różnych systemach uprawy roli. *Progress in Plant Protection/Postępy w Ochronie Roślin, 51*(1), 469-472.

Sekutowski, T.; Rola, H. (2010). Wpływ monokultury i systemu uprawy roli oraz ochrony herbicydowej na agrofitocenozę kukurydzy. *Fragm. Agron., 27*(1), 128-140.

Sulewska, H.; Koziara, W.; Panasiewicz, K.; Jazic, P. (2007). Efekty stosowania nawozów naturalnych w uprawie kukurydzy na ziarno i kiszonkę. *Journal of Research and Applications in Agricultural Engineering, 52*(4), 75-79.

Baza środków ochrony roślin. Instytut Ochrony Roślin, Poznań. Obtained from: *http://www.ior.poznan.pl/baza/*

Woźnica, Z.; Waniorek, W. (2008). Znaczenie kondycjonerów wody dla skuteczności chwastobójczej glifosatu. *Progres in Plant Protection/Postęp w Ochronie Roślin, 48*(1), 329-335.

Paweł Kołosowski, Tomasz K. Dobek, Patrycja Sałagan

PORÓWNANIE EFEKTYWNOŚCI EKONOMICZNEJ UPRAWY KUKURYDZY NA ZIARNO W GOSPODARSTWACH STOSUJĄCYCH RÓŻNE TECHNOLOGIE UPRAWY ROLI

Streszczenie. Ze względu na wzrastające koszty produkcji roślinnej poszukuje się alternatywnych metod uprawy poszczególnych gatunków roślin, które pozwolą ograniczyć koszty produkcji i, przy podobnych plonach, uzyskać wyższy dochód. Celem przeprowadzonych badań była ocena efektywności ekonomicznej produkcji kukurydzy na ziarno. Zakres badań obejmował uproszczoną i tradycyjną technologię uprawy kukurydzy na ziarno. Obliczono koszty produkcji kukurydzy z uwzględnieniem kosztów paliwa, kosztów pracy ludzkiej, kosztów materiałów i surowców oraz kosztów eksploatacji maszyn i narzędzi stosowanych w badanych technologiach. Określono przychód i dochód z produkcji kukurydzy w badanych gospodarstwach. Z przeprowadzonych badań wynika, że wyższą wartość wskaźnika efektywności ekonomicznej uzyskano w uproszczonej technologii produkcji, gdzie wyniosła ona średnio 2,06. Natomiast w technologii tradycyjnej średnia wartość ocenianego wskaźnika wyniosła 1,91.

Słowa kluczowe: glifosat, koszty produkcji, tradycyjna technologia, uproszczona technologia, wskaźnik efektywności ekonomicznej

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):85-93

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.109

COST ANALYSIS OF PREPARATION AND DISCHARGE IN SELECTED TIED-UP CATTLE BARNS

Marcin Majchrzak*, Jan Barwicki, Witold Jan Wardal, Kamila Mazur, Kinga Borek

Institute of Technology and Life Sciences, Warsaw Branch, Poland

*Contact details: ul. Rakowiecka 32, 02-532 Warszawa, e-mail: m.majchrzak@itp.edu.pl

ARTICLE INFO

Article history:
Received: January 2015
Received in the revised form: January 2015
Accepted: February 2015

Keywords:
feeding treatment
exploitation costs
labour inputs

ABSTRACT

Research work was conducted in 4 tied-up cattle barns with herd size 44.85-109 LU. It covers analysis of preparation and discharge of feed using machinery and equipment involved in this treatment. It also presents specified exploitation costs of machinery and equipment in livestock buildings and components of these costs such as maintenance cost and annual utilization of the machines. Also specified labor costs during treatment of feeding were described.

Introduction

Cattle feeding is one of the most important and necessary elements of production economy and has great influence on growth and development of animals, their health and productivity (Krzyżewski and Reklewski, 1997). Desirable results can be achieved when total mixed ration of feed can be obtained from mixing of concentrate and bulky feeds with vitamin and mineral supplements. To achieve the highest level of animal production, an increasing number of farms are equipped in modern machinery and equipment, and even in whole feeding lines for discharge of concentrate and bulky feeds.

The rational feeding system must meet the following requirements (Romaniuk et al., 2011b):

- feeds should fully cover animals demand for energy, protein, vitamins and mineral salts;
- discharge feeds, with appropriate quantity, should have a good quality, corresponding to the accepted standards;
- used feed methods should provide proper reproductive processes keeping animals in good health and provide good economic effects on total farm productivity;
- feeds for dairy cattle should be discharged in the form of a complete mixture (e.g. TMR), mixed in a mixer wagon using concentrate, bulky feeds and mineral ingredients as well;
- feed production should allow application of full mechanization during plants cultivation, maintenance, storage and feeding.

In cattle feeding it is very important to have high quality roughage. Feeds rations in bulky feeds are very diverse in terms of nutritional value. When increasing animal production it is very important to choose a proper feeding and discharge method. The feed ration must have both appropriate amount of minerals and energy (Winnicki et al., 2009).

The objective and scope of study

The objective of study was to analyze the cost of preparation and discharge of feeds. Also specified exploitation costs of machinery and equipment used in the cattle feeding and labor inputs that occur in the studied livestock buildings were taken into consideration.

The scope of the study includes studies conducted in 4 tied-up cattle barns with the herd size of 44.85-109 LU, characteristics of machinery and equipment for preparation and discharge of feeds, exploitation costs and labor input parameters.

Methods

The study was conducted taking into account the guidelines included in the research carried out by (Muzalewski, 2010; Gancarz, 2007 and 2010; Romaniuk et al., 2011a, b) – for example 4 tied-up cattle barns on farms. In the feeding treatment a mobile mixing wagon or hanged feeding robots were utilized. The calculations were conducted according to the following formulas:

Exploitation cost – K_e concerning machinery and equipment utilized for the mechanization of preparation and discharge of feeds, K_e consists of maintenance cost K_{utrz} and total costs $K_{uż}$ (Muzalewski, 2010; Gazzarin and Lips, 2013):

$$K_e = K_{utrz} + K_{uż} \ \text{(PLN·year}^{-1}\text{)} \tag{1}$$

K_{utrz} – maintenance cost,
$K_{uż}$ – operating costs.

The combined maintenance costs are the sum of depreciation costs K_a and insurance costs K_{ub}. Dividing the sum of costs by the equipment operating time in the year W_R, unitary cost of machines maintenance per 1 hour was obtained (Muzalewski, 2010; Gazzarin and Lips, 2013).

$$K_{utrz} = K_a + K_{ub} \ \text{(PLN·year}^{-1}\text{)} \tag{2}$$

Depreciation expenses are costs of replacement in the value of a particular machine. At the time of its use by a fixed number of years T_{lat}, the depreciation costs are equal to the value of total machine market cost C_m (Muzalewski, 2010).

$$K_a = \frac{C_m}{T_{lat}} \ \text{(PLN·year}^{-1}\text{)} \tag{3}$$

Insurance costs K_{ub} of machines were adopted according to the data provided by the farmers of the investgated objects.

The operating costs of equipment were as follows (Muzalewski, 2010):

$$K_{uż} = K_r + K_{ee} + K_{em} + K_n \quad (PLN \cdot year^{-1}) \tag{4}$$

K_r – labor inputs costs, ($PLN \cdot year^{-1}$)
K_{ee} – cost of the electricity consumed by machinery and equipment, ($PLN \cdot year^{-1}$)
K_{em} – mechanical energy costs, ($PLN \cdot year^{-1}$)
K_n – repair costs, ($PLN \cdot year^{-1}$)

Labor costs (Muzalewski, 2010):

$$K_r = N_r \cdot N_{DJP} \cdot C_j \quad (PLN \cdot year^{-1}) \tag{5}$$

$$N_r = n'_r \cdot 200\ days + n''_r \cdot 165\ days \quad (man\text{-}hour \cdot year^{-1}) \tag{6}$$

N_r – labor inputs costs, ($man\text{-}hour \cdot year^{-1}$)
n'_r – unitary labor inputs in the winter, ($man\text{-}hour \cdot LU^{-1} \cdot day^{-1}$)
n''_r – unitary labor inputs in the summer, ($man\text{-}hour \cdot LU^{-1} \cdot day^{-1}$)
C_j – labor cost, ($PLN \cdot h^{-1}$)
n'_r i n''_r = 60 minutes = working hour
N_{DJP} – number of animals based on the LU

Costs of repair (Muzalewski, 2010):

$$K_n = \sum_{i=1}^{n} S \cdot \left(\frac{C_m}{T_{lat}}\right) \quad (PLN \cdot year^{-1}) \tag{7}$$

S=0.6-1.1 factor of the repair costs depending on the machinery or equipment (based on data from the System of Agriculture Machinery IBMER *[Institute for Construction, Mechanization and Electrification in Agriculture]* (SMR).

$$k_e = \frac{\sum_{i=1}^{n} K_{utrz} + \sum_{i=1}^{n} K_{uż}}{N_{DJP}} \quad (PLN \cdot year^{-1} \cdot LU^{-1}) \tag{8}$$

k_e – unitary cost of exploitation for feed preparation and discharge
N_{DJP} – number of animals based on the LU

Research results

Characteristics of the investigated cattle barns were presented in Table 1. Characteristics of the machines and equipment used in the feeding treatment and their annual use were presented in Table 2 and Table 3: cumulative results of research with different feed discharge systems, machinery and equipment purchase costs, exploitation costs of equipment involved in feed preparation and discharge. Table 4 presents labor input for cows feeding treatment in the investigated barns.

Table 1
Characteristics of investigated barns

No. barn	Cattle maintenance system	Herd size (LU)	Length of feeding corridor (cm)	Width of feeding corridor (cm)
1	tied-up	44.85	3100	450
2	tied-up	54.4	2400	180
3	tied-up	100	3800	278
4	tied-up	109	6200	330

Table 2
Machinery and equipment utilized for mechanization of feeding in investigated farms

No. barn	Utilized machinery	Type	Yearly utilization ($h \cdot year^{-1}$)	Amount (pcs.)	Replacement value (PLN)
1	Tractor	Fendt 62 kW	400	1	120 000
	Front loader	T210	200	1	4 000
	Silage cutter	TU 115	185	1	6 000
	Feeding fences	-	3000	set	10 000
	Water bowls	-	1500	31	3100
	Silo	Michał 8t	4000	2	10 000
	Total outfit (PLN)				153 100
2	Tractor	DeutzFahr 66 kW	300	1	190 000
	Front loader	T210	100	1	4 800
	Silage cutter	-	100	1	11 000
	Feeding fences	-	3000	set	10 000
	Water bowls	-	1500	19	100
	Silo	Michał 10 t	4000	1	8 000
	Feeding robot	Pellon	730	1	37 000
	Mixer for feed concentrates 2 t	-	100	1	12 000
	Total outfit (PLN)				274 700
3	Tractor	John Deere 80 kW	700	1	150 000
	Telescopic loader	Deutz Fahr 66 kW	540	1	220 000
	Robot of bulky feeds	Pellon	800	1	140 000
	Stationary feeder of bulky feeds	Pellon 10 m^3	120	1	58 000
	Front loader	T261	120	1	5 500
	Water bowls	-	1500	13	1 300
	Feeding fences	-	3000	set	19 000
	Silo	Michał 10 t	4000	1	8 000
	Silo	Michał 2 t	4000	1	4 000
	Total outfit (PLN)				610 300
4	Tractor	Ursus 1634; 114 kW	600	1	230 000
	Front loader	T210	150	1	10 000
	Silage cutter	-	120	1	8 000
	Feeding fences	-	3000	set	12 000
	Water bowls	-	1500	54	5 400
	Silo	Pellon 14 m^3	4000	1	7 000
	Robot of concentrate feeds	Pellon	700	1	37 000
	Mixing wagon	Strautman 9 m^3	550	1	40 000
	Total outfit (PLN)				349 400

Table 3
Methods of feeding systems, evaluation of maintenance and exploitation costs

No of barn	Herd size (LU)	Method of feed discharge	Replacement value of machinery and equipment		Maintenance costs $K_{utrz.}$		Exploitation costs	
			(PLN)	(PLN·LU^{-1})	(PLN·year^{-1})	(PLN·year^{-1}·LU^{-1})	(PLN·year^{-1})	(PLN·year^{-1}·LU^{-1})
1	44.85	Manually	153 100	3 413.6	12 134.68	270.56	32 946.34	734.59
2	54.4	Robot for concentrate feeds + manual discharge of bulky feeds	274 700	5 049.63	21 041.35	386.79	41 461.51	762.16
3	100	Robot for bulky feeds	610 300	6 103	54 507.4	545.07	62 250.5	640.29
4	109	Mixing wagon + robot for concentrate feeds	349 400	3 205.50	29 532.01	270.93	69 302.01	635.79

Table 4
Daily labour input for preparation and discharge of feed in investigated farms

No. barn	Operation	Utilization of machinery and equipment	Numbers of workers	Operation time (min)	Days of labour input (work min)
1	Silage cutting	Fendt tractor with silage cutter TU 115	2	30	30
	Feed transportation to barn	Fendt tractor with front loader		20	20
	Feed discharge	Hand work		180	180
Total (work min)			2	230	230
Total (work min LU^{-1})			2	5.12	5.12
2	Silage cutting	Deutz Fahr tractor with silage cutter	1	20	20
	Feed transportation to barn	Deutz Fahr tractor with front loader		5	5
	Refilling of feed in silo	Screw conveyor		6	6
	Batching of bulky feed	Hand work		40	40
Total			1	71	71
Total (work min LU^{-1})			1	1.30	1.30
3	Silage cutting	Telescopic front loader	1	60	60
	Loading stationary feeder Pellon with bulky feeds	Telescopic front loader		30	30
	Refilling of concentrate feed in silo	Screw conveyor		5	5
	Loading of liquid feed	Circulation pump		3	3
	Downloading feed ingredients by robot (automatically)	Screw conveyor		20	0
	Mixing feeds (automatically)	Robot Pellon for bulky feeds		40	0
	Feed discharge (automatically)	Robot Pellon for bulky feeds		120	0
Total			1	278	98
Total (work min LU^{-1})			1	2.78	0.98

No. barn	Operation	Utilization of machinery and equipment	Numbers of workers	Operation time (min)	Days of labour input (work min)
4	Silage cutting	Tractor with silage cutter	1	25	25
	Loading of feed wagon	Tractor with front loader		20	20
	Mixing of bulky feeds	Tractor with mixing wagon		35	35
	Discharge of bulky feeds	Tractor with mixing wagon		25	25
	Loading of concentrate feeds into silo	Screw conveyor		5	5
	Loading of concentrate feed components into robot (automatically)	Screw conveyor		20	0
	Discharge of concentrate feeds by robot (automatical-ly)	Robot Pellon for concentrate feeds		90	0
Total			1	220	110
Total (work min LU^{-1})			1	2.01	1

Figure 1 presents daily labor input depending on the herd size on the farms under research. Comparative evaluation of investment costs of machinery and equipment for feeding mechanization is shown in figure 2. Summary of the comparative exploitation costs of machines and equipment for preparation and discharge of feeds in the tested farms is presented in figure 3.

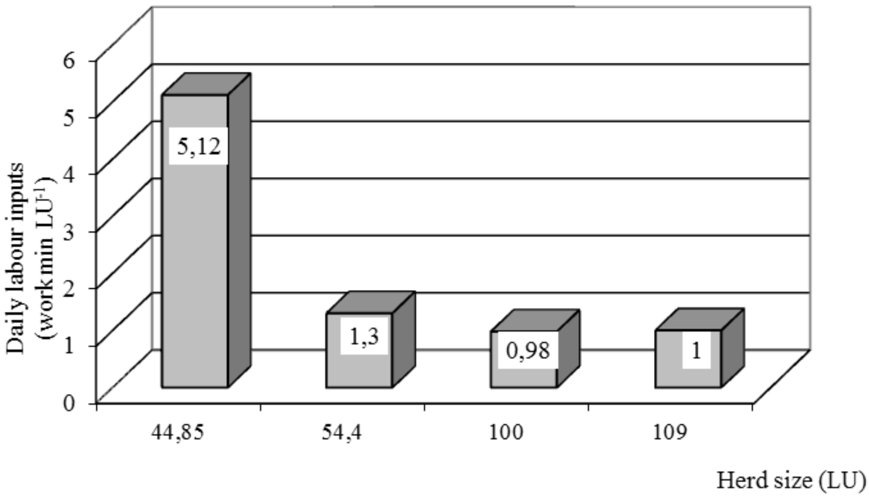


Figure 1. Combined daily labor input per LU in investigated farms

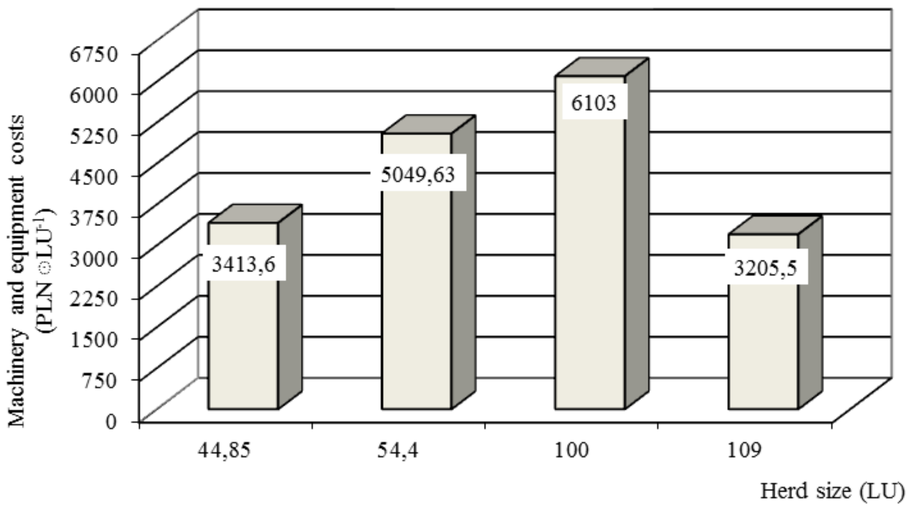


Figure 2. Combined comparative investment costs of machinery and equipment of feeding in farms tested

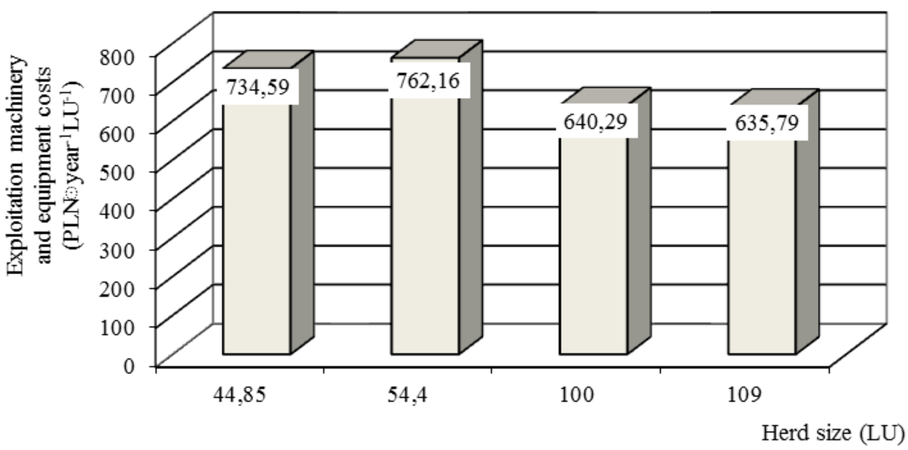


Figure 3. Combined comparative exploitation costs of machinery and equipment for feeding in investigated farms

Conclusion

The study proves that the use of modern machinery and equipment for feeding leads to savings in daily labor input and in the cost involved despite the high herd size.

- The cost of machinery and equipment in the investigated cattle barns was varied was within the range from 3200 to 6100 PLN·LU^{-1}, but they dependent on the herd size and applied mechanization for feed preparation and discharge.
- The highest daily labor input occurred in the cattle barn no. 1 and contained over 5 min·LU^{-1}. This was due to the fact that the feeding system in this barn was performed manually and provided by two service persons. The lowest labor input occurred in the cattle barn no. 3, where, thanks to the use of modern machinery and equipment managed to get the result below 1 man-hour/min·LU^{-1} with the herd size equal to 100 LU.
- The lowest exploitation costs of machinery and equipment were present in barn no. 4 with a result over 635 PLN·year^{-1}·LU^{-1}, which was the most optimal concerning the treatment of preparation and discharge of feed in cattle breeding systems.

References

Gncarz, F. (2007). Analiza kosztów mechanizacji procesu żywienia w oborach wolnostanowiskowych o zróżnicowanej obsadzie krów. *Problemy Inżynierii Rolniczej, Vol. 2,* 153-158.

Garncarz, F. (2010). Koszty wyposażenia i eksploatacji do przygotowywania i zadawania pasz w różnych systemach żywienia krów. *Problemy Inżynierii Rolniczej, Vol. 3*, 85-93.

Gazzarin, C.; Lips, M. (2013). *Maschinenkosten, ART-Bericht vol. 767*, ISBN 1661-756.

Krzyżewski, J.; Reklewski, Z. (1997). *Chów i hodowla zwierząt gospodarskich*. Warszawa. SGGW. ISBN 83-86980-47-8, 284.

Muzalewski, A. (2010). *Koszty eksploatacji maszyn, Vol. 25*. Falenty ITP. ISBN 978-83-62416-05-9.

Romaniuk, W.; Biskupska, K.; Pierednia, V.; Romanovich, A. (2011a). Dobór wozu paszowego mieszającego w zależności od koncentracji bydła w gospodarstwie. *Problemy Inżynierii Rolniczej, Vol. 3*, 121-130.

Romaniuk, W.; Fiedorowicz, G.; Biskupska, K. (2011b). *Analiza standardów technologicznych obór dla krów mlecznych w gospodarstwach rodzinnych i farmerskich*. Monografia. Falenty-Warszawa. ITP. ISBN 978-83-62416-21-9, 66.

Winnicki, S.; Domagalski, Z.; Pleskot, R. (2009). *Technika w zakresie konserwacji, przechowywania i zadawania pasz dla bydła*. Ekspertyza. Poznań. IBMER, 15.

ANALIZA KOSZTÓW PRZYGOTOWANIA I ZADAWANIA PASZ W WYBRANYCH OBORACH STANOWISKOWYCH

Streszczenie. W pracy przeprowadzono badania w 4 oborach stanowiskowych o obsadzie 44.85-109 DJP. Przeanalizowano sposoby przygotowania i zadawania pasz w oborach przy wykorzystaniu maszyn i urządzeń biorących udział w zabiegu żywienia. Dokonano analizy kosztów przygotowania i zadawania pasz dla bydła mlecznego. Określono koszty eksploatacji maszyn i urządzeń w obiektach inwentarskich oraz składowe tych kosztów: koszty utrzymania i koszty użytkowania, wykorzystanie roczne maszyn. Określono również nakłady robocizny, występujące w badanych obiektach inwentarskich w zabiegu żywieniu bydła.

Słowa kluczowe: zabieg żywienia, koszty eksploatacji, nakłady robocizny

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):95-106

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.110

ECONOMIC ANALYSIS OF NON-LITTER CATTLE BARNS

Kamila Mazur*, Jan Barwicki, Marcin Majchrzak, Kinga Borek, Witold Jan Wardal

Institute of Technology and Life Sciences, Warsaw Branch, Poland

**Contact details: ul. Rakowiecka 32, 02-532 Warsaw, e-mail:k.mazur@itp.edu.pl*

ARTICLE INFO

Article history:
Received: January 2015
Received in the revised form: February 2015
Accepted: February 2015

Keywords:
energy inputs
labour inputs
exploitation costs
loose housing

ABSTRACT

The objective of the article was to show exploitation costs from three cattle barns in a non-litter loose housing system. The method was based on the multi criteria approach which referred to following factors: technical, technological (mainly energetic and labour), economic (costs of energy, labour, investment). Within technical assessment, the building characteristics was carried out which pertained to the areas of productivity, building, laying and cubage. In order to carry out technological assessment, all methods of mechanization were analysed and as a result, energetic, energy and investment inputs were obtained. Exploitation costs of machinery, equipment and cattle barn buildings were calculated according to the methodology developed in IBMER *[Institute for Construction, Mechanization and Electrification in Agriculture]*. The lowest exploitation cost was in a cattle barn with a traditional "herring bone" milking unit and amounted to 2 132.01 PLN·year^{-1}·LU^{-1}. The highest exploitation costs amounting to 2 670.65 PLN·year^{-1}·LU^{-1}, were in a cattle barn with one milking robot and the lowest herd size.

Introduction

Adapting buildings, barns and their equipment to the requirements of animal welfare, environmental protection, with ensuring production profitability is a necessary condition for sustainable development in view of the intensification of production (Romaniuk and Mazur, 2014; Mazur, 2012). The overview of literature leads to the conclusion that there are no studies, which fully describe the problem of impact of the applied solutions on the milk production costs in non-littered cattle barns, concerning buildings and their equipment with machinery. The analysis contained the human labour inputs, electrical and mechanical energy inputs, which constituted the basis for calculation of exploitation costs.

Till now, exploitation costs in agricultural production have been the objectives for studies carried out by many researchers (Freiberger et al., 2005, Jucherski and Król, 2011, Majchrzak, 2013, Naes et al., 2010, Muzalewski 2010, Naess and Stokstad 2010, Szulc, 2009; Szulc and Markiewicz, 2010). All these publications only describe chosen technological treatments and their costs, but none of them takes into account total exploitation costs of machinery, equipment and buildings.

The objective of research

The main objective of the performed research was to analyze the influence of technological solutions in non-littered cattle barns on labour, energy inputs and milk production costs.

The fragmentary objectives were as follows:
- determination of investment costs of buildings, equipment and machinery for technological treatment in milk production such as: milking and milk cooling, preparation of feed and feed discharge, manure removal, its storage and other works;
- determination of labour input and the mechanization level in milk production, in particular cattle barns;
- determination of electric and mechanical energy inputs,
- determination of exploitation costs of buildings and equipment for mechanization of all technological treatments.

The scope of research

Among many solutions three free-stall cattle barns were chosen in view of the possibility of mechanization and automation of all technological treatments.

The scope of research covered three cattle barns, which jointly met the following input conditions:
- herd size above 80 LU,
- at least 4^{th} level of mechanization,
- milk yield in herd above 8000 dm^3 milk in extra class.

In particular, the scope of research consisted of such elements as:
- *technical*: description of buildings, construction, mechanization of technological treatments in milk production – machinery and equipment, including three robots for milking, feed scraping and cleaning of slatted floor;
- *technological*: labour inputs, electric and mechanical energy inputs,
- *economic*: investment costs, electric energy costs, mechanical energy costs, labor costs, exploitation costs.

Methodology

The field tests were conducted by a direct moderated interview method, a picture of a working day was taken, and a timing scheme was made. In all buildings the same activities within a year were performed. Unitary exploitation costs of buildings and equipment with machinery taking part in mechanization of four treatments were the sum of the unitary maintenance and use costs. Equations (1) to (3) show the method of calculation of these costs (Muzalewski, 2010; Gazzarin and Lips, 2013; Gazzarin and Hilty, 2002).

$$C_e = \frac{\mathrm{C_m + C_{us}}}{\mathrm{N}} \quad (\mathrm{PLN \cdot LU^{-1} \cdot year^{-1}}) \tag{1}$$

c_e – exploitation costs, (PLN· year^{-1})
C_m – costs of maintenance, (PLN· year^{-1})
C_{us} – operating costs, (PLN· year^{-1})
N – number of Livestock Units (Muzalewski 2010, Gazzarin and Hilty, 2013; Gazzarin and Lips, 2002)

Costs of maintenance:

Costs of maintenance (C_m) were the sum of amortization costs of buildings, machinery and their insurance (eq.2)

$$\mathrm{C_m} = \frac{C_{ib}}{T_b} + \sum \frac{C_{im}}{T_m} + \mathrm{C^b_{ins}} + C_{ui} \quad (\mathrm{PLN \cdot year^{-1}}) \tag{2}$$

C_{ib} – replacement value of buildings, (PLN)
T_b – the assumed stability of the building, (number of years)
C^b_{ins} – insurance costs of building, (PLN·year^{-1})
C_{im} – price (value) replacement of machinery or equipment, (PLN)
T_m – the assumed stability of the machinery, (number of years)
C_{ui} – costs of insurance of machinery and equipment, (PLN·year^{-1}) (Muzalewski 2010)

Operating costs:

$$\mathrm{C}_u = \mathrm{C^b_{ee}} + \mathrm{C}^b_r + \mathrm{C^m_{ee}} + \mathrm{C_{me}} + \mathrm{C^m_r} + \mathrm{C_L} \quad (\mathrm{PLN \cdot year^{-1}}) \tag{3}$$

C_u – operating costs, (PLN·year^{-1})
C^b_{ee} – costs of electrical energy of buildings, (PLN·year^{-1})
C^b_r – costs of repairs in buildings, (PLN·year^{-1})
C^m_{ee} – costs of electrical energy of machinery and equipment for mechanization, (PLN·year^{-1})
C_{me} – costs of mechanical energy, (PLN·year^{-1})
C^m_r – costs of repair of machinery and equipment, (PLN·year^{-1})
C_L – costs of labour inputs, (PLN·year^{-1}) (Muzalewski 2010)

Research results

The farms tested were located in Podlaskie (1 cattle barn) and Mazowieckie Voivodships (2 cattle barns). The size of herds was between 83 and 170 LU (Livestock Units). The milk yield was from 8500 to 9600 liters of milk in extra class. These cattle barns were characterized with at least fourth level of mechanization, i.e. diurnal human labour inputs below 10 working minutes per LU. In two cattle barns milking was conducted by milking robots (Automatic Milking System or Voluntary Milking System), one of them was equipped with a traditional dairy room. The milk cooling was provided in milk tanks, which were situated in milk rooms.

The cattle barns had a separated feeding corridor, on which feed was discharged by mixer wagons with the use of tractors, forage was in the PMR system (Partly Mixed Ratio). A supplementary dose of concentrates was provided in milking robots (2 barns) or in a feeding station (1 barn). The slurry was in deep channels under slatted floor, which was situated in manure-walking alleys, from which it was periodically pumped out. In all tested objects cows were in a non-littered area. The characteristic of the investigated farms and barns concerning the methods of mechanization of particular treatments was presented in Table 1.

Table 1
Characteristic of investigated cattle barns

No. of barn	LU milk yield (dm^3)	Mechanization of treatments: I – milking and milk cooling, II – feeding, III – removing and storing of natural manure; IV – other works			
		I type of dairy unit capacity of milk cooler (dm^3)	II feeding waggon, – company, capacity/ power of engine / the technological line for concentrates feeding	III type of manure, power of tractors engine + capacity of slurry spreader	IV hoof knife power/ swinging brushes power
1	109 9600	„herring bone" 2x5(10) 7000	Siloking 12 m^3/ 110 kW/ 2 feeding stations, spiral transporter, silos 12,5 m^3	slurry, deep channels, tractor 56 kW + slurry spreader 10m^3	electrical 0.25 kW
2	170 8500	2 robots Astronaut A4 10000	RMH 14m^3/ 65 kW/ feeding in two milking robots, spiral transporter, silos 14 m^3 and 15 m^3	slurry, deep channels, tractor 117 kW+ slurry spreader 14.2 m^3	electrical 0.25kW/, 3 electrical swinging cow brushes 0.12 kW
3	83 9500	robot VMS 5000	SEKO 11 m^3/ 80 kW/ feeding in milking robot and 1 feeding station, spiral transporter, silos 8 m^3 and 10 m^3	slurry, deep channels, tractor 90 kW + slurry spreader 12.7 m^3	electrical 0,25kW/ 2 electrical swinging brushes 0.12 kW

Table 2 shows the characteristic of buildings, regarding the area of a building, using, resting areas, cubage, the type of roof construction and a ventilation system, size of slatted floor and capacities of slurry channels.

Two barns had the construction of roof founded on columns, the remaining building had non-columned construction i.e. steel frames. Steel frames although more expensive, are recommended for objects with width up to 30 meters. Due to this solution there are possibilities for future adaptation of a building in case of further development (Romaniuk et.al., 2012). Lack of internal partitions in one-room spaced cattle barns causes, that ventilation is more effective, because there are no partitions which disturb gravitational movement of air, causing bad exchange of air and worse quality of air. This means, that when we have the same number of windows and doors, directions of wind and its velocity and geographical location of buildings, in a building without columns (steel frame construction) there is much bigger freedom for movement.

Table 2
Building characteristic of cattle barns including: building utilization, production and resting areas, slatted floor and capacities of channels for liquid manure.

No of barn	Construction of buildings	Cubage ($m^3 \cdot LU^{-1}$)	Ventilation/ air inflow/ air outflow	Areas					Unitary capacities of slurry channels
				building ($m^2 \cdot LU^{-1}$)	using ($m^2 \cdot LU^{-1}$)	production ($m^2 \cdot LU^{-1}$)	resting (m^2)/ ($m^2 \cdot LU^{-1}$)	slatted floor (m^2)	($m^3 \cdot LU^{-1}$)
1	One – room spaced non-columned, steel frames	39.74	gravitational /windows roof ridge gap	9.38	9.01	7.85	120/1.10	361.4	3.95
2	Three-room spaced, columned	70.64	gravitational/ adjustable curtains/ roof ridge gap	12.44	11.64	10.98	363.5/3.3	1094.8	33.9
3	Three-room spaced, columned	74.43	gravitational /windows roof ridge gap	14.86	14.35	11.73	82.8/0.99	461.72	10.43

Tables 3-6 contain the set of machinery and equipment in investigated barns, including prices and costs of cattle buildings.

Table 3

Machinery, equipment and prices set for mechanization of technological treatments, costs of cattle barn no 1

Treatment	Machinery or equipment	Price Cm (PLN·pcs.$^{-1}$)	Number of pieces	Replacement value (PLN)
I	„herring bone" 2x5(10) DeLaval	110 000	1	110 000
	milk cooler 7000 dm^3	49 000	1	49 000
	heater	500	1	500
II	mixing wagon Siloking 12 m^3	76 000	1	76 000
	tractor for mixing wagon Ursus 1614 110 kW	199 348	1	199 348
	telescopic, self-going loader MLT 627 20 Zoll 74 kW	158 600	1	158 600
	the technological line for concentrates feeding: spiral transporter, 2 feeding stations, silo	45 000	set[1]	45 000
	self-locking feed ladder Meprozet Koscian	17 300	set[1]	17 300
	drinking bowls with two chambers, with constant water level Arntjen	700	2	1400
	drinking pots with one chamber with constant water level Arntjen	520	2	1040
III	slurry mixer (own production)	4500		4500
	tractor for slurry mixer MF 255 (35 kW)	87 200	1	87 200
	slurry spreader with pump Meprozet Koscian 10 000 dm^3	59 778	1	59 778
	tractor for slurry spreader	215 000	1	215 000
IV	hoof knife	350	1	350
	electric aggregate	6 500	1	6 500
Total outfit (PLN)				1 031 516
Replacement value of building (barn no. 1) (PLN)				824 236
Replacement value of equipment and cattle barn building (PLN·LU^{-1})				17025

Table 4
Machinery, equipment and prices set for mechanization of technological treatments, costs of cattle barn no 2.

Treatment	Machinery or equipment	Replacement value Cm (PLN·pcs.$^{-1}$)	Number of pieces	Replacement value Total (PLN)
I	milking robot LELY Astronaut A4	350 000	2	700 000
	milk cooler LELY 10000 dm^3	140 000	1	140 000
	heater	14 000	1	14 000
II	mixing wagon RMH 14 m^3	98 400	1	98 400
	tractor for mixing wagon SAME 69 kW	105 000	1	105 000
III	telescopic, self-propelled loader	221 400	1	221 400
	silage cutter	8 100	1	8 100
	the technological line for concentrates feeding (spiral transporter, silos 14 m^3 and 15 m^3)	40 000	set	40 000
	feed pusher (robot) LELY JUNO 150 NN765	65 700	1	65 700
	chambered drinking bowls	2 500	4	10 000
	drinking bowls	80	7	560
	slurry mixer	16 000	1	16 000
	tractor for slurry mixer 69 kW	172 200	1	172 200
	slurry spreader with pump for slurry 14 200 dm^3	120 000	1	120 000
	tractor for slurry spreader 117 kW	466 000	1	466 000
	robot for cleaning of slatted floor	52 200	1	52 200
IV	hoof knife	350	1	350
	swinging cow brush LELY	6000	3	18 000
Total outfit (PLN)				2 247 910
Replacement value of building (barn no.2) (PLN)				1 500 000
Replacement value of equipment and cattle barn building no. 2 (PLN·LU^{-1})				22 047

Table 5
Machinery, equipment and prices for mechanization of technological treatments, of cattle barn no 3.

Treatment	Machinery or equipment	Replacement value Cm ($PLN \cdot pcs.^{-1}$)	Number of pieces	Replacement value total (PLN)
I	milking robot VMS	400 000	1	400 000
	milk cooler DeLaval 5000 dm^3	55 000	1	55 000
	heater (with heat recovery)	850	1	850
II	mixing wagon SEKO 11 m^3	70 000	1	70 000
	tractor for mixing vagon SAME Roller 450 60 kW	120 000	1	120 000
	tractor SAME 74 kW	200 000	1	200 000
	the technological line for concentrates feeding (spiral transporter, 2 feeding stations, silos PRO AGRO)	40 000	1	40 000
	head- loader TUR -6	25 000	1	25 000
	feed pusher (robot) LELY JUNO	50 000	1	50 000
	chambered drinking bowls	1 000	2	2 000
	drinking bowls	80	4	320
III	slurry mixer (own production)	4 000	1	4 000
	tractor for slurry mixing SAME 74 kW	-	-	-
	slurry spreader 12 600 dm^3	67 000	1	67 000
	tractor for slurry spreader SAME 74 kW	the same for mixing vagon	-	-
	robot for slatted floor cleaning	64 500	1	64 500
IV	hoof knife	350	1	350
	swinging cow brush DeLaval	6 250	2	12 500
Total outfit (PLN)				1 111 525
Replacement value of building (barn no.3) (PLN)				1 100 525
Replacement value of machinery, equipment and cattle barn building no. 3 ($PLN \cdot LU^{-1}$)				21 169

Tables 6-8 shows labour and energetic inputs in cattle barns tested. Remarks to tables 6-8: [1)]vacuum pump, [2)]milk pump,[3)]heater, [4)]aggregate, [5)]ventilator, [6)]mixer.

The electric energy for lighting was calculated based on normative 2W per m^2 of the building area for animals assuming the “artificial day” duration in months from September to March from 3 pm to 8 am, and in the remaining days from 6 pm to 6 am.

Table 6
Labour, electrical and mechanical energy input in cattle barn no 1.

Treatment	Activity /process	Process time (h·LU^{-1}·year^{-1})	Process time (h· year^{-1})	Labour input (man- mi-nute· year^{-1})	Energy source (kW)	Energy input on process (kWh·year^{-1})
I	milking + dairy unit washing	12.24	1 334.67	85 775.00	2.20[1]; 0.55[2] 1.50[3]	4 953.05
	milk cooling+ milk tank washing	174.13	18 980.00	1 825.00	4.0[4]; 0.75[5]; 0.12[6]	9 909.75
II	feed loading	1.83	200.00	12 000.00	74.,20	14 840.00
	feed mixing and discharge	2.75	300.00	18 000.00	110.30	33 090.00
III	slurry mixing	0.18	20.00	1 200.00	35.30	706.00
	slurry pumping out	0.83	90.00	5 400.00	77.20	6 948.00
IV	decornization	2.00	218.00	13 080.00	0.25	54.50
	ordering activities, cleaning the walls /ceiling	0.11	12.00	720.00	1.75	21.83
	lighting	-	-	not appl.	-	2 640,09
Total labour per year				138000	-	73 163.22
Daily labour inputs per LU				3.468	-	1.84

Table 7
Labour, electrical and mechanical energy inputs in cattle barn no 2.

Treatment	Activity /process	Process time (h·LU^{-1}·year^{-1})	Process time (h·year^{-1})	Labour inputs (man-minute·year^{-1})	Power of energy source (kW)	Energy input on process (kWh·year^{-1})
I	milking -2 milking robots+ washing	89.75	8 200.00	21 717.50	2.20[1]; 0.55[2]	22 550.00
	milk cooling +washing of milk tank	27.06	4 200.00	1 930.44	5.00[4]; 2x0.22[5] 2x0.07[6]; 1,20[3]	22 932.65
II	feed loading	1.17	200.00	12 000.00	58.80	11 760.00
	feed mixing and discharge	2.35	400.00	18 000.00	69.80	27 920.00
	feed pushing	2.47	420.00	not appl.	3.67	4964.00
III	slurry mixing	0.73	124.00	7 440.00	95.60	11 854.40
	slurry pumping out	0.73	124.00	7 440.00	110.30	13 677.20
	slatted floor cleaning	10.74	1 825.00	not appl.	0.17	310.25
IV	decornization	1.66	283.00	16 980.00	0.25	70.75
	ordering, cleaning the walls/ceiling	0.08	14.57	874.20	1.75	25.50
	lighting	not appl.	not appl.	not appl.		6 105.89
	swinging cow brush-es	18.81	not appl.	not appl.	3x0.12=0.36	799.45
Total labour per year				84451.70	-	122 970.00
Daily labour inputs per LU				1.36	-	1.98

Table 8
Labour, electrical and mechanical energy inputs in cattle barn no 3.

Treatment	Activity/process	Process time ($h \cdot LU^{-1} \cdot year^{-1}$)	Process time ($h \cdot year^{-1}$)	Labour inputs (man-minute $\cdot year^{-1}$)	Power of energy source (kW)	Energy inputs on process ($kWh \cdot year^{-1}$)
I	milking + 1 milking robot, washing (water heating)	89.76	7 450.00	29 200.00	2.2[1)]; 0.55[2)]; 2.0[3)]	12 309.30
	milk cooling (aggregate, ventilator, mixer;), water heater)	53.01	4400.00	3 650.00	6.0[4)]; 0.75[5)] 0.13[6)] 2.0[3)]	11 351.10
II	feed loading	1.20	100.00	6 000.00	74	7 400.00
	feed mixing and discharge	3.01	250.00	15 000.00	66	16 500.00
	feed pushing	5.18	430.00	not appl.	55Ah	1578.10
III	slurry mixing	0.05	4.00	240	66	264.00
	slurry pumping out	0.96	80.00	4800.00	74	5 920.00
	slatted floor cleaning	13.19	1 095	not appl.	0.165	180.68
	decornization	1.66	138	8280	0.25	34.58
IV	ordering, cleaning the walls/ceiling	0.18	14.57	874.20	1.75	25.50
	lighting	-	-	not appl.	-	3 004.83
	swinging cow brushes	24.09	2000.00	not appl.	0.12	240.00
Total labour per year				68044.20	-	58 808.08
Daily labour inputs per LU				2.24	-	1.94

Table 9 presents exploitation costs, table 10 total labour, mechanical and electrical energy, as well as exploitation costs of buildings, machinery and equipment.

Table 9
Costs of exploitation of buildings, machinery and equipment involved in mechanization of production processes

No of barn	Costs of maintenance (machinery) C^m_m	Costs of maintenance (building) C^b_m	Operating costs (machinery) C^m_u	Operating costs (building) C^b_u	Exploitation costs (machinery) Ce^m	Exploitation costs (building) Ce^b	Total exploitation costs C_e		Investment costs C_i
	($PLN \cdot year^{-1}$)						($PLN \cdot year^{-1}$)	($PLN \cdot year^{-1} \cdot LU^{-1}$)	($PLN \cdot LU^{-1}$)
1	84894.9	16 744.7	124462.8	6 286.9	209357.7	23 031.6	232389.4	2132.0	17025.5
2	178166.9	30 400.0	207200.4	11 831.7	385367.3	42 231.7	427599.0	2515.3	22 046.5
3	89188.5	22 410.5	101826.7	8 238.3	191015.2	30 648.8	221663.9	2670.7	26651.1

Table 10
Energetical and electrical indicators of investigated cattle barns

No. of cattle barn	Unitary investment costs	Unitary daily labour inputs	Mechanization level	Unitary daily energy inputs	Unitary exploitation costs
	$(PLN \cdot LU^{-1})$	$(Man\text{-}minute \cdot day^{-1} \cdot LU^{-1})$		$(kWh \cdot day^{-1} \cdot LU^{-1})$	$(PLN \cdot year^{-1} \cdot LU^{-1})$
1	17 025.52	3.47	V	1.838	2 132.01
2	22 046.52	1.36	V	1.981	2 515.28
3	26 651.14	2.24	V	1.941	2 670.65

Conclusions

1. The lowest daily labour input was in a barn equipped with two robots for milking, one robot for feed pushing and cleaning of slatted floor. The highest labour inputs were in a cattle barn with a "herringbone" 2x5 milking unit (10) and amounted to 3.47 working minutes per day and per LU – fifth level of mechanization was ensured. The automatic milking systems could be with all certainty used everywhere, where there are no human resources for service.
2. A significantly higher investment cost for buildings and their equipment and machinery for mechanization as well as exploitation costs were observed in cattle barns with robots, whereas the lowest was in a cattle barn with more livestock (170 LU).
3. The energy inputs calculated for 1 LU per day were the highest in a cattle barn with one milking robot.
4. The highest exploitation costs of buildings were in a farm with the highest herd size and with two milking robots. The highest total exploitation costs (regarding buildings and their equipment with machinery) were in cattle barns with milking robots. Higher exploitation costs in robotized cattle barns resulted in higher investment costs, but also higher, compared to other buildings – electric energy inputs.

References

Freiberger, F.; Klindtworht, K.; Baumeister, J.; Gierse, A.; Lehman, B.; Ohnesorge, M.; Harms, J.; Wendl, G. (2005). *Automatisches Melken in modernen Milchviehställen*. KTBL, Darmstadt, ISBN 3-7843-2174-7.

Gazzarin, C.; Hilty, R. (2002). *Stallsysteme für Milchvieh: Vergleich der Bauinvestitionen. FAT Berichte*, Tänikon, Schweiz, CH-8356 Ettenhausen, *Vol. 586*, 20.

Gazzarin, C.; Lips, M. (2013). *Maschinenkosten*, *ART-Bericht, vol. 767.*

Jucherski, A., Król A. (2011). Nakłady pracy żywej i mechanicznej w chowie bydła mlecznego w górskich gospodarstwach rodzinnych, *Problemy Inżynierii Rolniczej*, *Vol. 71*(1), 59-67.

Majchrzak, M. (2013). Wpływ mechanizacji w różnych systemach żywienia bydła na nakłady produkcji, *Problemy Inżynierii Rolniczej*, *vol.* 2(80), 141-150.

Mazur, K. (2012). *Ocena wielokryterialna obór wolnostanowiskowych dla krów mlecznych*. Rozprawa doktorska, Instytut Technologiczno-Przyrodniczy, Warszawa, 157.

Muzalewski A. (2010). *Koszty eksploatacji maszyn*, ITP Falenty, ISBN 978-83-62416-05-9.

Naess G.; Stokstad, G. (2010). Dairy barn layout and construction: effects on initial building costs, *Biosystems Engineering*, *vol. 109*(3), 196-202.

Romaniuk, W.; Mazur, K. (2014). Development of environmental conditions in free-stall cattle barns, *Journal of Research and Applications in Agricultural Engineering*, *vol. 59* (1), 109-115.

Romaniuk, W.; Rudnik, K.; Biskupska, K. (2012). *Kształtowanie obiektów budowlanych i działek zagrodowych w gospodarstwach specjalizujących się w chowie bydła – wytyczne projektowe,* Inżynieria w rolnictwie. Monografie Nr 5, Instytut Technologiczno-Przyrodniczy, Falenty, ISBN 978-83-62416-43-1.

Szulc, R. (2009). Ocena systemu odzyskiwania ciepła podczas mycia urządzeń udojowych. *Prace Naukowe IBMER*, *Vol.13*(2), ISSN 0209-1380.

Szulc, R., Markiewicz K. (2010). Position and research methodology of two-systems heat recovery system in the barn of dairy cattle. *Journal of Research and Applications in Agricultural Engineering*, *vol. 55*(2), 92-93.

ANALIZA EKONOMICZNA OBÓR BEZŚCIÓŁKOWYCH

Streszczenie. Celem artykułu było przedstawienie kosztów eksploatacji trzech obór w bezściółkowym systemie utrzymania bydła. Metoda bazowała na podejściu wielokryterialnym, które odnosi się do następujących czynników: technicznych, technologicznych (głównie energetycznych i nakładów pracy), ekonomicznych (koszt energii, robocizny, inwestycji). W ramach oceny technicznej przeprowadzono charakterystykę budowlaną, która dotyczyła powierzchni produkcyjnych, zabudowy, legowiskowych i kubatury. W celu przeprowadzenia oceny technologicznej zostały przeanalizowane wszystkie sposoby mechanizacji i jako wynik uzyskano nakłady energetyczne i inwestycyjne. Koszty eksploatacji maszyn, wyposażenia i obór dla bydła obliczono zgodnie z metodologią opracowaną w IBMER *[Instytut Budownictwa, Mechanizacji i Elektryfikacji Rolnictwa]*. Najniższe koszty eksploatacji były w oborze z tradycyjną dojarnią „rybia ość" i wynosiły 2 132.01 PLN$\cdot$rok$^{-1}\cdot$DJP^{-1}. Najwyższe koszty eksploatacji wynoszące 2 670.65 PLN$\cdot$rok$^{-1}\cdot$DJP^{-1} były w oborze z jednym robotem do dojenia i najwyższą obsadą.

Słowa kluczowe: nakłady energii, nakłady robocizny, koszty eksploatacji, wolnostanowiskowe utrzymanie

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):107-116

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.111

BRIQUETTING WASTE MATERIAL IN A PROTOTYPE PELLETIZING AND BRIQUETTING ARRANGEMENT[1]

Sławomir Obidziński*, Roman Hejft

Division of Agri-Food and Forestry Engineering, University of Technology in Białystok
*Contact details: ul. Wiejska 45E, 15-351 Białystok, e-mail: s.obidzinski@pb.edu.pl

ARTICLE INFO

Article history:
Received: November 2014
Received in the revised form: December 2014
Accepted: January 2015

Keywords:
briquetting
vegetal waste
buckwheat husk
potato pulp

ABSTRACT

The objective of the paper was to determine usefulness of a new, prototype pelletizing and briquetting device for the process of briquetting waste vegetal material. During research the impact of potato pulp content (15, 20 and 25%) in the mixture with buckwheat husk and the mass intensity of raw material flow (100, 150 and 200 $kg \cdot h^{-1}$) on the demand of a device for power and kinetic strength of the obtained briquette were determined. Tests on briquetting were carried out with the use of a flat briquetting matrix with a diameter of meshes of 28 mm and the length of 80 mm cooperating with the system of three densifying rolls, which move with the speed of 120 $rot \cdot min^{-1}$ and with the fissure between the rolls and the matrix equal to 0.4 mm. The quality of briquettes was assessed with the use of a rotating tester according to recommendations of standards GOST-18691-73 and ASAE S.269-1A. Based on the research which was carried out, a significant impact of the mass intensity of raw material flow and the percentage share of potato pulp in the compacted mixture for the power demand and kinetic strength of the obtained briquette was found.

Introduction

In the process of briquetting, loose (crumbled) vegetal material is compacted under external and internal force and the obtained product reaches a determined permanent geometric form. Most frequently it is in the form of a cylinder with a diameter of 20÷100 mm and length of 30÷500 mm. The product (briquette) obtained in the process should have appropriate mechanical strength so that during transportation or storing it does not crumble. In case of fuel briquettes made of plant material, their higher strength, which is the most frequently related to their higher density, results in their better combustion kinetics.

According to many authors (Hejft, 1995; Hejft and Demianiuk, 1999) vegetal waste in the form of briquettes have many advantages therefore they can be used e.g. for combustion in many types of furnaces, kinetics of their combustion is similar to combustion of wood pieces (logs), several times higher density of briquettes in comparison to chips and sawdust

[1] The article was written as a part of the statute work S/WBiIŚ/2/2015

significantly decreases the area of their storing and the costs of transportation, combustion of briquettes is safe and brings no risk of explosion, briquettes may be exported as organic fuel with prices higher than coal etc.

Most frequently, wood material waste average in size (chips) and small (sawdust, dust left after grinding wood) are processed into fuel briquette (Hejft, 2000). However, in the recent years development of briquetting technology of vegetal waste useful, took place. Moreover, other waste vegetal materials are used for production of briquettes. These are: straw briquetted with a rolling method (Adamczyk, 2010; Fiszer, 2008), fodder maize (Niedziółka et al., 2008), grasses (Karunanithy et al., 2012), waste from production of bananas (Wilaipon, 2007; Sellin et al., 2013), rice straw (Chou et al., 2009) or rapeseed straw, wheat straw, meadow straw and Virginia mallow stem (Niedziółka et al., 2011).

According to Demianiuk (2003) on account of a varied "susceptibility" to compaction, some materials should be mixed with other vegetal material or gluing material (most preferably organic one) should be used. This is confirmed by Oladeji's (2010) research, who briquetted mixtures of maize cob waste and rice husk or research carried out by Yaman and co-authors (Yaman et al., 2000), who compacted mixtures of olive oil refuse after production and paper mill waste.

There are such waste materials, in case of which production of fuel briquettes is non-profitable. Thus, for new vegetal material subjected to briquetting, tests should be carried out in order to determine its susceptibility to compaction, determination of optimal parameters of the compaction process, which will allow obtaining a product with good quality and will answer the question whether the compaction process is economically profitable.

Objective of the paper

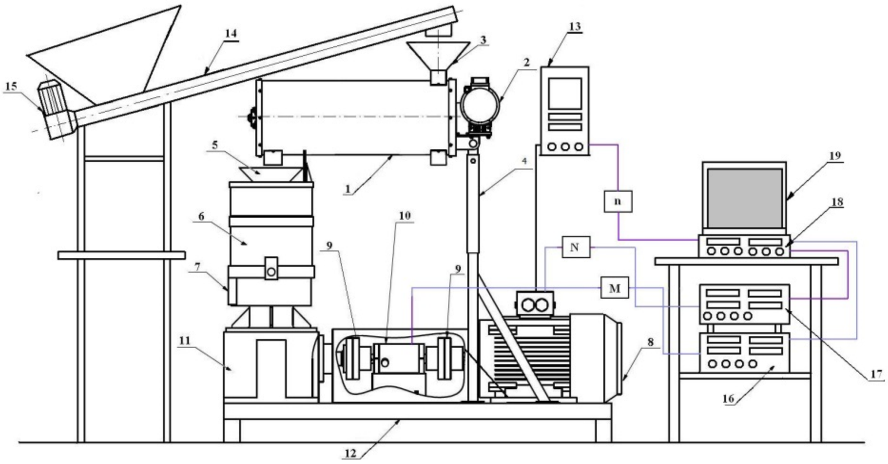
The objective of the paper was to carry out initial evaluation of the usefulness of the new, prototype pelletizing and briquetting device for performance of the briquetting process of waste vegetal material or determination of the impact of the potato pulp content in the mixture with buckwheat husk and mass intensification of raw material flow on the power demand of the prototype pelletizing and briquetting device and on the kinetic strength of the obtained briquette.

Methodology of research

A mixture of buckwheat husk and potato pulp constituted the research material subjected to the pelletizing process in the working system of the new, prototype pelletizing and briquetting device.

Tests with regard to the briquetting process were carried out on the prototype pelletizing and briquetting device (fig. 1) with the use of a flat matrix (fig.2) with a diameter of meshes of 28 mm and length of 80 mm cooperating with the system of three compacting rolls.

a)



b)

Figure 1. Test rigs with new prototype densifying-briquetting device with a flat immovable matrix: a) scheme of test rigs: 1 – mixing–densifying–dosing system, 2 – drive of mixing–densifying–dosing drive (electric engine connected to reducer), 3 – feed of raw material to mixing-densifying-dosing system, 4 – mounting frame for mixing-densifying-dosing system, 5 – batch of initially compacted raw material to working system of pelletizer, 6 – working system of pelletizer, 7 – discharge of pellets from working system, 8 – drive of pelletizer (electric engine), 9 – clutch, 10 – measuring torque Mi20, 11 – toothed gear, 12 – base, 13 – frequency converter, 14 – batcher, 15 – drive of batcher (electric engine connected to reducer), 16 – index of rotational moment and force WT-1, 17 – device for measuring active power METROL KWS 1083, 18 – recorder Spider 8, 19 – PC computer b) view of test rigs

Innovativeness of a device is related to a new solution of a dividng material device to the working system of a pelletizer, with introduction in the mixing-densifying-dosing device to the working system of a pelletizer and with the use of a densifying-briquetting matrix.

Figure 2. Briqetting matrix with diameter of meshes of 28 mm and length of meshes (sleeves) 80 mm

Drive of the pelletizer 6 is composed of the electric engine 8 from which torque was transferred to the pelletizer shaft 6 through the system of two clutches 9 (between which the measuring torque 10 is mounted) through the conic toothed gear 11. For regulation of torque of the pelletizer shaft 6 the frequency converter 13 coupled with the electric engine 8 was used.

Feeding the compacted raw material to the working system of the pelletizer 6 was ensured by the use of the screw batcher 14, the drive of which 15 is made of the electric engine combined with a reducer. The screw conveyor 14 is also equipped with a frequency converter, which enables the change of the fed raw material to the working system of the pelletizer 6. From the screw conveyor, raw material gets through the feed 3 into the mixing-densifying-dosing system 1. The driveline of the mixing-densifying-dosing device 1 consists of the electric engine 2 from which the drive is transferred through the chain transmission onto the shaft of the mixing-densifying-dosing device 1. From the mixing-densifying-dosing device 1 raw material gets to the working system of the pelletizer 6.

The test rigs was equipped with a universal measuring device for measurement of the power demand of the device 17 in the indicating device of the torque and force 16 (WT-1 type) and the recorder 15 clutched with a computer 19. Signals from the measuring tool of the power demand of the device 17, from the indicator of torque and force 16 were transmitted to the recorder 18 in the form of binary flies, which were subjected to further processing in Statistica 10.0 PL.

During the research, the impact of the potato pulp content (15, 20 and 25%) in the mixture with buckwheat husk and the mass intensity of raw material flow (100 kg·h^{-1}, 150 kg·h^{-1} and 200 kg·h^{-1}) on the demand of a device for power and for the kinetic strength of the obtained briquette were determined. Tests were carried out at the rotational speed of compacting shafts equal to 120 rot·min^{-1} and at the fissure between the shafts and the matrix of 0.4 mm.

The quality of briquettes was assessed at the test rigs for measurement of the kinetic strength with the use of a rotating tester according to the recommendations of standards GOST-18691-73 and ASAE S.269-1A. During the test 10 randomly selected briquettes with a similar mass were fed to the chamber (±10%). The test was carried out within three minutes with the velocity of 13 rot·min^{-1}. Relation of the mass of briquettes after the test to the mass of briquettes before the test (expressed in %) determined the kinetic strength of briquettes.

Moisture of the mixture components and mixtures of the tested waste were determined according to PN-EN 14774-1:2010 with the use of a moisture meter WPE 300S, determining each time moisture of five samples with mass of 5 g, which were dried in the temperature of 105ºC to the moment a fixed mass was obtained. Average value from the obtained determinations was assumed as the final result of moisture.

Results of the research

Table 1 presents the research results of the compaction process of the mixture of buckwheat husk with potato pulp on the new, prototype densifying-briquetting device with a flat, immovable briquetting matrix.

Table 1
Research results of compaction process of mixture of buckwheat husk with potato pulp on new prototype densifying-briquetting device with the use of a briquetting matrix

x_i / No. of measurement	Independent variables		Dependent variables		
	$x_1=z_w$ (%)	$x_2=Q_m$ (kg·h^{-1})	Power demand of device N_g (kW)	Unit energy consumption of process E_j (kWh·t^{-1})	Kinetic strength of briquette P_{dx} (%)
1	15	100	6.01	60.10	94.50
2	15	150	8.21	54.73	93.95
3	15	200	11.37	56.85	93.01
4	20	100	5.01	50.10	92.10
5	20	150	7.89	52.60	92.10
6	20	200	8.69	43.45	89.82
7	25	100	3.95	39.50	83.40
8	25	150	4.93	32.87	81.60
9	25	200	5.19	25.95	77.60

z_w – content of potato pulp in mixture; Q_m – mass intensity of raw material flow

Figure 3 presents a graphic interpretation of the obtained results of research on the impact of the potato pulp content in the mixture with buckwheat husk and mass intensity of raw material flow on the power demand of the device during compaction of the mixture of buckwheat husk and potato pulp with the use of a briquetting matrix.

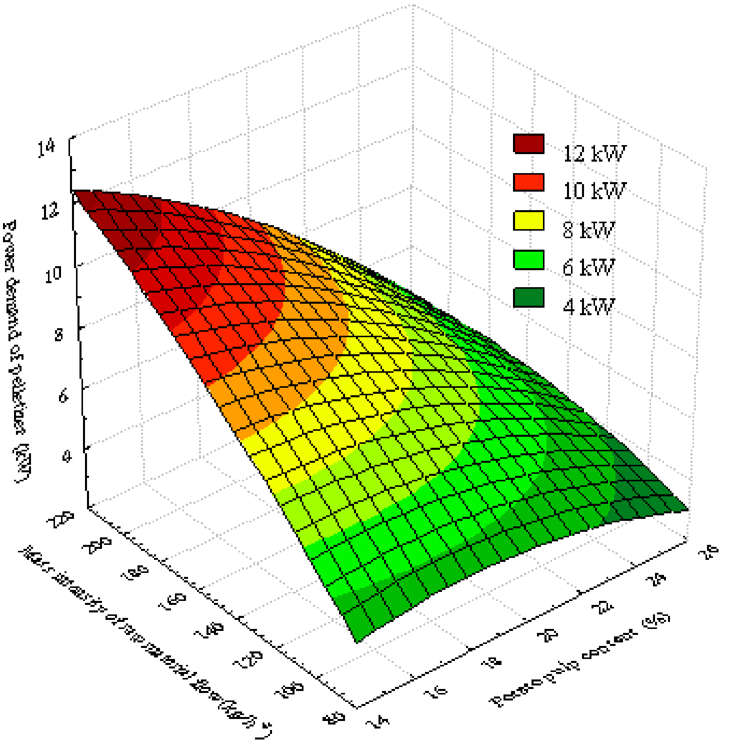


Figure 3. Impact of the potato pulp content in the mixture of buckwheat husk and mass intensity of raw material flow on power demand of pelletizer

Based on the research (fig. 3 and table 1) it was found out that increase of the mass intensity of raw material flow from 100 to 200 kg·h^{-1} causes the increase of the power demand of the engine which drives the device during compaction process of the mixture of buckwheat husk and potato pulp. Whereas increase of the potato pulp content from 15 to 25% in the mixture with buckwheat husk caused decrease of the power demand value of the device. For example, the increase of the mass intensity of raw material flow from 100 to 200 kg·h^{-1}, at 15% of the potato pulp content in the mixture with buckwheat husk causes the growth of power demand of the engine which drives the device by approx. 89% (from 6.01 to 11.37 kW), at 20% of the pulp content in the mixture with buckwheat husk results in the growth on the power demand by approx. 73% and at the 25% pulp content in the mixture with buckwheat husk – growth of demand was approx. 31%.

The obtained decrease of power demand of the pelletizer results mainly from a considerable growth of mixture moisture caused by the increase of the potato pulp content from 15 to 25%. Moisture of the compacted mixture increased from 18.63% (at 15% pulp content in the compacted mixture) to 26.23 % (at 25% of the pulp content in the compacted mixture). Increase of the pulp content in the compacted mixture caused formation of higher amounts of binder (in the form of viscous liquid from starch and moisture) during pelletizing. The growing content of viscous liquid caused the effect of "smearing" of the surface of meshes in the matrix of a pelletizer and decrease of the pressing resistance. Reduction of pressing resistance allowed as a consequence decrease of the value of power demand of a pelletizer. It is confirmed by other tests carried out for the mixture of oat bran and potato pulp (Obidziński and Hejft, 2013).

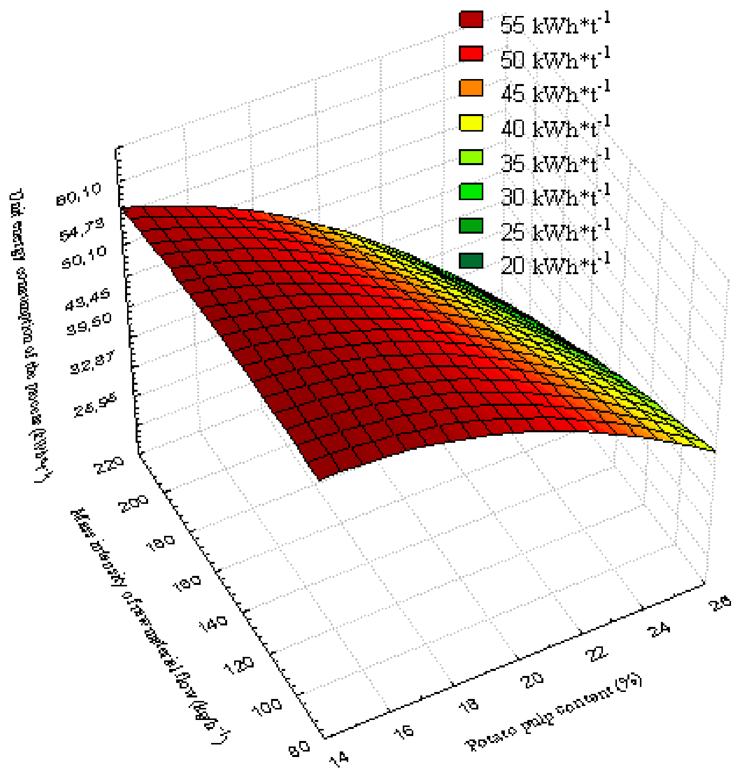


Figure 4. Impact of potato pulp content in mixture of buckwheat husk and mass intensity of raw material flow on the unit energy consumption of compaction process

The research, which was carried out (fig. 4 and table 1) allow stating that the increase of both mass intensity of flow of raw material from 100 to 200 $kg \cdot h^{-1}$, as well as the increase of the potato pulp content from 15 to 25% in the mixture with buckwheat husk causes also decrease of the unit energy consumption of the compaction process.

Figure 5 presents results of research on the impact of the potato pulp content in the mixture with buckwheat husk and mass intensity of raw material flow on the kinetic strength of briquette obtained during compaction of the mixture of buckwheat husk and potato pulp with the use of a briquetting matrix.

Results of the research (fig. 5 and table 1) allow stating that both the increase of mass intensity of flow of raw material from 100 to 200 kg·h^{-1}, as well as the increase of the potato pulp content from 15 to 25% in the mixture with buckwheat husk causes also decrease of the kinetic strength of briquette. For instance, the increase of the mass intensity of raw material flow from 100 to 200 kg·h^{-1} (at the potato pulp content of 15% in the mixture with buckwheat husk) caused decrease of the kinetic strength of briquette from 94.5% to 93.01. Decrease was higher than the potato pulp content which was 25% in the mixture with buckwheat husk because the kinetic strength dropped from 83.4 to 77.6%.

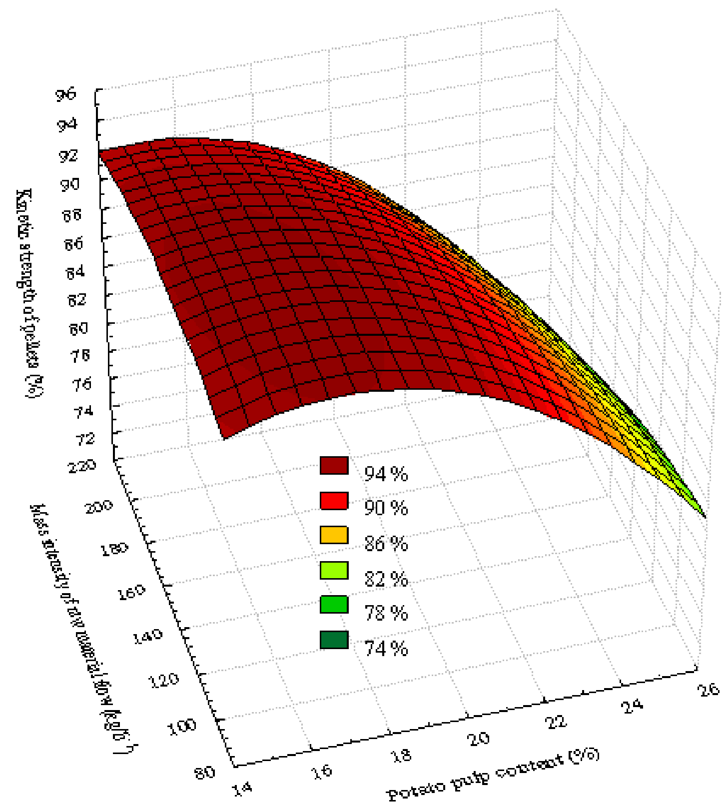


Figure 5. Impact of potato pulp content in mixture of buckwheat husk and mass intensity of raw material flow on kinetic strength

Based on the research which was carried out, it may be stated that the potato pulp addition up to approx. 20% to buckwheat husk allows obtaining briquette of a satisfactory quality.

Conclusions

1. The research which was carried out confirmed that the new, prototype pelletizing – briquetting device was useful for the process of briquetting waste vegetal material.
2. Increase of the mass intensity of flow of raw material from 100 to 200 kg·h^{-1}caused the increase of the power demand of the engine which drives the device during the compaction process of the mixture of buckwheat husk and potato pulp even by approx. 89% (at 15% of the potato pulp content in the mixture with buckwheat husk from 6.01 to 11.37 kW) whereas the decrease of the content of potato pulp from 15 to 25% in the mixture with buckwheat husk caused the decrease of the value of power demand of the device to approx. 35% (from 6.01 to 3.95 kW at the mass intensity of flow of 100 kg·h^{-1}).
3. The increase of the mass intensity of flow of raw material from 100 to 200 kg·h^{-1}, as well as the increase of the potato pulp content from 15 to 25% in the mixture with buckwheat husk causes also decrease of the unit energy consumption of the compaction process.
4. The increase of the mass intensity of flow of raw material from 100 to 200 kg·h^{-1}, as well as the increase of the potato pulp content from 15 to 25% in the mixture with buckwheat husk causes also a slight decrease of the kinetic strength of briquette obtained from the mixture of buckwheat husk and potato pulp.

References

Adamczyk, F. (2010). Wpływ wilgotności słomy zbożowej na stopień zagęszczenia uzyskiwanych brykietów. *Inżynieria Rolnicza, 1*(119), 7-13.

ASAE S269.4. (1989). *Cubes, pellets, and crumbles – definition and, methods for determining density, durability, and moisture content.*

Chou, CS.; Lin.; SH, Peng.; CC, Lu.; WC. (2009). The optimum conditions for preparing solid fuel briquette of rice straw by a piston-mold process using the Taguchi method. *Fuel Processing Technology, 90,* 1041-1046.

Demianiuk, L. (2003). Utylizacja wybranych odpadowych materiałów roślinnych - brykietowanie łuski gryki na cele energetyczne. *Materiały konferencyjne: VII Recyklace odpadú, Ostrava 2003,* 19-22.

Fiszer, A. (2008). Badania porównawcze współczynnika trwałości brykietów ze słomy. *Journal of Research and Applications in Agricultural Engineering, Vol. 53(3),* 69-70.

GOST-18691-73. *Artificially dried grass feeds. Specifications.*

Hejft, R. (1995). Wpływ nacisków prasujących na gęstość brykietów z pasz słomiastych, formowanych w komorach zamkniętych. *Zeszyty Naukowe Politechniki Białostockiej. Budowa i Eksploatacja Maszyn, Z. 3,* 43-50.

Hejft, R.; Demianiuk, L. (1999).Wytwarzanie brykietów opałowych z odpadowych surowców pochodzenia roślinnego. *Zeszyty Naukowe Politechniki Łódzkiej. Inżynieria Chemiczna i Procesowa, 27,* 123-130.

Hejft, R. (2000). Wykorzystanie odpadów pochodzenia roślinnego do celów energetycznych. *Materiały konferencyjne: „Recyklace odpadů IV”*, 165-174. Ostrawa 2000.

Karunanithy, C.; Wang, Y.; Muthukumarappan, K.; Pugalendhi, S. (2012). Physiochemical characterization of briquettesmade from different feedstocks. *Biotechnology Research International, Volume 2012,* 12. DOI: 10.1155/2012/165202.

Niedziółka, I.; Szymanek, M.; Zuchniarz, A. (2008). Ocena trwałości brykietów wytworzonych z masy roślinnej. kukurydzy pastewnej. *Inżynieria Rolnicza, 9*(107)*,* 235-240.

Niedziłóka, I.; Szpryngiel, M.; Kraszkiewicz, A.; Kachel-Jakubowska, M. (2011). Ocena wydajności brykietowania oraz jakości brykietów wytworzonych z wybranych surowców roślinnych. *Inżynieria Rolnicza, 6*(131), 149-155.

Oladeji, J.T. (2010). Fuel characterization of briquettes produced from corncob and rice husk resides, *The Pacific Journal of Science and Technology, 11,* 101-106.

PN-EN 14774-1:2010. *Biopaliwa stałe. Oznaczanie zawartości wilgoci - Metoda suszarkowa*. Część 1: Wilgoć całkowita – Metoda referencyjna.

Sellin, N. (2014). Production and characterization of fuel briquettes from banana leaves waste. *Chemical Engineering Transactions,Vol. 37,* 439-444.

Wilaipon, P. (2007). Physical characteristics of maize cob briquette under moderate die pressure. *American Journal of Applied Sciences, 4,* 995-998.

Yaman, S.; Sahan, M. H.; Sesen, K. H.; Kucukbayrak, S. (2000). Production of fuel briquettes from olive refuse and paper mill waste, *Fuel Processing Technology*, *68,* 23-31.

BRYKIETOWANIE MATERIAŁÓW ODPADOWYCH W PROTOTYPOWYM UKŁADZIE GRANULUJĄCO-BRYKIETUJĄCYM

Streszczenie. Celem pracy było określenie przydatności nowego, prototypowego urządzenia granulująco-brykietującego do realizacji procesu brykietowania odpadowych materiałów roślinnych. W trakcie badań określano wpływu zawartości wycierki ziemniaczanej (15, 20 i 25%) w mieszaninie z łuską gryki i masowego natężenia przepływu surowca (100, 150 i 200 $kg \cdot h^{-1}$) na zapotrzebowanie urządzenia na moc oraz na wytrzymałość kinetyczną otrzymanego brykietu. Badania brykietowania przeprowadzono z wykorzystaniem płaskiej matrycy brykietującej o średnicy otworów 28 mm i długości 80 mm współpracującej z układem trzech rolek zagęszczających, poruszających się z prędkością 120 $obr \cdot min^{-1}$ oraz przy szczelinie między rolkami a matrycą równej 0,4 mm. Jakość brykietów oceniono z wykorzystaniem testera obrotowego, zgodnie z zaleceniami norm GOST-18691-73 oraz ASAE S.269-1A. Na podstawie przeprowadzonych badań stwierdzono istotny wpływ masowego natężenia przepływu surowca oraz udziału procentowego wycierki ziemniaczanej w zagęszczanej mieszaninie na zapotrzebowanie na moc oraz wytrzymałość kinetyczną otrzymanego brykietu.

Słowa kluczowe: brykietowanie, odpady roślinne, łuska gryki, wycierka ziemniaczana

Scientific quarterly journal e-ISNN 2449-5999
Agricultural Engineering
2015: 1(153):117-125
Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.112

IMPACT OF THE SPEED OF CULTIVATION UNITS AND CULTIVATION AND SOWING UNITS ON THE WORKING RESISTANCE IN THE ASPECT OF LONG-TERM USE OF DIFFERENT SYSTEMS OF SOIL CULTIVATION

Krzysztof Pieczarka*, Krzysztof Lejman, Zygmunt Owsiak, Leszek Kordas

Institute of Agricultural Engineering, Wrocław University of Environmental and Life Sciences
*Contact details: *ul. Chełmońskiego 37/41, 51-630 Wrocław, e-mail: krzysztof.pieczarka@up.wroc.pl*

ARTICLE INFO

Article history:
Received: May 2014
Received in the revised form: November 2014
Accepted: December 2014

Keywords:
cultivation unit
working resistance
cultivation
speed of the unit

ABSTRACT

Results of tests on working resistance of cultivation units and cultivation and sowing units used in various systems of soil cultivation. The objective of the paper was to determine the impact of speed of cultivation units and cultivation and sowing units on working resistance including diversity of previous cultivation systems. Properties of soil on the analysed fields, where different cultivation system was used, was characterised with the use of physical and mechanical properties of soil such as: moisture, compactness and maximum shear stress. Working resistance was determined for: a stiff tine cultivator, a disc harrow and a cultivation and sowing unit used in the direct sowing technology. Working depth was determined for all units as equal to 0.05 m. Measurements of working resistance were carried out with the use of two tractors connected with a haul, where strain gauge force transducer was mounted. Significant impact of the used unit and working speed was determined, whereas no impact of the previous soil cultivation system on the measured working resistance was reported.

Introduction

The issue of reducing the costs of farming equipment maintenance has gained greater and greater importance in recent years. Commercial success is reserved only for those farms that are able to offer high-quality goods for a competitive, that is lower, price. Therefore, the reduction of farming equipment maintenance costs, as well as losses related to such maintenance, poses a challenge to the national agricultural industry.

The primary source of implemented savings stems from the elimination of individual cultivation treatments, which leads to the energy outlay reduction and, therefore, financial savings. According to Vilde (2003), when one resigns from ploughing, one can reduce the outlay even by six times. The higher energy consumption of traditional ploughing cultivation, when compared with the simplified non-ploughing technology, was confirmed by such authors as Gonet (1991), Heyland et al. (1997), Roszkowski (1980) and Krysztofiak et al. (1996). The departure from traditional cultivation system with the use of a plough towards simplified systems caused that the cultivator has become the main tool employed in these systems. This resulted in the increased interest in research concerning both agro-technical effects and energy consumption of treatments employing exactly this tool in the cultivation system (Przybył et al., 2009; Šařec and Šařec, 2003; Sahu and Raheman, 2006; Talarczyk and Zbytek, 2006; Zbytek, 2010). The research conducted so far allows one to state that the essential unit maintenance factors in the mechanical soil cultivation that affect their resistance are, for example, depth of cutting with tools and working speed of the units (Lejman and Owsiak, 2001; Owsiak et al., 2006). It was also shown that such resistance was directly determined by soil condition described with the use of its physical and mechanical properties. One may, therefore, ask the question how long-term use of simplified soil cultivation systems affects its physical and mechanical properties, and how it will impact the working resistance of tools used for working in the soil cultivated in such systems. In the relevant literature there are no studies concerning working resistance of tools used for working in the soil cultivated in various systems, so the authors attempted to analyse this issue.

Objective of the paper and methodology

The objective of the paper is to determine the impact of speed of cultivation units and cultivation and sowing units on working resistance, with consideration given to diversification of previous cultivation systems.

The research was conducted on a farmland plot of 6.6 hectares, divided into three research fields of equal surface area. The experiment started in 2007, and for three consecutive vegetation periods various soil cultivation systems were used on every field, as characterised in Table 1.

Table 1
The list of agro-technical treatments and the used machines for particular cultivation systems

Distinction	Traditional cultivation	Simplified cultivation	Direct sowing
Crop residue cultivation	Skimming – Farmet stiff tine cultivator	No	No
Pre-sowing cultivation	Ploughing – Kverneland EM 100 plough with Packomat S Cultivation – Farmet stiff tine cultivator	Cultivation – Farmet stiff tine cultivator	No
Sowing	Köckerling Ultima cultivation and sowing unit	Köckerling Ultima cultivation and sowing unit	Köckerling Ultima cultivation and sowing unit

The experiment involved the implementation of crop rotation of winter wheat, spring barley, and winter rapeseed on every field.

The working resistance of three cultivation units and one cultivation and sowing unit was measured in 2010 after the rapeseed harvest on the intact stubble in separate crossings for every unit repeated three times. The research was conducted for the Farmet stiff tine cultivator with the working width of 3 metres, Becker stiff tine cultivator with the working width of 4.5 metres, Strom disc harrow with the working width of 4 metres, and Köckerling Ultima cultivation and sowing unit with the working width of 4 metres. During the research three unit speeds were employed at 1.1 $m \cdot s^{-1}$; 2.2 $m \cdot s^{-1}$; 3.3 $m \cdot s^{-1}$. In order to obtain comparable research conditions, the working depth for all units was set at 0.05 m due to the fact that this is the maximum value applicable to Köckerling Ultima seed metering drill for direct sowing.

The research was conducted in soil classified as very good rye complex with IIIa valuation class. The granulometric composition of the soil was determined according to the PN-R-04032 standard; the soil was classified as light clay. The soil humidity was determined according to the ISO11461:2001 standard at 12.5%. The mechanical properties of the soil at individual fields where various cultivation systems were used were characterised with the help of maximum shear stress in the layer of 0.00÷0.15 m and compactness in the layer of 0.00÷0.20 m. Despite the fact that the working depth of units for research purposes was set at 0.05 m, it was decided to measure the mechanical properties of the soil for higher values in order to describe the changes taking place as a result of long-term use of various cultivation systems in greater detail. In order to determine the maximum shear stress the VANE H-60 shear vane by Eijkelkamp was used. The measurements were made for the following depths: 0.00÷0.05; 0.05÷0.10 and 0.10÷0.15 m. The authors calculated the arithmetic mean for the received measurements. The compactness was measured with the use of cone penetrometer with electronic recording of penetration resistance and depth employing a cone with the base area of 0.0001 m^2 and the apex angle of 60°; the penetration speed was set at 0.03 $m \cdot s^{-1}$.

The working resistance was measured with the use of two Fendt 820 tractors connected with a haul, where strain gauge force transducer was mounted (Fig. 1).

Figure 1. Measurement of the working resistance of a unit with a pulling method

The speed adopted for research purposes was maintained by programming it in the TMS systems fitted in the tractors. The unit working resistance was calculated by deducting the pulling resistance force of the support tractor (determined with additional measurements) from the measured values.

Research results and their analysis

The results of conducted measurements of mechanical properties of the soil are presented in table 2. Traditional cultivation is characterised by the lowest values in terms of both compactness and maximum shear stress, which stems from the conducted cultivation treatments loosening the soil. The simplification of the cultivation system results in the increased values of mechanical parameters of the soil.

Table 2
Values of maximum shear stress and soil compactness

	Traditional cultivation	Simplified cultivation	Direct sowing
Maximum shear stress (kpa)	38	45	48
Compactness (MPa)	1.11	1.45	1.63

Figure 2 presents the unit values of working resistance of units at the speeds adopted for research purposes and measured at the field where traditional cultivation system was used.

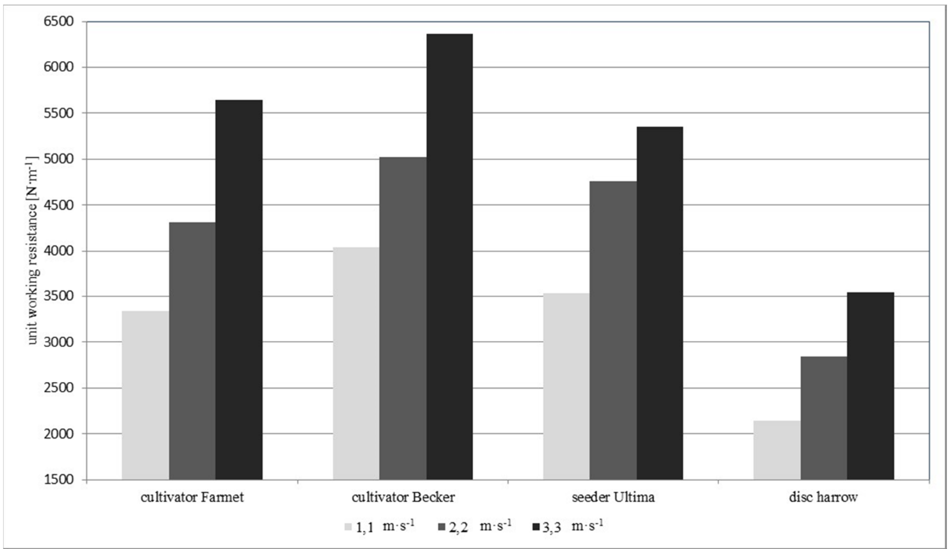


Figure 2. Values of unit working resistance measured on the field where traditional cultivation system was applied

The highest value of unit working resistance was observed for the Becker cultivator (6360 N·m^{-1} for the speed of 3.3 m·s^{-1}), whereas the lowest value was noted for the disc harrow (2140 N·m^{-1} for the speed of 1.1 m·s^{-1}). Similar values of unit resistance were found for the Farmet cultivator and the Ultima seed metering drill, when working at analogous working speeds. The increase in working speed for every analysed unit always led to the increase in unit working resistance. When the speed was increased from 1.1 to 3.3 m·s^{-1}, the greatest resistance growth was observed for the Farmet cultivator at 2311 N·m^{-1}, which corresponded to the rise of 69%, while the lowest growth was noted for the Ultima seed metering drill at 1821 N·m^{-1}, which accounted for 52%.

The values of unit working resistance of units measured on the field where a simplified cultivation system was applied is presented in Figure 3.

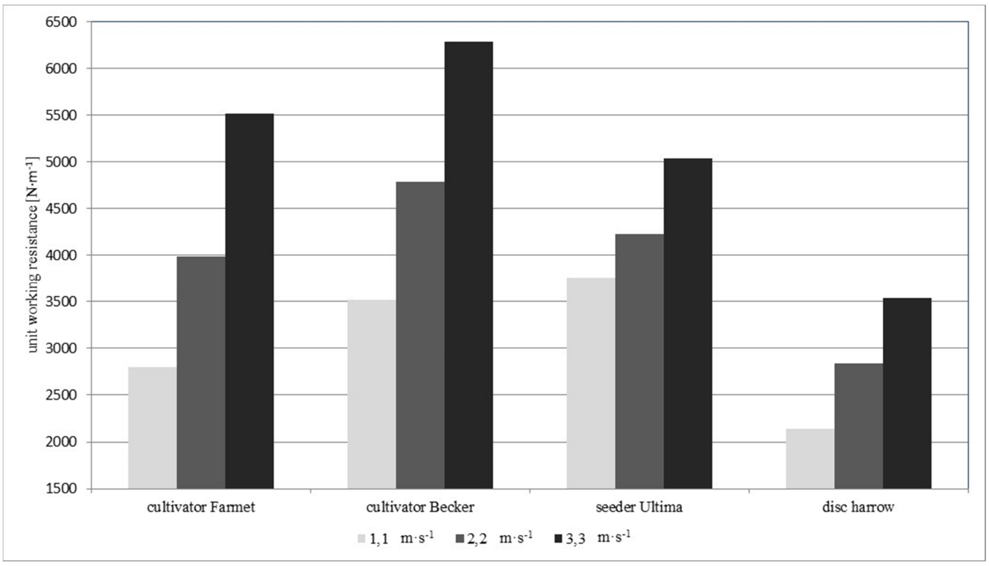


Figure 3. Values of unit working resistance measured on the field where a simplified cultivation system was applied

Similarly to the traditional cultivation system, the highest value of unit working resistance was measured for the Becker cultivator (6284 N·m^{-1} at the speed of 3.3 m·s^{-1}), while the lowest value was noted for the disc harrow (2137 N·m^{-1} at the speed of 1.1 m·s^{-1}), as shown in Figure 3. At the speed of 1.1 m·s^{-1}, the greatest resistance of 3755 N·m^{-1} was measured for the Ultima seed metering drill. In comparison to the Farmet cultivator, higher values of unit resistance were found for the Becker cultivator, similarly as in the traditional cultivation system. The increase in working speed for every analysed unit always led to the increase in the unit working resistance. When the speed was increased from 1.1 to 3.3 m·s^{-1}, the greatest growth of resistance was measured for the Farmet cultivator at 2715 N·m^{-1}, which corresponded to the resistance rise of 97%, while the lowest growth was noted for the Ultima seed metering drill at 1280 N·m^{-1}, which accounted for 34%.

Figure 4 shows the values of unit working resistance of units for the working speeds adopted for research purposes, when measured in the direct sowing system.

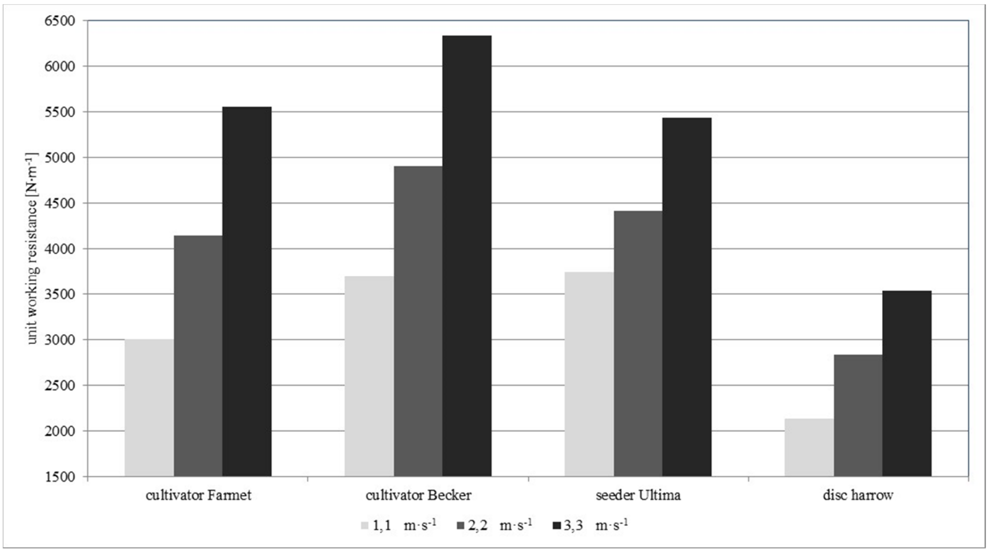


Figure 4. Values of unit working resistance measured in the direct sowing system

When analysing the values presented in Figure 4, similarly to the traditional and simplified systems, one can state that the higher value of unit working resistance was measured for the Becker cultivator (6331 $N \cdot m^{-1}$ at the speed of 3.3 $m \cdot s^{-1}$), whereas the lowest value was noted for the disc harrow (2135 $N \cdot m^{-1}$ at the speed of 1.1 $m \cdot s^{-1}$). At the speed of 1.1 $m \cdot s^{-1}$ the highest resistance of 3755 $N \cdot m^{-1}$ was measured for the Ultima seed metering drill. In comparison to the Farmet cultivator, the values of unit resistance for the Becker cultivator were higher, similarly to other analysed cultivation systems. The increase in the working speed for every analysed unit always led to the increase of unit working resistance. When the speed was increased from 1.1 to 3.3 $m \cdot s^{-1}$, the highest resistance growth was observed for the Farmet cultivator at 2548 $N \cdot m^{-1}$, which corresponded to 85%, while the lowest growth was noted for the Ultima seed metering drill at 1689 $N \cdot m^{-1}$, which accounted for 45%.

Figure 5 presents the values of unit working resistance of units for the analysed cultivation systems at the working speed of 2.2 $m \cdot s^{-1}$.

The values of unit working resistance measured for the disc harrow in individual cultivation systems were nearly identical (the difference is 5 $N \cdot m^{-1}$), as shown in Figure 5. In the context of analysed cultivators and Ultima seed metering drill, the lowest resistance values were measured in the simplified technology, while the highest values were observed with traditional technology used.

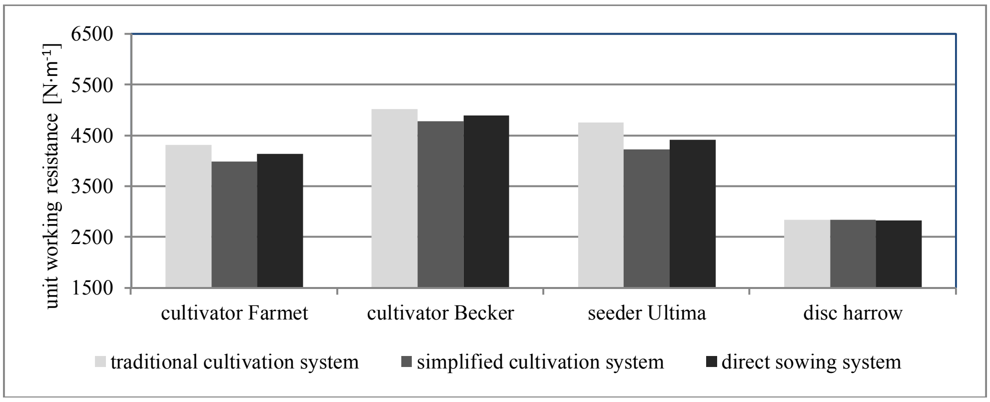


Figure 5. Values of unit working resistance of units for the analysed cultivation systems at the working speed of 2.2 m·s^{-1}

In order to determine the impact of analysed factors on the values of unit working resistance, the research findings were subjected to statistical analysis with the use of Statistica 9.0 package. The results of the conducted multi-factor analysis of variance are presented in Table 3.

Table 3
Results of multi-factor analysis of variance – coefficient of significance α

Independent variable / Dependent variable	Unit type	Cultivation technology	Working speed
Unit working resistance	0.0002*	0.9199	0.0001*

* with significant effect at the level of α=0.05

The conducted analysis indicated a considerable impact of the type of used unit and the working speed on the value of unit working resistance. On the other hand, no relevant impact of the cultivation system was found. The NIR homogeneous group test was also conducted. As a result of test conducted for the unit type, two homogeneous groups were found: 1 – disc harrow, 2 – Ultima seed metering drill, Farmet and Becker cultivators.

Conclusions

1. Long-term use of various cultivation systems does not significantly affect the value of the generated unit working resistance of the analysed cultivation units and cultivation and sowing units for the working speeds adopted for research purposes.

2. The increase in the working speed of the unit leads to the increase in the unit working resistance, regardless of the previously used cultivation system, and the greatest growth of resistance was noted for the Farmet cultivator and the lowest for the Ultima seed metering drill.
3. At the working speed of 2.2 $m \cdot s^{-1}$ the highest values of unit working resistance were measured for the Becker cultivator, while the lowest were noted for the disc harrow, regardless of the previously used cultivation system. As far as other speeds adopted for research purposes, the values of unit working resistance were similar for individual cultivation systems.

References

Gonet, Z. (1991). Metoda i niektóre wyniki badań energochłonności systemów uprawy roli. *Fragmenta Agronomica, 2*, 7-18.

Heyland, K.; Solansky S. (1997). Berichte über Landwirtschaft. *Neue Folge 195*, 15-30.

Krysztofiak, A.; Podsiadłowski, S.; Michalak, M. (1996). Oddziaływanie ciągników i maszyn rolniczych na glebę. *Problemy inżynierii rolniczej, 1*, 29-36.

Lejman, K.; Owsiak, Z. (2001). Wpływ prędkości przemieszczania narzędzi skrawających glebę na wartości oporów. *Inżynieria Rolnicza, 13*(33), 261-267.

Owsiak, Z.; Lejman, K.; Wołoszyn M. (2006). Wpływ zmienności głębokości pracy narzędzia na opory skrawania gleby. *Inżynieria Rolnicza, 4*(79), 45-53.

Przybył, J.; Kowalik, I.; Dach, J.; Zbytek, Z. (2009). Analiza jakości pracy agregatów do uprawy przedsiewnej. Jou*rnal of Research and Application in Agriculture Engineering. Vol. 54*(4), 62-68.

Roszkowski, A. (1980). *Ocena efektywności energetycznej i ekonomicznej produkcji kukurydzy i jęczmienia*. IBMER Warszawa.

Sahu, R. K; Raheman, H. (2006). An approach for draft prediction of combination tillage implements in sandy clay loam soil. *Soil and Tillage Research, Vol. 90*(1-2), 145-155.

Šařec, O.; Šařec, P. (2003). Ocena efektów pracy brony talerzowej i kultywatora podorywkowego. *Inżynieria Rolnicza, 10*(52), 255-261.

Talarczyk, W.; Zbytek, Z. (2006). Wpływ głębokości roboczej agregatu do bezorkowej uprawy gleby na obciążenia eksploatacyjne. *Inżynieria Rolnicza, 4*(79), 303-312.

Vilde, A. (2003). *Up-to-date trends in soil tillage engineering*. Polish Academy of Sciences Branch in Lublin. TEKA Commision of Motorization and Power Industry in Agriculture, Volume III. Lublin, Poland, 257-262.

Zbytek, Z. (2010). Wpływ stosowania różnych elementów roboczych na obciążenia eksploatacyjne maszyn do uprawy dwuwarstwowej. *Journal of Research and Applications in Agricultural Engineering. Vol. 55*(1), 117-119.

WPŁYW PRĘDKOŚCI AGREGATU UPRAWOWEGO I UPRAWOWO-SIEWNEGO NA OPÓR ROBOCZY W ASPEKCIE WIELOLETNIEGO STOSOWANIA ODMIENNEGO SYSTEMU UPRAWY GLEBY

Streszczenie. Przedstawiono wyniki badań oporów roboczych agregatów uprawowych i uprawowo-siewnych stosowanych w zróżnicowanych systemach uprawy gleby. Celem badań było wyznaczenie wpływu prędkości agregatów uprawowych i uprawowo-siewnych na opory robocze z uwzględnieniem zróżnicowania systemów upraw poprzedzających. Właściwości gleby na analizowanych poletkach, na których stosowano odmienny system uprawy scharakteryzowano za pomocą wybranych właściwości fizyczno-mechanicznych gleby takich jak: wilgotność, zwięzłość oraz maksymalne naprężenia ścinające. Wyznaczono opory robocze dla: kultywatora o zębach sztywnych, brony talerzowej oraz agregatu uprawowo-siewnego stosowanego w technologii siewu bezpośredniego. Głębokość roboczą ustalono dla wszystkich agregatów równą 0,05 m. Pomiary oporów roboczych wykonano przy pomocy dwóch ciągników połączonych holem, w którym zamontowano tensometryczny przetwornik siły. Stwierdzono istotny wpływ zastosowanego agregatu i prędkości roboczej, nie stwierdzono natomiast wpływu poprzedzającego systemu uprawy gleby na zmierzony opór roboczy.

Słowa kluczowe: agregat uprawowy, opór roboczy, uprawa, prędkość agregatu

Scientific quarterly journal e-ISNN 2449-5999
Agricultural Engineering
2015: 1(153):127-132
Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.113

A NEW STRUCTURE OF THE STABILIZATION SYSTEM OF A SUSPENDED SPRAYER BOOM[1]

Szczepan Michał Sobotka, Adam Józef Lipiński*

Department of Mills and Methodology of Research, University of Warmia and Mazury in Olsztyn
*Contact details: ul. Oczapowskiego 11, 10-719 Olsztyn; e-mail: adam.lipinski@uwm.edu.pl

ARTICLE INFO

Article history:
Received: December 2014
Received in the revised form: January 2015
Accepted: March 2015

Keywords:
sprayer boom
quality of spray
stabilization system of sprayer boom

ABSTRACT

The paper presents a new system that stabilizes a sprayer boom in the vertical plane. The presented system is protected by patent law. The article shows, inter alia, the idea and principle of operation of the stabilization system of the sprayer boom which uses the centre of gravity of the sprayer boom frame suspended on the beared axis of a sprayer. The angle of deflection of sprayer boom arms depends on the height/depth of an obstacle for tractor wheels. The stabilization system is designed for use with a field suspended sprayer and is one of the systems based on passive elements. The main design assumption was to develop a system that ensures a satisfactory level of stabilization of a boom and maintaining acceptable production costs. The presented solution is prepared for realization and for carrying out field research.

Introduction

Effectiveness of chemical plant protection depends on many factors. A biological result is obtained at maintenance of the appropriate type, dose, time limit and conditions of the treatment. An incorrect method of spraying often results in unavailability of the planned effect. It often happens that the spraying treatment is carried out on fields with considerably uneven surface. Such surface causes, inter alia, fluctuations of a sprayer boom in the vertical plane, which results in irregular deposition of working liquid on sprayed plants (Lipiński et al., 2011). On the sprayed area which corresponds to the working width of a sprayer both deposition of too high amount of liquid, namely, its "overdosing" as well as deposition of too low amount of liquid, namely its "underspraying" may take place. Both cases are undesired and the simplest way to avoid them is to ensure that during the spraying treatment a sprayer boom is constantly parallel to the sprayed surface of plants (Hołownicki, 2005; Szulc, 2011; Szewczyk et al., 2010).

[1] Participant of the project "Grants for doctorates of the Podlaskie Voivodeship", co-funded as a part of the Operational Programme Human Capital, Measure 8.2. Knowledge transfer, Submeasure 8.2.2 Regional Strategies of Innovations from the funds of the European Social Fund, state budget and budget means of the Podlaskie Voivodeship

In order to eliminate unfavourable phenomenon, which is fluctuation of a sprayer boom during spraying, stabilizing systems embodied in the structure of sprayers are used. The stabilization systems of a sprayer boom used in sprayers are based on two basic structural systems: a trapezoid and fluctuation (Anthonis et al., 2005; Lipiński et al., 2011; Popławski and Szulc, 2010). Regardless their structure, they are used to limit the boom movements, mainly in the vertical plane. Generally, it should be stated that stabilization of a sprayer boom of a sprayer during its operation is not easy and systems used for this purpose are frequently based on complex technical solutions with a complicated structure and are expensive in realization. It often happens that their value exceeds the cost of the remaining structure of a sprayer.

It forces to search for new solutions, optimal in the context of compromise between the quality of stabilization and costs of making the system. Hence the inspiration to undertake this issue and the attempt to develop a new structure of the stabilization system of a sprayer boom.

The paper shows basic solutions applied in order to stabilize a sprayer boom and a proposal of a new, innovative, mechanical stabilization system of sprayer boom position in the vertical plane was presented.

Objective and scope of the study

The objective of the paper was to present the problem concerning a correct way of leading a sprayer boom over the sprayed objects and discussion on commonly applied stabilization systems of a sprayer boom. Based on the analysis of the existing solutions, a new system that improves stability of a sprayer boom dedicated for small farms, description of which constitutes a basic content of the article, has been described. The presented system was granted patent protection (Lipiński and Sobotka, 2014).

Stabilization systems of a sprayer boom

Operations of the systems which are used for stabilization of a sprayer boom are based on the fundamental physics law. There are two basic structures of stabilization systems. Pendulum systems (fig. 1a) work on one pull rod and joint, whereas trapezoid ones (fig. 1 b) on two pull rods and four joints. A sprayer boom returns to balance under the influence of gravitational force.

Both methods are the simplest in structure and operation. Such a structure favours uncontrolled movements which could unfavourably influence the quality of the treatment. Particularly in sprayers with the boom length exceeding 10 m, correct leading of a boom over the sprayed objects is considerably impeded. In such cases, more complex systems are used, which aim at the correction of sprayer boom vertical and horizontal deflection. Stabilization systems differ with the place and manner of use and are divided into systems which use only passive elements such as shock absorbers or stabilizing springs (Kamiński and Kruk, 2012; Kennes et al., 1999; Rahman et al., 2011), and systems with active elements such as e.g. servomotors controlled based on signals from electronic (most frequently ultrasound) distance sensors (Deprez et al., 2002; Jeon et al., 2004; Tahmasebi et al., 2012).

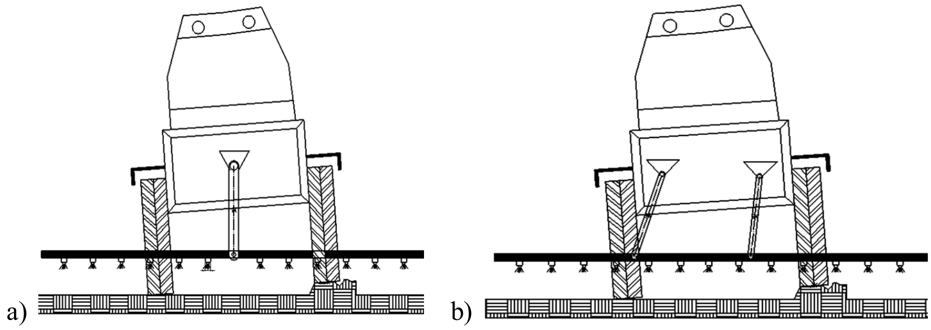


Figure 1. Pendulum (a) and trapezoid (b) stabilization system of a sprayer boom

Regardless the approach, the aim is to always maintain the distance of sprayers from the sprayed plants, because such location of a sprayer boom allows obtaining the highest quality treatment (Szulc, 2011).

Description of the new stabilization system of a sprayer boom

The control system of the sprayer boom leading, which has been shown in figure 2, is a passive system. The basis of the developed solution is the use of the centre of gravity and the force of gravity. In order to keep the boom perpendicularly to the surface (of sprayed plants) connectors and flat bars were used. The leading system of a boom consists of the main frame of a sprayer (1) where a rotation axis is mounted stiffly (2). A sprayer boom frame (3) is suspended on the rotation axis. The rotation axis is mounted in the centre of gravity of the main frame and goes through the centre of gravity of the beared frame of a sprayer boom. On the frame of a sprayer boom there are plugs mounted (4) where arms of a sprayer boom are suspended: left (5) and right (6). Internal ends of the boom arms are connected to leading levers (7) with a lever connector (8), mounted on the axis through cylindrical gum shock absorbers (9).

A stable balanced position of the sprayer boom suspended frame is guaranteed by the use of additional leading elements, i.e. levers, which influence directly the sprayer boom arms. Connection of the axis with a leading connector through cylindrical gum shock absorbers eliminates direct vibrations.

The presented stabilization system is equipped with the connection system which ensures stable position of sprayer boom arms when a sprayer is in the rest state as well as correct lead of the sprayer boom arms during operation of a sprayer. Operation of the stabilization system depends on the position of a sprayer towards the field surface. Each deflection of a sprayer from the parallel surface of a field should be immediately and automatically corrected on the sprayer boom arms.

In order to know the operation of the system better, a case was described when left wheels of a sprayer meet an obstacle in the form of a furrow: a sprayer will deflect from the parallel position and the rotation axis will automatically turn left in the sprayer boom frame. The pressure made by a leading connector, will turn the left arm of the field boom in the vertical plane by such an angle as defection of the entire unit.

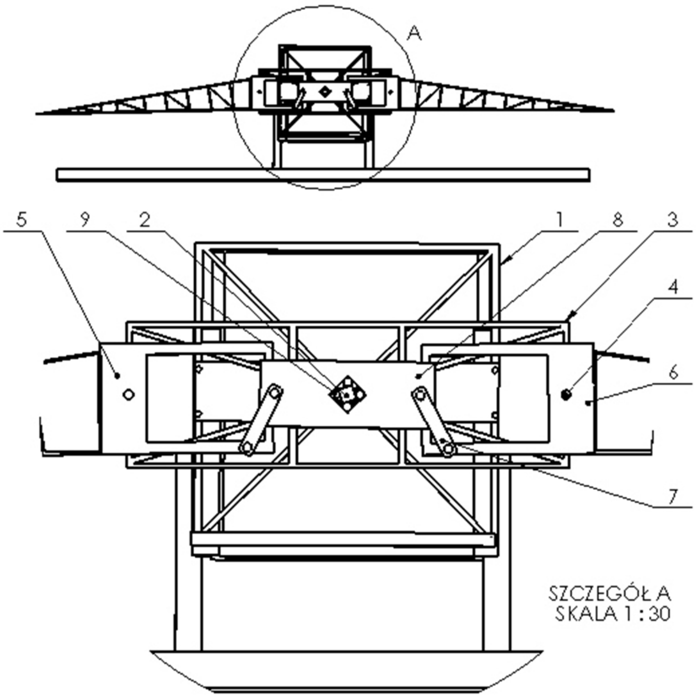


Figure 2. The stabilization system of a sprayer boom - view from the back in the spread position along with an enlarged A detail: 1 – main frame of a sprayer, 2 – rotation axis, 3 – sprayer boom frame, 4 – plugs, 5 – left arm of sprayer boom, 6 – right arms of sprayer boom, 7 – leading levers, 8 – lever connector, 9 – gum shock absorbers.

Analogically, the right arm of a sprayer boom will drop in the opposite direction to the arm of a boom so that the entire boom is positioned parallel to the surface of a field (fig. 3). It means automatic correction of the boom position. In case, a tractor drives with its right wheels into a furrow, the system will act identically but in the reverse order.

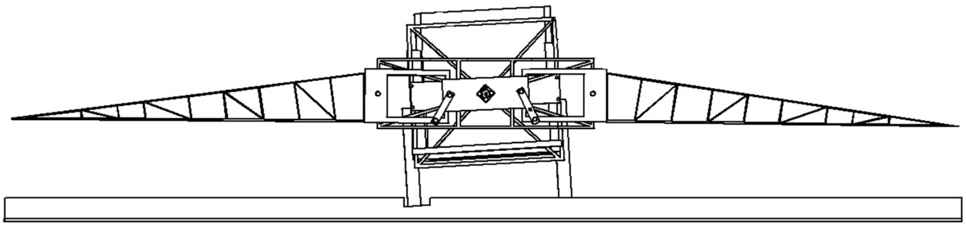


Figure 3. Operation of the stabilization system after left wheels of a tractor drive into a furrow

Summary and conclusions

The presented system is a modern technical solution, which ensures stabilization of a sprayer boom suspended on a tractor in case it meets obstacles during spraying. For this purpose, the suspension system of a sprayer boom in the centre of gravity was applied. It uses deflection of the unit towards the deflection of the relevant side of a sprayer boom. The presented system is a typical mechanical solution, relatively simple in its structure, which reacts directly when a sprayer meets obstacles. The system may be used in suspended sprayers dedicated for smaller farms. The suggested solution includes vertical movements of a sprayer boom, which result from the change of angle from the horizontal position of a sprayer. However, it does not include side horizontal movements. Work is carried out to construct a prototype of the described solution. Further, research aiming at assessment of the effectiveness of operation of the stabilization system in field conditions is planned.

An estimated cost of production of a prototype stabilization system of a sprayer boom is approximately five thousand PLN and includes costs of purchase of materials and construction of the stabilization system of a sprayer boom ready to be mounted on a field sprayer.

References

Anthonis, J.; Audenaert, J.; Ramon, H. (2005). Design Optimisation for the Vertical Suspension of a Crop Sprayer Boom. *Biosystems Engineering 90*(2), 153-160.

Deprez, K.; Anthonis, J.; Ramon, H.; Van Brussel, H. (2002). Development of a Slow Active Suspension for Stabilizing the Roll of Spray Booms, Part 1: Controller Design. *Biosystems Engineering, 81*(3), 273-279.

Hołownicki, R. (2005). Stabilizacja belki polowej. *Rolniczy Przegląd Techniczny, 7*(2), 30-33.

Jeon, H.Y.; Womac, A.R.; Wilkerson, J.B.; Hart, W.E. (2004). Sprayer boom instrumentation for field use. *Transactions of the ASAE 47*(3), 659-666.

Kamiński, E.; Kruk, I.S. (2012). Tłumienie drgań poprzecznych belki opryskiwacza polowego za pomocą amortyzatorów. *Problemy Inżynierii Rolniczej, 20*, 83-94.

Kennes, P.; Ramon, H.; De Baerdemaeker, J. (1999). Modelling the Effect of Passive Vertical Suspensions on the Dynamic Behaviour of Sprayer Booms. *Journal of Agricultural Engineering Research, 72*(3), 217-229.

Lipiński, A.; Sobotka, S.; Lipiński S. (2011). Przegląd systemów stabilizacji belek polowych opryskiwaczy. *Inżynieria Rolnicza, 15*(8), 181-187.

Lipiński, A.; Sobotka, S. (2014). Układ stabilizacji belki polowej opryskiwacza, Zgłoszenie patentowe nr P. 397464, Prawo wyłączne nr 16555, *Wiadomości Urzędu Patentowego, 4*, 818.

Popławski, Z.; Szulc, T. (2010). Innowacyjne rozwiązania w technice ochrony roślin. Cz. 1. Elementy wyposażenia rolniczych opryskiwaczy polowych. *Technika Rolnicza Ogrodnicza Leśna 7*(1), 17-22.

Rahman, R.A.; Tahmasebi, M.; Gohari, M. (2011). Design and Simulation of a Passive Vertical Suspension System for Spray Boom Structure. *Journal of Mechanics Engineering and Automation, 1*(6), 420-424.

Szewczyk A., Owsiak Z., Lejman K., Rojek G. (2010). Wpływ wybranych parametrów i warunków pracy opryskiwacza na położenie belki polowej w płaszczyźnie poziomej. *Inżynieria Rolnicza*, 2 (120), 217-224.

Szulc, T. (2011). Systemy stabilizacji belek polowych. Cel równomierny oprysk. *Rolniczy Przegląd Techniczny, 14*(3), 52-54.

Tahmasebi, M.; Rahman, R.A.; Mailah, M.; Gohari, M. (2012). Sprayer Boom Active Suspension Using Intelligent Active Force Control. *Journal of World Academy of Science, Engineering and Technology, 68*, 1277-1281.

NOWA KONSTRUKCJA UKŁADU STABILIZACJI BELKI POLOWEJ OPRYSKIWACZA ZAWIESZANEGO

Streszczenie. W pracy opisano nowy układ stabilizujący belkę polową opryskiwacza w płaszczyźnie pionowej. Zaprezentowany układ jest chroniony prawem patentowym. Artykuł pokazuje m.in. ideę i zasadę działania układu stabilizacji belki polowej, wykorzystującego środek ciężkości ramy belki polowej zawieszonej na ułożyskowanej osi opryskiwacza. Kąt wychylenia ramion belki polowej uzależniony jest od wysokości/głębokości przeszkody napotkanej przez koła ciągnika. Układ stabilizacji przeznaczony jest do zastosowania z opryskiwaczem polowym zawieszanym i należy do systemów opartych na elementach biernych. Głównym założeniem projektowym było opracowanie układu zapewniającego satysfakcjonujący poziom stabilizacji belki przy zachowaniu akceptowalnych kosztów produkcji. Zaprezentowane rozwiązanie jest przygotowywane do realizacji oraz przeprowadzenia badań polowych.

Słowa kluczowe: opryskiwacz polowy, jakość oprysku, układ stabilizacji belki polowej

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153): 133-139

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.114

ANALYSIS OF SEASONALITY OF DEMAND FOR MAINTENANCE SERVICES OF AGRICULTURAL TRACTORS

Żaneta Staszak*, Tatiana Buchwald

Institute of Biosystem Engineering, Poznań University of Life Sciences

Contact details: ul. Wojska Polskiego 50, 60-627 Poznań, e-mail: staszak@up.poznan.pl

ARTICLE INFO

Article history:
Received: August 2014
Received in the revised form: September 2014
Accepted: February 2015

Keywords:
repair of agricultural tractors
tractor service
warranty and post-warranty service

ABSTRACT

Agricultural tractors produced in the twenty-first century will require high-quality services related to their servicing. The aim of the work is to obtain information on the distribution of demand in each month for maintenance services of agricultural machinery based on the service facility located in Wielkopolska Region. The paper presents the analysis of the demand for warranty and post-warranty services for farm tractors over the year. The results have been developed statistically in order to determine the period of greatest demand for service. In the form of histograms quarterly distributions of values of the demand for warranty services, guarantee services and the total number of service were presented. The results have been analysed in terms of time limits for performance of agrotechnical treatments recommended for vegetable crops in Poland.

Introduction

Modern farm tractors have a great number of complex technical systems, which face high requirements related to their reliability, strength and efficiency. Such criteria follow from specificity of agricultural production, where the date of performing works is dictated by atmospheric and climatic factors (Juściński and Piekarski, 2009a). The basic condition of good exploitation of farm machines is technical maintenance (periodical diagnostics, technical service) which consists, inter alia, in replacing exploitation material, proper protection of protective layers against harmful atmospheric, soil and chemical factors, regulation of units etc. (Niziński and Michalski, 2007; Rybacki and Durczak, 2011; Rzeźnik, 2008; Legutko, 2004; Tomczyk, 2009; Wiśniewski, 2012). Giving up a periodical technical service leads to wear and tear and faster ageing of a machine, which affects the change of their operation parameters through achieving or exceeding border values for a given working unit reducing at the same time their reliability (Rzeźnik, 2008; Rybacki, 2011; Juściński and Piekarski, 2008).

Periodical technical maintenance should be carried out within a time limit specified by a manufacturer to prevent a situation, when an exploited tractor is unfit for use during intense field works. A period of exploitative fitness is expressed with a number of moto hours of a particular tractor. The use of farm tractors in farms depends highly on agrotechnical periods. Such distribution of machines use is an important obstacle in careful planning of services demand by the service department (Juściński and Piekarski, 2009b).

Aiming at achieving high reliability, quality and effective operation of farm tractors, it is important to carry out high quality technical service. Services of farm tractors should render services for their clients in adequately equipped and organized repair facilities (Durczak and Rybacki, 2011; Skudlarski, 2006; Juściński and Szczepaniak, 2008). A good quality of technical services brings overtime financial advantages to producers of farm machines as well as users, shaping a seller-client bond, which displays loyalty towards a company in case of the first purchase (Juściński and Piekarski, 2010; Durczak and Rybacki, 2011).

Variable demand for service during a year is a great impediment in functioning of the service facility. Service facilities, who want to reduce uneven demand for the offered services use various solutions, such as: service offers, price discounts, client's card, etc.

Monitoring the maintenance service demand in a narrow scope influences accumulation of orders for such services, because damages to machines are random in nature and the time limits of planned inspections (e.g. warranty) are determined with the amount of performed work (in moto hours, working hours, kilometres). The issue undertaken in this paper is crucial for organization of work in repair-maintenance facilities. Unfortunately, service facilities have no greater impact on accumulation of notifications in particular periods, thus in order to keep clients they introduce internal changes of work organization and they employ additional mechanics or they extend work time from 8 hours to 10 or 12 hours for those employed based on the employment contract. In some situations they introduce a two-shift work system.

Objective of the paper

The objective of research is to identify present distribution of seasonality of demand for warranty and post-warranty maintenance services and suggesting a possibility of decreasing the demand changes for services in the selected service facility located in Wielkopolskie Voivodeship.

Methodology

Presently a services market is very competitive which influences constant raise and improvement of the services quality by service facilities. It consists in constant control of production process, enhancing actions related to the improvement of quality, implementation of new technologies for companies and such organization and management, which takes into account client's satisfaction.

For realization of the objective of the paper, data from orders of the authorized service facility which renders technical services of farm tractors in Wielkopolskie Voivodeship were analysed. The investigated company employs seven workers of the service department for the fixed period of employment and has two cars with service equipment which is used for diagnostic purposes of tractors, in which failure occurred during field works. Investigations were carried out from 1st October 2012 to 30th September 2013. In order to reflect the actual state of the company functioning, orders concerning tractors were not selected. All maintenance services, both warranty and post-warranty, carried out in those establishments, were analysed. The scope of power of tractors was neither selected.

The collected data were developed in the form of histograms which present distribution of the annual demand for warranty and post-warranty services of farm tractors of the investigated company. Demand for maintenance services was measured with the number of orders in the investigated time intervals, which is some kind of a simplification.

Research results and their analysis

The research which was carried out shows that the company since 1st October 2012 to 30th September 2013 had executed 359 orders of all maintenance repairs of tractors including 154 repairs of machines covered with the manufacturer's warranty and the rest are machines which were not covered by warranty. The time limit of performing maintenance service was previously provided in 121 orders concerning tractors covered by warranty and 139 in case of tractors which were in the post-warranty period. The remaining orders were opened in the moment of notifying a failure and rendering a disposition by the service representative to the tractor operator or after providing a machine to the repair facility. During a year, the most because as much as 58% of orders, was related to tractors with power from 100 to 199 KM, another groups consisted of machines with power below 100 KM (37%). Tractors with power exceeding 200 KM constituted 5% of all the investigated orders. Such distribution of power results from the fact that farms in Wielkopolska region are average farms acc. to the Agency for Restructuring and Modernization of Agriculture (as of 3rd January 2014). Average area of agricultural farms in 2013 was 13.46 ha (for the country it was 10.42 ha).

Demand for warranty services in the analysed period is presented in figure 1. Distribution of demand for maintenance services of new tractors considerably depends on the date of their purchase and intensity of exploitation during field, transportation and other works carried out in a farm.

Owners of new machines after determined service life in moto hours notify the need of warranty service (also called inspection).

In the last quarter of 2012 demand for warranty services in comparison to all warranty inspections in the investigated period were 10%. In the monthly distribution the lowest number of operations related to warranty service of tractors was carried out in October and November. The end of the third decade of November and the beginning of December had the increase of the number of notifications concerning the need for maintenance services, whereas the end of the year reduced the number of notifications to zero. The reason for such distribution of orders is reduction of intensity of use of farm tractors related to the winter season and the end of field works. Sowing winter cereals at the end of September and beginning of October results in formation of a reserve related to unused possibilities of repairs and warranty inspections.

The first quarter of 2013 is an increase in the number of service orders concerning warranty inspections. At the end of January and the beginning of February higher demand for warranty service was reported – in comparison to the previous month; in the second decade of February decrease was reported. On the other hand, at the end of the first and in the beginning of the second quarter demand for warranty orders increased considerably. It was related to the increase of intensity of exploitation of farm tractors. The end of March and beginning of April is a period, when field works related to cultivation, fertilization and sowing of spring plants are initiated. In the second quarter, 34% of all notifications related to warranty service of machines were reported. A systematic decrease of orders and another increase in June had been reported since April. In the beginning of the third quarter the number of inspections and warranty inspections and repairs of farm tractors was dropping systematically and achieved stabilization in August. In the first decade of September, a sudden increase of orders took place, which resulted from the greater exploitation of tractors during harvest in July and August and the required moto hours, which qualified a tractor for warranty inspection and service.

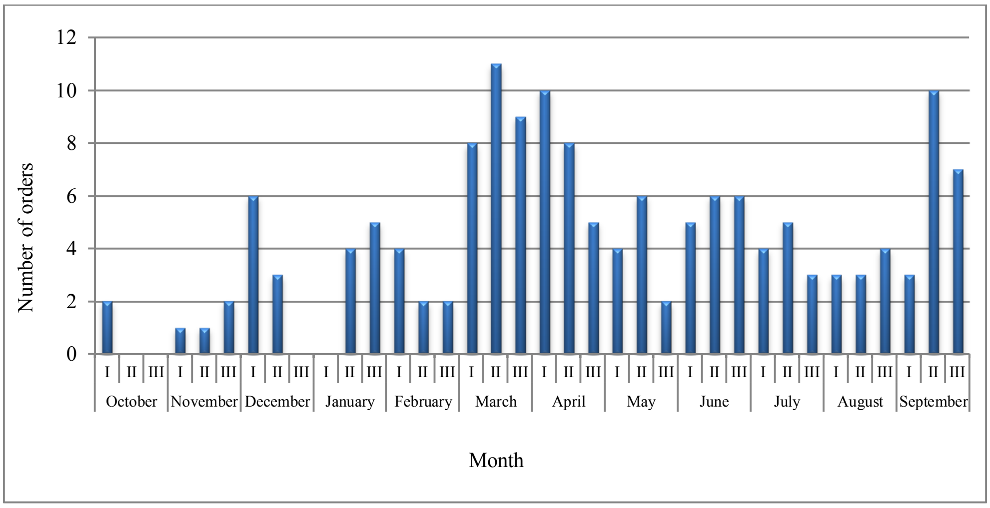


Figure 1. Distribution of demand for warranty service of farm tractors

Seasonality of works performed with the use of farm tractors influenced accumulation of warranty services demand in the investigated period. In winter months, intensity of tractors exploitation is reduced which is related to abandoning plant production, which causes decrease in the number of warranty orders. Users of farm tractors usually perform warranty inspections shortly before field works begin – the period for such works is uniform for a given region - thus the maintenance service carries out orders in March and April, which could have been carried out earlier.

Figure 2 presents a histogram of distribution of post-warranty services demands of the company from the beginning of October 2012 to the end of September 2013.

The objective of the post-warranty service is maintaining a machine in the fit condition. It mainly consists in inspection and post-warranty repair which eliminates failures of a farm tractor, which are mainly random.

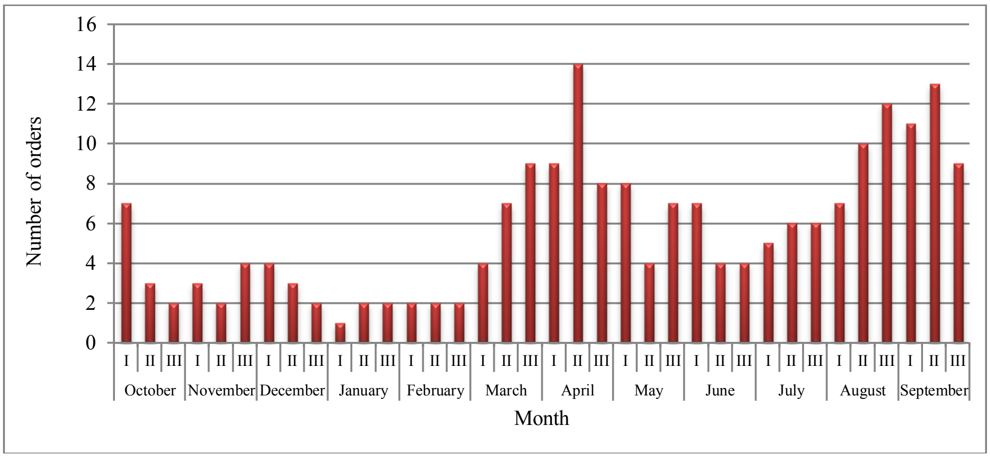


Figure 2. Distribution of demand for post-warranty service of farm tractors

Post-warranty orders in the last quarter of 2012 and the first quarter of 2013 constituted the same number of orders and were in total 30% of the total annual number of all repairs covered by warranty. In these months, post-warranty repairs concerned mainly machines working for animal farms, because such farms exploit tractors more regularly during the entire year. In the first decade of January demand for this type of repair was minimal. Increase was visible in the second decade of March as late as to the last decade of April. It is related to the beginning of field works and thus with the increase of intensity of exploitation of farm tractors. Post-warranty repairs of farm tractors in the second quarter were 31% of all orders analysed for the given period. The highest number of orders related to repair of tractors which did not have warranty was reported in the second quarter of 2013. It is a period of intense exploitation of farm tractors during harvest of grains and post-harvest works. These works are carried out in summer months, when draughts occur and thus machines are more threatened to failures due to dusting their units and possibility of overheating working units.

In case of tractors, when the producer's warranty expires, the increase of failure takes place from March to October, which results from the higher number of field works. Along with the age of a machine its unreliability increases. Often it is random and therefore it is more difficult in this case- in comparison to the warranty service – to suggest reduction of accumulation.

A histogram (fig. 3) presents total demand for maintenance services (warranty and post-warranty) in the investigated period of time. Distribution of maintenance orders since October 2012 to the end of February 2013 does not exceed 10 orders in total. The increase of the total number of orders takes place in March when the field works begin during which farm tractors are exploited more intensively. Post-warranty orders mainly affected the increase of the number of orders from June to August. But accumulations in April, May and September were equally affected by warranty and post-warranty orders.

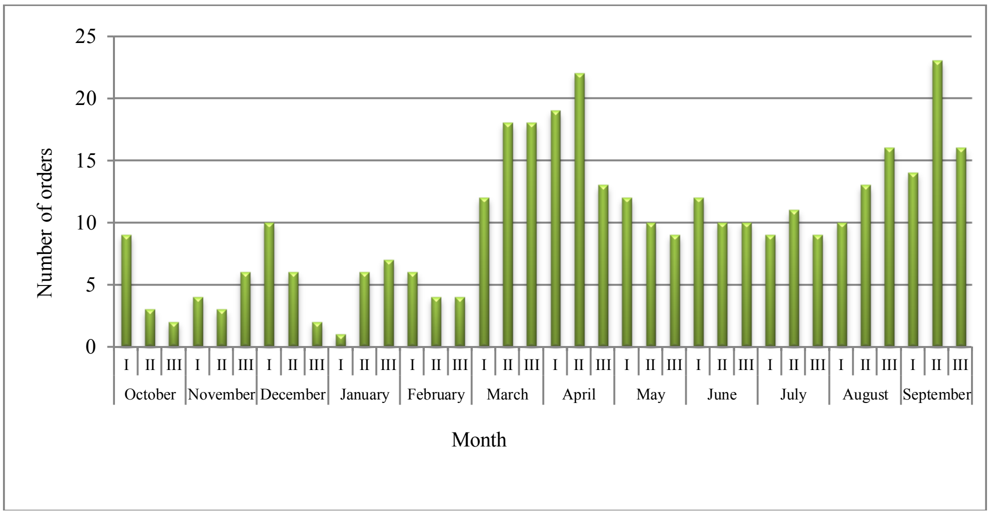


Figure 3. Total demand for warranty and post-warranty service of farm tractors

Conclusions

The research, which was carried out, development of results and their analysis allow formulation of the following conclusions:

1. In the investigated facility, great seasonality of demand for maintenance services took place, which impeded its functioning.
2. Observations made during investigations enable to produce a statement that particular orders are repeatable to some extend and time of their realization is similar.
3. In the investigated company, 10 orders at the average are for a decade; this number increases from March to May and in August and September. Thus, in this period, the following issues should be taken into consideration: employing additional specialists, extension of work time of employees, who are employed based on the contract for employment or implementation of the shift system in a facility. Such solution would provide a possibility of performing repair in a shorter time and thus it would reduce the time of stoppage resulting from a machine fault.

References

Durczak, K.; Rybacki, P. (2011). Hierarchizacja kryteriów oceny jakości usług serwisowych maszyn rolniczych – opinia konsumenta. *Technika Rolnicza Ogrodnicza Leśna*, *1*, 22-24.

Juściński, S.; Piekarski, W. (2008). Analiza statystyczna obsługi serwisowej ciągników rolniczych w aspekcie odległości od siedziby firmy. *Inżynieria Rolnicza*, *2*(100), 57-64.

Juściński, S.; Szczepanik, M. (2008). Naprawy gwarancyjne i pogwarancyjne ciągników rolniczych jako potransakcyjne elementy logistycznej obsługi klienta. *Inżynieria Rolnicza*, *2*(100), 67-74.

Juściński, S.; Piekarski, W. (2009a). Naprawy pogwarancyjne ciągników rolniczych jako element autoryzowanego systemu dystrybucji. *Inżynieria Rolnicza*, *8*(117), 23-30.

Juściński, S.; Piekarski, W. (2009b). Rozkład zapotrzebowania na przeglądy serwisowe ciągników rolniczych w aspekcie terminów agrotechnicznych. *Inżynieria Rolnicza*, *8*(117), 31-38.

Juściński, S.; Piekarski, W. (2010). Eksploatacja pojazdów rolniczych w aspekcie struktury popytu na usługi przeglądów serwisowych. *Maintenance and Reliability*, *1*, 59-68.

Legutko, S. (2004). Podstawy eksploatacji maszyn i urządzeń. *WSiP*, Warszawa, ISBN 978-83-02-08998-5, 70-84.

Niziński, S.; Michalski, R. (2007). Utrzymanie pojazdów i maszyn. *Wyd. Instytutu Technologii Eksploatacji*, Radom, ISBN 978-83-72-04646-8, 324-349.

Rybacki, P. (2011). Investigation of the decision – making process of service station for agricultural tractors using the AHP method. *Journal of Research and Applications in Agricultural Engineering*, *2*(56), 126-130.

Rybacki, P.; Durczak, K. (2011). Ocena jakości serwisu technicznego maszyn rolniczych. *Inżynieria Rolnicza*, *9*(134), 201-206.

Rzeźnik, C. (2008). Podstawy obsługi technicznej maszyn rolniczych. *Wyd. Akademii Rolniczej im. Augusta Cieszkowskiego*, Poznań, ISBN 978-83-7160-485-0, 53-65.

Skudlarski, J. (2006). Procedura badania strat na skutek przestojów jako element kosztów eksploatacji ciągnika. *Inżynieria Rolnicza*, *1*1(86), 431-436.

Tomczyk, W. (2009). Obsługa techniczna w procesie odnowy i utrzymania maszyn i urządzeń rolniczych. *Inżynieria Rolnicza*, *6*(115), 301-307.

Wiśniewski, M. (2012). *Kryteria jakości operacji serwisowych ciągników rolniczych*. Praca magisterska. Uniwersytet Przyrodniczy w Poznaniu, Instytut Inżynierii Rolniczej, Poznań.

Ogłoszenie Prezesa Agencji Restrukturyzacji i Modernizacji Rolnictwa z dnia 20 września 2013 r. w sprawie wielkości średniej powierzchni gruntów rolnych w gospodarstwie rolnym w poszczególnych województwach oraz średniej powierzchni gruntów rolnych w gospodarstwie rolnym w kraju w 2013 roku, http://www.arimr.gov.pl/dla-beneficjenta/srednia-powierzchnia-gospodarstwa.html, ARiMR, dostęp z dnia 10.01.2014 r.

ANALIZA ZAPOTRZEBOWANIA MOCY PRZEROBOWEJ WARSZTATÓW NAPRAWCZYCH CIĄGNIKÓW ROLNICZYCH NA PRZYKŁADZIE WOJEWÓDZTWA WIELKOPOLSKIEGO

Streszczenie. Ciągniki rolnicze wyprodukowane w XXI wieku wymagają wysokiej jakości usług związanych z ich serwisowaniem. Celem pracy jest uzyskanie informacji dotyczącej rozkładu zapotrzebowania w poszczególnych miesiącach roku na usługi serwisowe maszyn rolniczych na podstawie danych z zakładu serwisowego zlokalizowanego w województwie wielkopolskim. Przedstawiono analizę zapotrzebowania na usługi serwisowe gwarancyjne i pogwarancyjne ciągników rolniczych na przestrzeni roku. Wyniki opracowano statystycznie w celu wyznaczenia okresu największego zapotrzebowania na usługi serwisowe. W postaci histogramów przedstawiono kwartalne rozkłady wartości zapotrzebowania na usługi gwarancyjne, pogwarancyjne oraz łączną liczbę usług serwisowych. Wyniki przeanalizowano w aspekcie terminów realizacji zabiegów agrotechnicznych zalecanych dla upraw roślinnych na terenie Polski.

Słowa kluczowe: naprawa ciągników rolniczych, obsługa serwisowa ciągnika, serwis gwarancyjny i pogwarancyjny

Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):141-150

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.115

IMPACT OF DIAMETER OF PRESSING CHANNELS AND MOISTURE ON PARAMETERS OF PELLETING PROCESS OF VIRGINIA MALLOW BIOMASS

Grzegorz Zając*

Department of Power Engineering and Vehicles, University of Life Sciences in Lublin

Contact details: ul. Głęboka 28, 20-612 Lublin; e-mail: grzegorz.zajac@up.lublin.pl

ARTICLE INFO

Article history:
Received: January 2015
Received in the revised form: February 2015
Accepted: March 2015

Keywords:
biomass
pellets
energy consumption
quality of pellets

ABSTRACT

The objective of the paper was to evaluate the impact of biomass subjected to pelleting and diameter of pressing openings of a matrix of a pelleting machine on unit consumption of energy and quality of pellets. Virginia mallow biomass (*Sida hermaphrodita* R.) was investigated. The pelleting process was carried out on a pelleting machine with a flat matrix with the set of pressing rolls. Matrices with three diameters of pressing channels 6, 8, 10 mm were used for pelleting. Pelleting attempts were carried out at the material moisture which was 10, 15 and 20%. It was found out that energy consumption of the process of pellet production from Virginia mallow biomass depended on the raw material moisture and on diameter of pressing channels in the matrix of a pelleting machine. Unit consumption of electric energy during the pelleting process was within 45.3 and 70.2 $Wh \cdot kg^{-1}$. The lowest value was reported for moisture of 15% and diameter of pressing channels of 10 mm. Durability of the obtained pellets was within 88.9-93.5% of pellets. The highest durability was in case of pellets obtained at the moisture of 15% but higher durability was obtained at lower diameters of pressing openings. The highest relative density was in case of pellets obtained at the moisture of 15% and it was 1133.6-1094.8 $kg \cdot m^{-3}$ but density got reduced along with the increase of a diameter of channels.

Introduction

The use of plant biomass for production of heat and electric energy has become more important on account of partial replacement of fossil fuels and striving to reduce emission of carbon dioxide to atmosphere (Smeets et al., 2007; Stelte et al., 2011a; Nunes et al., 2014; Blaschke et al., 2013).

Solid biomass is presently obtained from forestry, agriculture, wood industry, urban greenery waste and some amount from segregated organic municipal waste. Balance of biomass supply on the power industry market may be supplemented by obtaining it from perennial domestic plants plantations and those introduced to Poland (Niedziółka et al., 2015). Biomass advantage consists in local production, however, it has low density and low calorific value (referred to volumetric unit) thus high transport costs and an impeded manner of charging boilers. These problems may be solved through appropriate processing and pressure agglomeration- briquetting and pelleting. Main advantages from biomass agglomeration include higher energy density and lower costs of transport and storing (Stelte et al., 2011b; Niedziółka and Szpryngiel, 2012; Niedziółka and Szpryngiel, 2014).

Pellets have become popular in many countries, particularly in Europe, their use has been systematically increasing recently (Liu et al., 2014; Stelte et al., 2011a; Stelte et al., 2011b). Demand for this type of fuel results mainly from comfort of use and possibility of using it both in heating individual installations and in heating systems. In comparison to traditional calorific wood, pellets may ensure possibility of automation and optimization of combustion, similar to calorific oil or natural gas along with high combustion efficiency and low amount of combustion residue.

Basic raw material for production of pellets is wood waste, presently energy plants and post-production farm waste is also used.

Processes of pressure agglomeration cause many difficulties with respect to technique, technology and exploitation, which result from complexity and variability of issues which occur during the process, carried out in working systems with various structures. Variability of physical, chemical and biological materials subjected to agglomeration is an impediment (Hejft, 2011). Except for information concerning the course of agglomeration process, information concerning energy inputs incurred in the process is important.

The objective of the paper was to evaluate the impact of biomass subjected to compaction and diameter of pressing openings of a matrix of a pelleting machine on unit consumption of energy and quality of Virginia mallow pellets (*Sida hermaphrodita* R.).

Methodology and conditions of research

The researched raw material was Virginia mallow biomass, which came from the field experiment. Initial fragmentation of biomass was carried out with the use of a beater grinder. Target raw material fraction was obtained in a hammer mill H111 equipped with sieves with 3 mm meshes.

The pelleting process was carried out on a pelleting machine with a flat matrix with the set of pressing rolls. The pelleting machine was equipped with a matrix with 380 mm diameter and three pressing rolls, which ensure capacity up to 300 $kg \cdot h^{-1}$ (sawdust with 13% moisture and fraction up to 5 mm), electric engine power was 12 kW.

Matrices with three diameters of pressing channels 6, 8, 10 mm and length of 36 mm each were used for pelleting. Pelleting attempts were carried out at the material moisture which was 10, 15 and 20%.

It allowed preparation of 9 measurement variants presented in table 1. Measurements were carried out in 5 iterations for each variant. Biomass was moistened in the conditioning process with the use of a steam generator. Moisture during research was determined with the use of a moisture meter WTR-1N.

Table 1.
Measurement variants of research

Measurement variant	Moisture (%)	Diameter of pressing channels (mm)
1	10	6
2	10	8
3	10	10
4	15	6
5	15	8
6	15	10
7	20	6
8	20	8
9	20	10

In order to determine unit energy consumption, electric energy consumption charged by an electric engine, which drives the device was registered. Measurements of electric energy were made when the device reached stable speed. Power converter A/C Lumel P13P was used for measurement and registration of electric energy. This system enabled registration of active power collected by the device and visualization of actual value on the computer screen with the use of Lumel 3000 software. In order to determine energy consumption for fighting over own resistance of the device, instantaneous power was recorded during idle running. During pelleting of each of the tested raw materials, values of instantaneous power in one second intervals were recorded. Energy consumption was determined in relation:

$$E_j = \frac{E_p - E_{op}}{m} \tag{1}$$

where:
- E_j – energy consumption of the process, ($Wh \cdot kg^{-1}$)
- E_p – energy inputs during the process, ($W \cdot h$)
- E_{op} – energy inputs during light running, ($W \cdot h$)
- m – mass of the obtained pellets, (kg)

In order to determine mechanical properties of the obtained Virginia mallow pellets the following were determined:
- Specific density – with the use of a set for determination of density of solid bodies of RADWAG company WPS 510/C/1 model, where the measurement was based on the measurement of the mass of a sample in air and in liquid with known density.
- Durability – with the use of Pfost apparatus. In the container which is mechanically rotated, samples of 0.5 kg mass were placed and it was set in rotary motion with the speed of 50 rpm for 10 minutes. After the tester was stopped, the sample was sieved and the mass of not damaged granules was determined. By referring the mass of the remaining pellets to the mass of the entire sample kinetic resistance of pellet was obtained.

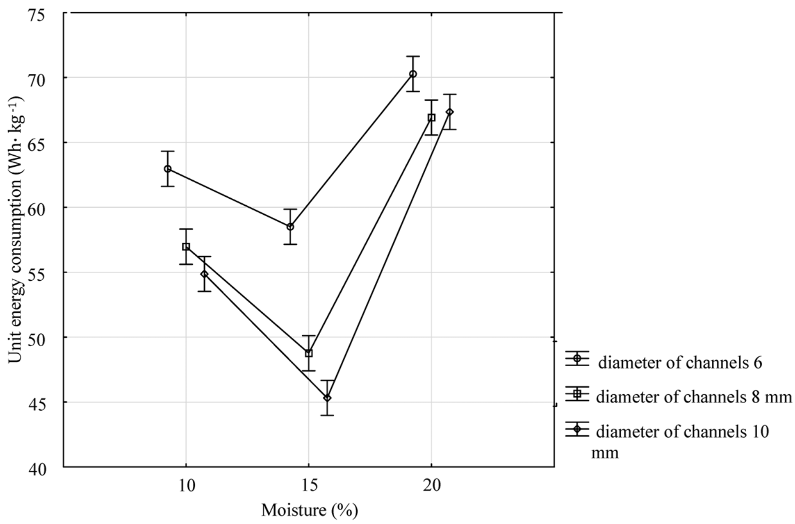
The obtained results of measurement of energy consumed for production of pellets from the investigated plant materials were subjected to statistical analysis with the use of analysis of variance and Tukey's test. In all analyses the level of significance was assumed as α=0.05 The obtained results were presented in tables of analysis of variance and tables which include appropriate means along with determination of their impact on statistically significant differences of analysed properties.

Results of the research

Figure 1 presents results of the research of energy consumption of pellets production depending on the moisture of raw material and diameter of pressing channels. The lowest unit energy consumption which amounts to 45.3 Wh·kg^{-1} was obtained for moisture of 15% and ϕ10 mm. The highest energy consumption – 70.27 Wh·kg^{-1} was in case of the compaction process for biomass moisture of 20% and ϕ 6 mm.

High energy consumption at the moisture of 20% resulted from unstable operation of a pelleting machine. While at the moisture of 10% before compaction of material, rolls of the device additionally milled material which caused a buildup of material and reduction of capacity of the compaction process.

Reduction of energy consumption for matrices with higher diameters of pressing channels may be justified by decrease of friction force, which results from the reduction of the total area of friction of agglomerate by areas of all compacting channels (Frączek, 2010).



Vertical columns stand for 0.95 confidence interval

Figure 1. Relation of unit energy consumption to moisture of raw material and diameter of pressing channels of matrix

In order to determine the impact of biomass moisture fed to a pelleting machine and diameter of pressing channels on energy consumption of the process, two-way analysis of variance (ANOVA) with interaction was carried out. Results of the analysis were presented in table 2. The analysis of variance which was carried out proved that both moisture of raw material as well as diameter of pressing channels and their interaction significantly influence unit energy consumption.

Table 2
Analysis of variance of unit energy consumption in relation to moisture and diameter of pressing channels

Source of variability	Degrees of freedom	Sum of squares	Root mean square	Value F_0	P ($F > F_0$)
Moisture	2	2264.8	1132.4	510.35	0.000000
Diameter of channels	2	543.0	271.5	122.35	0.000000
Moisture* diameter of channels	4	134.9	33.7	15.20	0.000000
Error	36	79.9	2.2		0.000000

The procedure of Tukey's test which compares results of research on the energy consumption of the pelleting process obtained in particular measurement variants (1-9) formed seven unit groups (table 3): first group – measurement variant 2 and 3, second: measurement variant 2 and 4, third: measurement variant 8 and 9, fourth: measurement variant 7 and 9, fifth: measurement variant 6, sixth: measurement variant 5 and seventh: measurement variant 1.

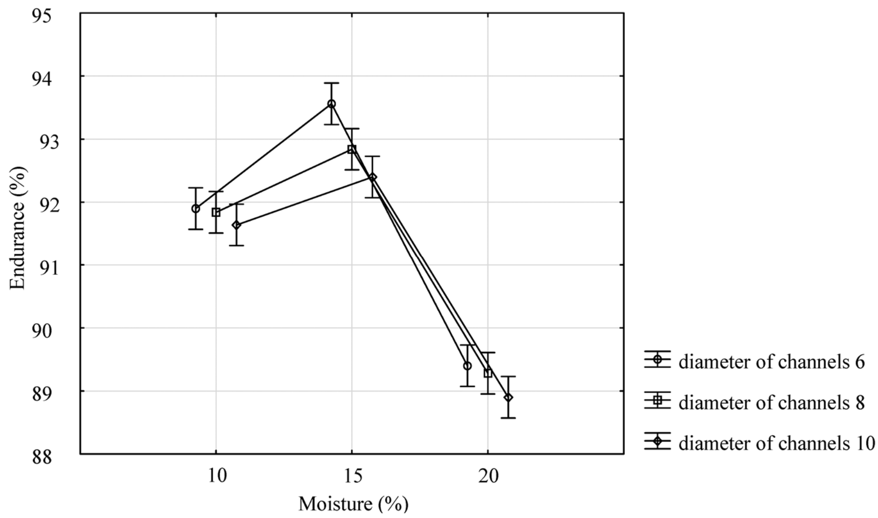
Table 3
Average values of energy intake during production of pellets ($Wh \cdot kg^{-1}$)

Measurement variant	Moisture (%)	Diameter of channels (mm)	Average energy consumption ($Wh \cdot kg^{-1}$)
6	15	10	45.32 ^{a}
5	15	8	48.76 ^{b}
3	10	10	54.86 ^{c}
2	10	8	56.97 ^{c,d}
4	15	6	58.50 ^{d}
1	10	6	62.96 ^{e}
8	20	8	66.91 ^{f}
9	20	10	67.35 ^{f}
7	20	6	70.28 ^{f,g}

Letters a, b, c, d, e, f, g in brackets stand for uniform groups
(average values of properties differ significantly between groups)

Relation between the durability of pellets and moisture for the applied matrices was presented in figure 2. Durability of the obtained pellets was within 88.9% to 93.56%. The lowest durability (<90%) was obtained for moisture of 20% independently from the applied matrices. Such low durability practically disqualifies them as fuel for use in household heating systems. The highest durability was obtained by pellets at the moisture of 15% for the matrix with a diameter of pressing channels of 6 mm – 93.56%.

Reduction of durability at moisture of 20% was caused by expansion of pellet after its passing through the matrix channel. Similar relations are presented in works (Kulig and Skonecki, 2011; 2010).



Vertical columns stand for 0.95 confidence interval

Figure 2. Relation of durability of obtained pellets to moisture of raw material and diameter of pressing channels of matrix

Impact of the moisture of raw material and diameter of pressing channels on thre durability of the obtained pellets was analysed with the use of a two-way analysis of variance (ANOVA) results of which were presented in table 4. Based on the obtained results it was found out that both the moisture of raw material and diameter of pressing channels had significant impact on the durability of the obtained pellets at 95% confidence interval. Effect of interaction of the moisture and diameter of pressing channels had no significant impact on durability of pellets.

Table 4
Analysis of variance of pellets durability in relation to moisture and diameter of pressing channels

Source of variability	Degrees of freedom	Sum of squares	Root mean square	Value F_0	P $(F > F_0)$
Moisture	2	110.2	55.1	421	0.000000
Diameter of channels	2	3.1	1.5	12	0.000119
Moisture* diameter of channels	4	4	0.3	2	0.074729
Error	36	4.7	0.1		

Table 5
Average values of durability of the obtained pellets (%)

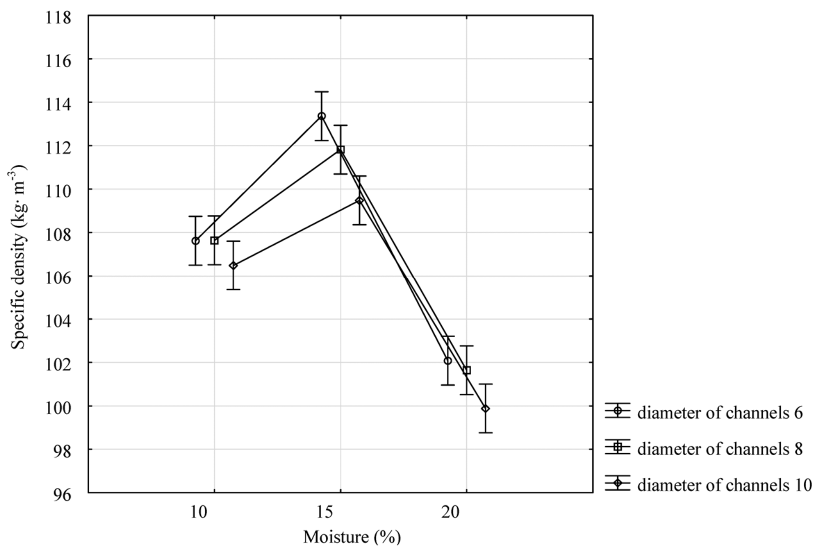
Measurement variant	Moisture (%)	Diameter of channels (mm)	Average durability (%)
9	20	10	88.90 [a]
8	20	8	89.28 [a]
7	20	6	89.40 [a]
3	10	10	91.64 [b]
2	10	8	91.84 [b,c]
1	10	6	91.90 [c]
6	15	10	92.40 [d]
5	15	8	92.84 [d]
4	15	6	93.56 [e]

Letters a, b, c, d, e in brackets stand for uniform groups
(average values of properties differ significantly betweengroups)

The applied Tukey's procedure which compares results of research on the durability of pellets obtained in particular measurement variants formed 5 uniform groups (table 5): first – measurement variant 7,8,9, second – measurement variant 1,2,3, third – measurement variant 6, fourth – measurement variant 5 and fifth measurement variant 4.

Specific density is one of the most important qualities of pellets. One of the factors influencing specific density is moisture and size of particles.

Figure 3 presents the obtained relation between specific density of pellets and moisture of raw material for the applied matrices.



Vertical columns stand for 0.95 confidence interval

Figure 3. Relation of specific density of the obtained pellets to moisture of raw material for diameters of pressing channels of matrix used in research

The highest values of the parameter were determined for moisture of 15% for all diameters of pressing channels – 1133.6-1094.8 kg·m^{-3}, whereas the lowest for moisture of 20% – 998.8-1002.8 kg·m^{-3}.

Low values of density at 20% moisture result from extension of agglomerate after being pushed from the matrix.

Kulig and Skonecki (2011) when investigating the compaction process of various energy plants including Virginia mallow determined similar relations by obtaining density exceeding 1000 kg·m^{-3} within the scope of moisture of 13-16%.

ANOVA analysis of variance (table 6) proved that moisture of raw material and diameter of pressing channels had significant impact ($p<0.05$) on specific density of the obtained pellets. Whereas for interaction of factors no statistically significant differences were determined.

Table 6
Analysis of variance of specific density of pellets in relation to moisture and diameter of pressing channels

Source of variability	Degrees of freedom	Sum of squares	Root mean square	Value F_0	P ($F> F_0$)
Moisture	2	81151	40575	264.9	0.000000
Diameter of channels	2	4647	2323	15.2	0.000017
Moisture* diameter of channels	4	967	242	1.6	0.201309
Error	36	5514	153		

Table 7
Average specific density of the obtained pellets

Measurement variant	Moisture (%)	Diameter of channels (mm)	Average specific density (kg·m^{-3})
9	25	10	998.8 ^{a}
8	25	8	1016.4 ^{a}
7	25	6	1020.8 ^{a}
3	15	10	1064.8 ^{b}
1	15	6	1076.2 $^{b, c}$
42	15	8	1076.4 $^{b, c}$
6	20	10	1094.8 $^{c, d}$
5	20	8	1118.2 $^{d, e}$
4	20	6	1133.6 ^{e}

Letters a, b, c, d, e in brackets stand for uniform groups
(average values of properties differ significantly between groups)

The procedure of Tukey's test which compares results of research on specific density of pellets obtained in particular measurement values (1-9) formed five uniform groups (table 7): first group – measurement variant 7-9 – measurement variant 1-3, third measurement variant 6, fourth 5 and sixth group measurement variant 4.

Conclusions

1. Analysis of the obtained results proved that energy consumption of the process of pellet production from Virginia mallow biomass depended on the raw material moisture and on the diameter of pressing channels in the matrix of a pelleting machine. Unit consumption of electric energy during the pelleting process was within 45.3 and 70.2 $W \cdot kg^{-1}$. The lowest energy consumption was obtained at the moisture of 15% and diameter of pressing channels of 10 mm.
2. The lowest durability was in case of pellets obtained at the moisture of 20% – 88.9-88.4%, the highest was in case of pellets obtained at the moisture of 15% 93.5-92.4%. The highest durability was obtained at lower diameters of pressing openings.
3. The highest specific density was obtained for pellets obtained at the moisture of 15% and it was 1133.6-1094.8 kg m^{-3}. The lowest density was obtained at the moisture of 20% – 998.8-1020.8 kg m^{-3} but density got reduced along with the increase of the diameter of pressing channels.

References

Blaschke, T., Biberacher, M., Gadocha, S., and Schardinger, I. (2013). "Energy landscapes": Meeting energy demands and human aspirations. *Biomass Bioenergy* 55, 3-16.

Frączek J. (red.) (2010). Produkcja biomasy na cele energetyczne. Kraków, PTIR, ISBN 978-83-917053-8-4.

Hejft, R. (2011). Granulowanie i brykietowanie słomy. Inż. Apar. Chem. 50, 13-14.

Kulig, R., and Skonecki, S. (2011). Wpływ wilgotności na parametry procesu zagęszczania wybranych roślin energetycznych. *Acta Agrophysica* 17 (2), 335–344.

Liu, Z., Quek, A., and Balasubramanian, R. (2014). Preparation and characterization of fuel pellets from woody biomass, agro-residues and their corresponding hydrochars. *Appl. Energy* 113, 1315–1322.

Niedziółka, I., and Szpryngiel, M. (2012). Ocena cech jakościowych peletów wytworzonych z biomasy roślinnej. *Inżynieria Rolnicza* 16 (2), 267-276.

Niedziółka, I., and Szpryngiel, M. (2014). Możliwości wykorzystania biomasy na cele energetyczne. *Inżynieria Rolnicza* 149, 145-154.

Niedziółka, I., Szpryngiel, M., Kachel-Jakubowska, M., Kraszkiewicz, A., Zawiślak, K., Sobczak, P., and Nadulski, R. (2015). Assessment of the energetic and mechanical properties of pellets produced from agricultural biomass. *Renew. Energy* 76, 312-317.

Nunes, L.J.R., Matias, J.C.O., and Catalão, J.P.S. (2014). Mixed biomass pellets for thermal energy production: A review of combustion models. *Appl. Energy* 127, 135-140.

Smeets, E.M.W., Faaij, A.P.C., Lewandowski, I.M., and Turkenburg, W.C. (2007). A bottom-up assessment and review of global bio-energy potentials to 2050. *Prog. Energy Combust. Sci*. 33, 56-106.

Stelte, W., Holm, J.K., Sanadi, A.R., Barsberg, S., Ahrenfeldt, J., and Henriksen, U.B. (2011a). A study of bonding and failure mechanisms in fuel pellets from different biomass resources. *Biomass Bioenergy* 35, 910-918.

Stelte, W., Holm, J.K., Sanadi, A.R., Barsberg, S., Ahrenfeldt, J., and Henriksen, U.B. (2011b). Fuel pellets from biomass: The importance of the pelletizing pressure and its dependency on the processing conditions. *Fuel* 90, 3285-3290.

WPŁYW ŚREDNICY KANAŁÓW ZAGĘSZCZAJĄCZYCH I WILGOTNOŚCI NA PARAMERTY PROCESU PELETOWANIA BIOMASY ŚLAZOWCA PENSYLWAŃSKIEGO

Streszczenie. Celem pracy była ocena wpływu wilgotności biomasy poddawanej peletowaniau oraz średnicy otworów prasujących matrycy peleciarki na jednostkowe zużycie energii i jakość peletów. Badanym surowcem była biomasa ślazowca pensylwańskiego (*Sida hermaphrodita* R.). Proces peletowania przeprowadzono na peleciarce z matrycą płaską z zespołem rolek prasujących. Do peletowania wykorzystano matryce o trzech średnicach kanałów prasujących 6, 8, 10 mm. Próby peletowania przeprowadzano przy wilgotności materiału wynoszącej 10, 15 i 20%. Stwierdzono, że energochłonność procesu wytwarzania peletów z biomasy ślazowca pensylwańskiego zależała od wilgotności surowca, a także od średnicy kanałów prasujących w matrycy peleciarki. Jednostkowe zużycie energii elektrycznej podczas procesu peletowania wahało w granicach od 45,3 do 70,2 $Wh{\cdot}kg^{-1}$. Najniższą wartość odnotowano dla wilgotności 15% i średnicy kanałów prasujących 10 mm. Trwałość uzyskanych peletów wahała się w zakresie 88,9-93,5% peletów. Najwyższą trwałością charakteryzowały się pelety uzyskane przy wilgotności 15% przy czym wyższą trwałość uzyskiwano przy mniejszych średnicach otworów prasujących. Największą gęstość właściwą uzyskano dla peletów uzyskanych przy wilgotności 15% 1133,6-1094,8 $kg{\cdot}m^{-3}$ przy czym gęstość malała wraz ze wzrostem średnicy kanałów.

Słowa kluczowe: biomasa, pelety, energochłonność, jakość peletów