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ENSILAGING OF BEET PULP WITH THE USE OF WRAPPING PRESS

Summary

The work determines the economic and material inputs occurred during ensiling of beet root pulp in the form of cylindrical bales with different "binding" methods, by net or foil and various number of utilized film layers during wrapping and described as: TSW, TSA and TP. A computational algorithm was developed that allowed to determine the criterion for which the following was assumed: fuel consumption, labor inputs and costs related to the unitary dry matter of ensiled pulp at the actual humidity and calculated to dry matter of the substance. In addition, a cost structure was developed, shared into the costs of: machinery and equipment, fuels, labor and auxiliary materials. The analysis of total unitary costs shows that in TSW and TSA technologies the costs are equal approximately. PLN 110 PLN ·Mg d.m.$^{-1}$, while TP technology is equal PLN 87.80 ·Mg d.m.$^{-1}$, and therefore they are smaller by 20%. The structure of costs has the largest share in costs occurred for auxiliary materials, which range from about 74.00 PLN Mg d.m.$^{-1}$, in variants TSW and TSA up to 51.30 PLN·Mg d.m.$^{-1}$ in TP, which is equal approximately to 67 and 52% of total costs. The share of costs of machinery and equipment utilized is also significant, and amounts to 30 PLN·Mg d.m.^{1}, which is equal to 27.5% in TSW and TSA technologies and 35% in TP technology.
***Key words**: technology, beet pulp, cost, auxiliary materials*

ZAKISZANIE WYSŁODKÓW BURACZANYCH Z ZASTOSOWANIEM PRASOOWIJARKI

Streszczenie

W pracy zostały określone nakłady ekonomiczne oraz materiałowe ponoszone przy zakiszaniu wysłodków burczanych w formie bel cylindrycznych przy zróżnicowanych sposobach „wiązania” siatką lub folią oraz różnej liczbie nałożonych warstw folii podczas owijania oznaczonych jako – TSW, TSA i TP. Opracowano algorytm obliczeniowy, który pozwolił na wyznaczenie wskaźników kryterialnych, za które przyjęto: zużycie paliwa, nakłady robocizny oraz koszty odniesione do jednostki masy zakiszanych wysłodków przy rzeczywistej wilgotności i w przeliczeniu na masę suchej substancji. Ponadto opracowano strukturę kosztów z podziałem na koszty: maszyn i urządzeń, paliwa, robocizny oraz materiałów pomocniczych. Z analizy całkowitych kosztów jednostkowych wynika, że w technologii TSW i TSA koszty są zbliżone na poziomie ok. 110 PLN·$Mg_{s.m}^{-1}$, zaś w technologii TP wynoszą 87,80 PLN·$Mg_{s.m}^{-1}$, a zatem są o 20% mniejsze. W strukturze kosztów największy udział mają koszty ponoszone na materiały pomocnicze, które mieszczą się w zakresie od ok. 74 PLN·$Mg_{s.m}^{-1}$, w wariantach TSW i TSA do 51,30 PLN·$Mg_{s.m.}^{-1}$ w TP, co stanowi odpowiednio ok. 67 i 52% kosztów całkowitych. Znaczący jest też udział kosztów zastosowanych maszyn i urządzeń który wynosi ok. 30 PLN·$Mg_{s.m}^{-1}$, co stanowi 27,5% w technologiach TSW i TSA i 35% w technologii TP.
***Słowa kluczowe**: technologie, wysłodki buraczane, koszty, materiały pomocnicze*

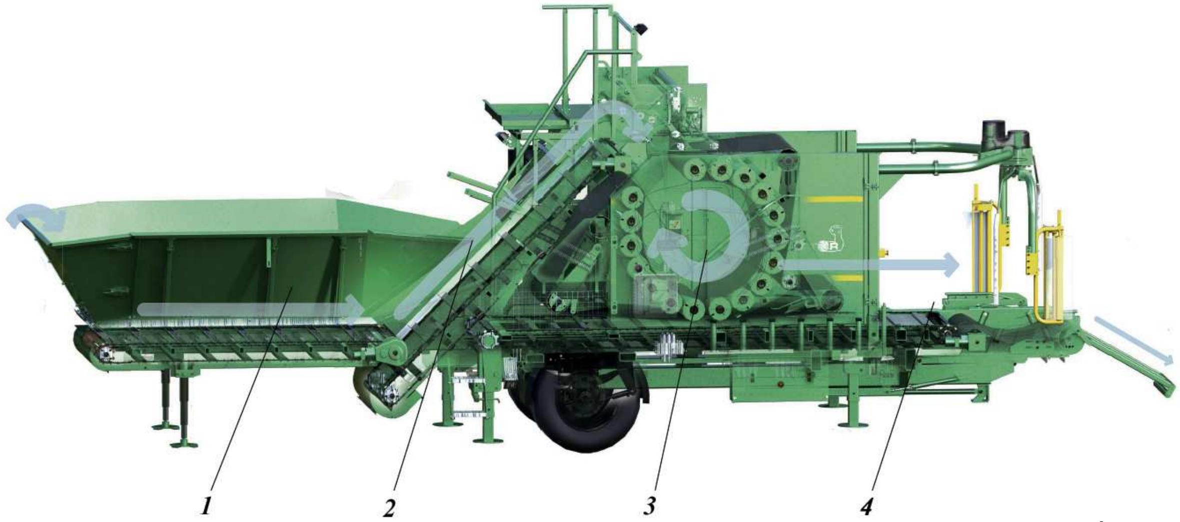
1. Introduction

Beet pulp is produced as a by-product during production of sugar beeing a valuable feed in the nutrition of almost all groups of farm animals [1, 12, 15]. However, it must be properly preserved by drying or much cheaper ensiling [8, 9, 12]. The ensilaging of the pulp, like other similar plant materials, can take place in passage silos or plastic bags [2, 3, 8, 9]. The latest method consists in ensiling in cylindrical bales wrapped with self-adhesive foil using stationary balers [4, 5, 6, 8, 9, 11, 13, 14]. The basic units of the classic stationary wrapping machine are: the press and wrapping machine together with the conveyor system (Fig. 1).

On the MP 2000 Compactor machine, the main working unit consists of driven smooth steel rollers and two conveyor belts forming the bale chamber. The chamber consists of two parts - the front and the back [11]. The working chamber is supplied with material through a channel located in its upper part. The material to be pressed is supplied to this channel by a conveyor constituting the extension of the conveyor of the machine hopper. In the initial phase of the bale formation, the belt conveyors of the winding chamber are arranged in a V-shaped relationship with each other. During the material supply, the positioning of these parts of the conveyors relative to the rolls of the winding chamber occurs. The density of the material in the formed bale is obtained as a result of the interaction of four sets of double springs connected to the tension rollers of the front conveyor and the rear part of the bale chamber.

The formed bale is wrapped by "binding" still in the press with a polyethylene net or foil (Fig. 2).

Displacement of the formed bale onto the wrapping table takes place after opening the rear hatch and automatic switching on the chain-slat conveyor. The rotating table of the wrapping machine consists of driven rollers supporting two conveyor belts. As can be seen in practice, it is possible to use a different method of binding the bales using a net or film and a different number of layers of the applied film during wrapping bales with foil.



Source / Źródło: www:orkel.no

Fig. 1. Press wrapper Orkel MP2000 Compactor – general construction: 1 - hopper, 2 - inclined conveyor, 3 - press chamber, 4 - foil wrapper

Rys. 1. Prasoowijarka Orkel MP2000 Compactor – ogólna budowa: 1 - kosz zasypowy, 2 - przenośnik pochyły, 3 - komora zwijania 4 - owijarka

Source / Źródło: KMRiL material

Fig. 2. Wrapped bale: a) net John Deere CoverEdge, b) foil Baletite

Rys. 2. Związana bela: a) siatką John Deere CoverEdge, b) folią Baletite

The purpose of the work was to determine unitary operating expenditures and costs incurred with different variants of "binding" and wrapping of beet pulp. In order to achieve the purpose of the work, operational and energetic tests of the baling and wrapping process as well as their close transport in production conditions at the Werbkowice Sugar Plant were carried out.

2. Material and methodes

Three variants of pressing and bales wrapping were considered:

• technology used in the Werbkowice Sugar Mill - "binding" bales with a net, and then wrapping with a self-adhesive foil - defined as TSW,

• alternative technology - "binding" bales with a thin foil, then wrapping with self-adhesive foil - TSA,

• technology similar to the previous one, that is, "binding" the bales with a thin foil, and then wrapping with applying a smaller number of TP film layers than in the TSA variant.

In the production conditions for pressing and wrapping cylindrical bales with a diameter of 1.15 m and a length of 1.20 m, a Orkel MP2000 Compactor stationary vacuum baling machine was used, whose charging hopper is supplied directly from the pulp conveyor transporting pulp in the sugar factory (Fig. 3a, 3b).

The drive of working teams was carried out with the participation of a 55 kW electric motor. The compressed bales were "net bound" and then wrapped with self-adhesive foil with a thickness of 0.025 mm. The transport of bales wrapped with foil to the place of storage took place using a JCB 530-60 telescopic loader equipped with a cylindrical bale handler (Fig. 3c, 3d).

As part of the research, detailed timekeeping of the work cycle was carried out - pressing, wrapping, as well as auxiliary operations of work of the loader for close transportation distance of bales in accordance with standards BN-76 / 9195-01 and BN-77 / 9195-02. In addition, the following measurements were made: net wear, foil wear, fuel and electricity consumption, as well as the number of bales produced during twelve-hours working cycle. The fuel consumption of the bale loader was determined using the full tank method and the energy consumption was based on the energy measurement using electric meters.

Source / Źródło: KMRiL materials

Fig. 3. Machines used in the process of beet pulp maintenance: a), b) press wrapper; c), d) loader JCB 530-60
Rys. 3. Maszyny stosowane w procesie konserwacji wysłodków buraczanych: a), b) prasoowijarka; c), d) ładowarka JCB 530-60

The tests showed that the working cycle time was equal on average to 110 s. The pressing time as the filling and compaction time in the press chamber lasted on average 66 s. The bale wrapping time lasted on average 35 s and was equal to about half the pressing time. The working cycle complements the time of transporting the bale to the wrapping table. At the machine settings adjusted by the operator, from one of the roller net, 126 bales were wrapped on average. Twelve grid rolls were used on average over a twelve-hour shift. In turn, 19 bales were wrapped on one roll of film. The average number of bales wrapped in one shift was 327 pieces. The bale wrapper was powered by an electric motor with a rated power of 55 kW and during the shift cycle it took energy of about 10.25 kW on average.

The last test parameter referred to the fuel consumption of a JCB loader equipped with a bale loader and transporting the wrapped bales to the storage place. The JCB loader on average consumed 40 liters of diesel fuel, which gives approx. 3.3 dm^3 of fuel per hour. To determine the consumption of auxiliary materials for binding and wrapping a single cylindrical bale next to the results of tests carried out under operating conditions, the following theoretical relations were used. Utilization of the net or film to wrap the "binding" of the bale in the press chamber is determined by the following relationship:

$$Z_{s,fn} = \pi \cdot D \cdot s \cdot i \cdot n \qquad (1)$$

where:
$Z_{s,f}$ – surface wear of a net or foil, m^2,
D – diameter of the bale, m,
s – width of the net or foil, m,
i – the number of net or film layers applied,
n – the number of wrapped bales.

Knowing the length and width of the net or film, the diameter of the wrapped bale and the number of bales wrapped with one net or film roll, using the dependence (1), we can determine the number of overlapping layers.

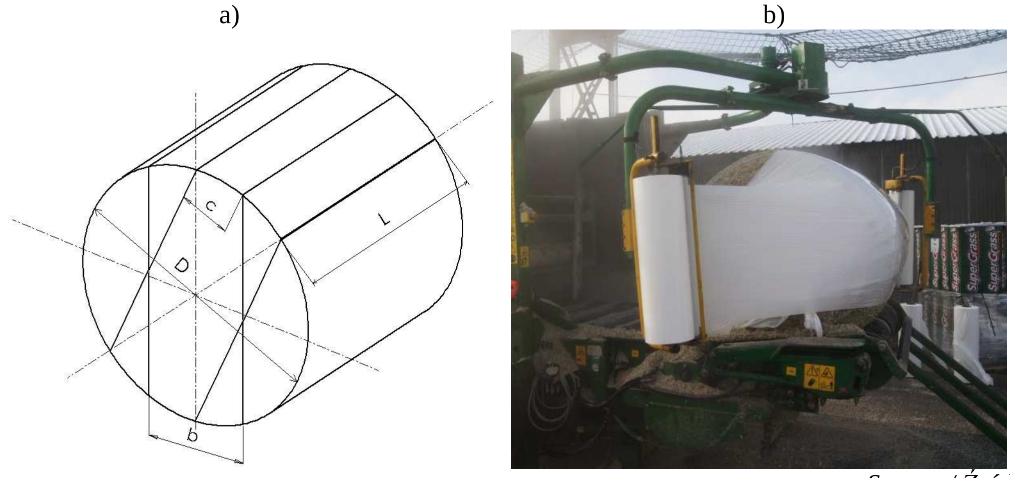
Wrapping cylindrical bales with the use of a wrapper, both with a movable table and with a rotating arm, consists in applying subsequent strips of foil, while maintaining the appropriate overlap (c) (Fig. 4). The value of the overlap is determined by kinematic considerations, or more precisely the value of the bale displacement over the circumference of the bale rotation on the table of the wrapper or the arm on which the foil roll is attached. The use of film for wrapping a single cylindrical bale is determined by the dependence [2]:

$$Z_{cpb} = \pi \cdot D \cdot (D + L) \cdot i \qquad (2)$$

where:
Z_{cpb} – consumption of net on a bale, m^2,
D – diameter of the bale,m,
L – diameter of the bale,, m,
i – number of applied foil layers.

It can be seen that the consumption of film on a bale does not depend on its width. However, when using a wider film, i.e. 0.75 m instead of 0.50 m, the wrapping occurs at a smaller number of table or roller rotations, which affects the efficiency of wrapping. Similarly as before, knowing the dimensions of the film in the roll and the dimensions of the wrapped bales from one roll of film, using the relationship (2), we can determine the number of overlapping layers.

a) b)



Source / Źródło: [7] and KMRiL materials

Fig. 4. Wrapping the bale with a foil: a - bale wrapping scheme: D-bale diameter, L-bale length, c-value of the overlap, b-width of the film, b - wrapping the bale with SuperGrass and rollers mounted on two arms
Rys. 4. Owijanie beli folią: a) schemat owijania beli: D - średnica beli, L - długość beli, c - wartość zakładki, b - szerokość folii; b) owijanie beli folią SuperGrass z rolek zamocowanych na dwóch ramionach

Then, taking into account the volume of the bale and the density of the compressed material, the dependence on the film consumption with respect to the unitary mass is obtained:

$$Z_{cpm} = \frac{4i}{\gamma_c} \cdot (\frac{1}{L} + \frac{1}{D}) \quad (3)$$

where:
Zcpm - foil consumption in relation to a unitary mass based on the weight of the dry matter substance, $m^2 \cdot Mg^{-1}$ d.m.,
γc - density of forage (based on the weight of dry matter substance) in a cylindrical bale, t d.m. m^{-3}.

These dependencies were verified by comparing the value of foil consumption from theoretical calculations with the results obtained from experimental research and the relative error rate was only 2.2%, which allows the use of theoretical relationships for analyzes and the obtained results are adequate to those obtained in real conditions [7].

The following criteria were adopted to assess the methods of ensilaging of beet pulp:
• value of fuel consumption: $dm^3 \cdot Mg^{-1}$, $dm^3 \cdot Mg_{d.m.}^{-1}$,
• value of labor input:· $rbh \cdot Mg^{-1}$, $rbh \cdot Mg_{d.m.}^{-1}$,
• value of operating costs of machinery and equipment used: $PLN \cdot Mg^{-1}$, $PLN \cdot Mg_{d.m.}^{-1}$.

Calculations of unitary operating expenditures and costs occurred in individual technologies of beet pulp were made using the developed computer program [9]. At the same time, elements resulting from methodological studies [10] and own research and theoretical analyzes carried out at the Department of Agricultural and Forestry Machines [2, 3, 8] were used. For calculations value of dry matter content of beet pulp was taken as equal to 25%.

The prices of fuel and auxiliary materials were adopted in accordance with the regulations in the last quarter of 2016. Other technical and operational values accepted for the calculation are: the purchase price of machines, electricity consumption by the bale wrapper, the minimum power demand, diesel oil consumption by the loader. Bale wrapper Orkel MP 2000 Compactor with a value of PLN 960000, powered by an induction motor with a rated power of 55 kW, consumed on average 0.85 kW per hour. The JCB loader, worth PLN 210000, equipped with a bale loader with value PLN 3,000, consumed about 3.3 liters of diesel per hour.

3. Results of calculations and their analysis

Consumption of auxiliary materials, i.e. net and foil within a twelve-hour duty cycle, are average values. Bale wrapper Orkel MP2000 Compactor with one John Deere CoverEdge net produces 126 bales. The technical parameters of the net used in the tests as well as the parameters of the alternatively used film are included in Table 1.

Table 1. Technical parameters and quantitative and economic indicators of auxiliary materials
Tab. 1. Parametry techniczne oraz wskaźniki ilościowe i ekonomiczne materiałów pomocniczych

Specification	Unit of measure	The technological variant		
		TSW	TSA	TP
		Net John Deere CoverEdge	Folia Baletite	Folia Baletite
Length	m	3800	2400	2400
Width	m	1.30	1.28	1.28
Thickness	μm	-	13	13
Price	$PLN \cdot m^{-2}$	0.15	0.20	0.20
Surface wear on a bale	m^2	39.52	30.72	30.72
The cost of bale binding	PLN	5.93	6.14	6.14

Source: own work / Źródło: opracowanie własne

By converting the dependence (1), you can specify the number of layers of a net or film in one wrapped bale. The calculations show that the CoverEdge bale is wrapped using almost 9 layers of net (exactly 8.4) in TSW technology, while replacing the net with a Baletite wide foil, the calculations indicate nearly 7 layers (exactly 6.7) for TSA and TP technologies. From one roll of net, about 126 bales of pulp are wrapped, and about 100 bales when using foil. As can be seen from the data in Table 2, for wrapping we need more net than the foil, but at the same time the unitary net price is smaller than the foil, which makes the cost of binding of one foil to only slightly larger amount than the net price - PLN 5.93 and PLN 6.14 respectively.

Table 2 lists the technical parameters as well as quantitative and economic indicators of the wrapping foil for bales. When wrapping bales in production conditions at the sugar factory in Werbkowice, on average one roll of wrapping foil produces 19 bales. Using the previously specified dependence (2) on usage of the foil for one bale, after the transformations, the number of foil layers applied to each other when wrapping the bale was calculated. As it results from tests and calculations in TSW and TSA technology, the same number of layers of the applied foil was equal to 7. TP technology is an economical technology and assumes 4 layers of wrapping foil. This is the minimum number of layers needed to wrap the bale so that the ensilage proceeds correctly and the shape of the bale is proper.

Table 2. Technical parameters and quantitative and economic indicators of the wrapping foil for bales
Tab. 2. Parametry techniczne oraz wskaźniki ilościowe i ekonomiczne folii do owijania bel

Specification	Unit of measure	The technological variant		
		TSW	TSA	TP
Length	m	1500		
Width	m	0.75		
Thickness	µm	25		
Price	PLN·m^{-2}	0.28		
Surface wear on a bale	m^2	59.2	59.2	34.1
The cost of bale binding	PLN	16.60	16.60	9.50

Source: own work / Źródło: opracowanie własne

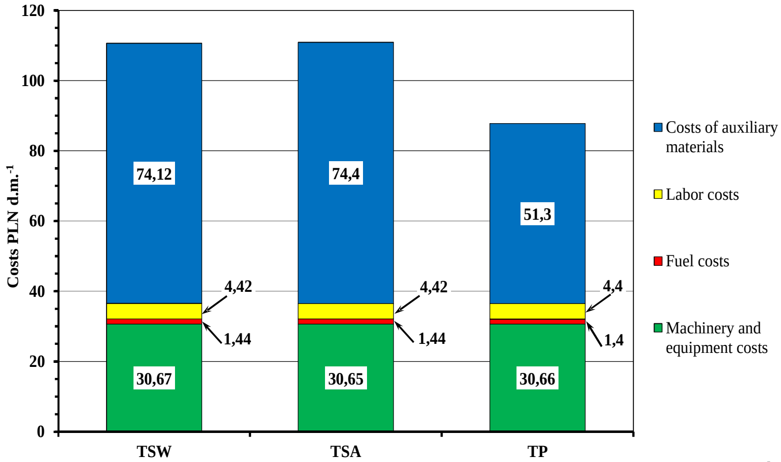
TP technology compared to TSW and TSA is characterized by the lowest costs associated with wrapping the bale with a foil. Reducing the number of layers when wrapping bales brings great savings. Despite the smaller number of layers of wrapping foil, the hermeticity of the bale will be preserved. As above calculated 7 layers of Baletite wide foil with a thickness of 13 µm is equal to 3 layers of 25 µm SuperGrass wrapping foil. As a result, it gives a total of 7 layers of foil on the perimeter of the bale, so the bale is sufficiently protected against air access. On the surface of flat bales, the layers intersect many times, therefore also the bale is adequately protected against air access.

The unitary cost values for dry matter weight are shown in Fig. 5. As can be seen, the total costs in the first two variants are almost the same: about PLN 110 · Mg d.m.$^{-1}$, which results not only from the same number of imposed foil layers for wrapping, but also from the same net costs and thin foil for "binding" bales. However the consumption of foil and net for bales is not identical, but it balances this differential price of auxiliary materials. TP technology requires cost of PLN 87.80 · Mg d.m.$^{-1}$, and therefore it is smaller by 20%. As can be seen on Fig. 5, the difference between TSW, TSA and TP resulting from the varied use of wrapping foil is significant. Reducing the number of foil layers reduces the total unitary cost by 20% compared to the technologies normally used. This is a huge saving on a yearly basis. With 30000 bales wrapped during the sugar campaign, this gives over PLN 200,000 in savings. Reducing the number of foil layers would also reduce the time of wrapping, thereby increasing the number of bales wrapped in a 12-hour shift. In addition, the number of bales wrapped in one roll of foil would increase - what was the essence of the introduction of TP technology.

The calculations show that the costs used for auxiliary materials in the TSW and TSA variants amount to approximately 74 PLN ·Mg d.m.$^{-1}$, which is approximately. 67% of total costs and 51.30 PLN Mgs.m. $^{-1}$ in the TP option, accounting for 52% of total costs.

The share of costs of machinery and equipment used is also significant, amounting to 30 PLN · Mg d.m.$^{-1}$, which is 27.5% in TSW and TSA technologies and 35% in TP technology.

Fuel costs amounting to 1.4 PLN Mg d.m.$^{-1}$ and costs for labor 4,4 PLN ·Mg d.m.$^{-1}$ are significantly smaller than the costs of auxiliary materials and machines and have a negligible share in the structure of total costs (Fig. 5).



Source: own work / Źródło: opracowanie własne

Fig. 5. Unitary costs for unit of dry matter of the substance
Rys. 5. Koszty jednostkowe w odniesieniu do jednostki suchej masy substancji

4. Conclusions

1. The analysis of total unitary costs shows that in TSW and TSA technologies, the costs are approximately equal to 110 PLN ·Mg d.m.$^{-1}$, while in TP technology they amount to 87.80 PLN· Mg d.m.$^{-1}$ and they are smaller by 20% .
2. Auxiliary costs of materials are approximately in the range from 74 PLN ·Mg d.m.-1 and have the largest share in the cost structure., in variants TSW and TSA up to PLN 51.30 ·Mg d.m.$^{-1}$ in TP, which is approximately 67% and 52% respectively of the total costs.
3. The share in the structure of total costs of the machines and equipment used is also significant, which is equal approximately to PLN 30 Mg d.m.$^{-1}$, what makes 27.5% in technologies TSW and TSA and 35% in TP technology.
4. The share of other components of unitary costs (energy and labor) is negligible and does not exceed 5%.
5. The proposed TP variant characterized by a lower number of applied foil layers during wrapping seems to be rational, as it is significantly cheaper, and taking into account the total production of bales during a sugar campaign may lead to the reduction in costs and thus to increase in profit.

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Standards utilized at work

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BN-77/9195 Agricultural machinery. Methods of exploitation tests.

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