PAN
POLSKA AKADEMIA NAUK

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2024.151569
2024, No. 62 (VII–IX): 212–219

Silage harvesting for small farms by using vacuum sealing in flexible polymer containers on a converted trailer

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RECEIVED 11.02.2024 ACCEPTED 02.08.2024 AVAILABLE ONLINE 18.10.2024

Abstract: The article presents an analysis of milk production in Kazakhstan and identifies the reason for its low level, which is due to deficient feed, especially in small farms and in the private sector. The difficulty of saving the limited silage volume is due to the lack of preparation technology for preventing spoilage. The objective of this work is to complete the necessary equipment of a mobile tractor-trailer to reduce the specific energy consumption when preparing silage in flexible containers using a vacuum seal to increase the productivity of dairy cattle farming in smallholder and the private sector of the Republic. The basic rational parameters for sealing the silage by vacuum in the field on a mobile tractor-trailer for ease of transport and storage are obtained: silage weight in a flexible container – 769.6 kg, geometric dimensions of the sealed container by height (0.90 m), width (0.85 m) and length (0.85 m). The efficiency of the specific energy consumption of the proposed method for silage preparation is established at 35% compared with the traditional method. The recommended technology of silage preparation in flexible containers will be possible when conventional tractor-trailers are retrofitted with standard portable equipment (internal combustion engine-based (ICE) electric generator, vacuum pump, film welder).

Keywords: ensiling, flexible container, forage trailer, livestock machinery, silage, vacuum

INTRODUCTION

Kazakhstan is a sparsely populated country with a developing agricultural and technology infrastructure (CIA, no date).

Kazakhstan has traditionally focused more on the livestock sector according to national custom. Therefore, forage production occupies a special place (Boyarskiy, 2001). Due to low milk output, Kazakhstan imports dairy products from neighbouring countries such as Kyrgyzstan, Belarus and Russia. It should be noted that 78% of the total volume of milk is produced in Kazakhstan by small farms with an average milk yield per cow of 2,341 kg·y^{-1}. This is four times lower than in the West and the US. For European and Northern American farmers, the feed content of silage is up to 40% (Karnatam *et al.*, 2023). Silage is the most important canned "winter" and, in some regions, year-round feed for dairy cattle.

One of the main reasons for low milk production in Kazakhstan is the lack of wholesome feed as a silage for small farms (less than 200 head of cattle). This is due to the lack of feed silage technology and equipment for it (Sagyndykova *et al.*, 2021a; Sagyndykova *et al.*, 2021b). In the Republic, about 90% of silage is prepared using the traditional method under stationary horizontal trenches. The construction of the trench is expensive, so the construction pays off in a long time and is only acceptable to a large economy. Existing silage preparation methods (vertical and horizontal) have losses of 3 to 40% after opening (air access causes mass decomposition during the day). Because of unacceptability, small-scale farmers and the private sector are largely silage-free and receive low milk yields (according to zootechnical standards the silage is more than 50% ration feed of dairy cattle).

Another constraint in the country for smallholders (with limited livestock) is the lack of government concessional credit. Therefore, commodity producers are looking for a very economical way of production.

Modern stationary silo is designed to be horizontal and vertical. Horizontal silos include heaps, clamps, and silage trenches. Vertical silos include ground and semi-recessed round or polygonal towers. In addition, silage pits are used for the preparation and storage of a small amount of silage or for farms, which have small amounts of livestock. In the silage pits, silage is semi-buried or completely buried in a trench to a depth of 2.0–4.2 m in the form of a circle with a diameter of 2.5 to 4.2 m. The trench silos have side and end walls made of concrete or wood. Depending on the local conditions of groundwater, the trenches are on the ground, semi-buried, and buried.

The above-listed silage storages have the following losses: silage pit – 25%; silage heap or clamp – 30–40%, tower silo – 5–8%, silage trench – 5–8%; silage sleeves – 3–5%. Silage losses are related to air access to the sealed layer, as the silage is always stored in an airless environment. All types of ensilage preparation technology provide a lot of machinery uses and movement (Sagyndykova *et al.*, 2021a). In this case, all liquid fractions are squeezed out of the silage mass to ground and up to 20% of nutrients are lost, that the silage is low-quality and ecology of the nearly trench territory is impaired.

In Kazakhstan, about 90% of silage is stored in silage trenches and these trenches exist mainly only in large enterprises. Silage preparation includes the following mechanised processes: mowing, grinding, and loading; transportation to the silo trench; unloading and compacting the silage in the trench; covering the compacted silage with film; storage (Photo 1).

The silage is ready for use 3–4 weeks after the storing. To distribute the compacted silage from the trench, the coverage of trench is opened at one end and cut vertically, then loaded onto a vehicle. All processes involve mechanised equipment and support personnel (where the technicians are unable to complete the operation).

At present, Kazakhstan has localised a certain number of small factories to produce agricultural machinery by assembling components supplied from near abroad (Klochkov, Novitsky and Khazimov, 2018). These machines are cheaper than foreign machinery in the order of 3–5 times. Improvements are also being made to certain types of agricultural machinery according to local requirements and the principles of new technology. Enough number of research and testing activities are being carried out to improve the design of equipment and technology in relation to climatic conditions. At the same time, great attention is paid to the accessibility of these equipment for farmers by costs (Khazimov and Khazimov, 2011; Khazimov *et al.*, 2018; Khazimov *et al.*, 2021; Niyazbayev *et al.*, 2022). The list of this equipment is oriented to the crop production industry. Because of the high construction, equipment use and service costs, only the large companies with more livestock are profitable. According to the Committee on Statistics, the average annual milking rate of one cow per year in the Republic was (including all categories of farms) 2,341 kg of milk. But this level is quite different depending on the form of farms that have cattle. In large agricultural enterprises, the milk yield is 4,338 kg, while in peasant farms it is 1,849 kg, and in private household it is 2,409 kg (Bukatov, 2018; Kovalev, 2020). Small farmers are unable to maintain such constructions and generate profit due to limited capital availability (ASM, 2020; Baillie *et al.*, 2020; Davydova and Starostin, 2021). High prices for equipment and technology force farmers to use new technologies that have been upgraded locally. This problem can be solved by using standard agriculture trailers and additional equipment for preparing silage in flexible polyethylene containers (Sagyndykova *et al.*, 2021a).

To solve the problem of supplying succulent fodder, such as silage, to small livestock farms and the private sector in Kazakhstan, techniques for silage harvesting (in the field) in flexible containers on a converted tractor-trailer should be evaluated (Darby and Jofriet, 1993; Muck and Holmes, 2001; Nekrashevich *et al.*, 2020a; Sagyndykova *et al.*, 2021a). The objective of this work is to complete the necessary equipment for the mobile tractor's trailer to reduce the specific energy consumption at preparation of the silage mass in flexible containers using a vacuum seal. According to the aim of the work, the following tasks are performed.

1. Equipment of the tractor-trailer with the necessary tools for vacuum sealing of green mass.
2. Evaluation of the technological factors of the process of sealing a green mass under vacuum in a flexible container on the tractor-trailer in field conditions.
3. Assessment of the operation energy consumption of green mass vacuum-sealing technology on the tractor-trailer in field conditions.

MATERIALS AND METHODS

VACUUM SILAGE TECHNOLOGY FOR FEED IN FLEXIBLE CONTAINER

The preparation and storage of silage on the forage trailer follow a sequence of operations (Fig. 1): mowing, grinding, filling, vacuuming, ensiling, reloading, transportation, unloading, and stacking behind vacuum containers (Sagyndykova *et al.*, 2021b).

By the using this technology, the main operations (3, 4, 5) for ensiling green mass for silage are performed on the forage trailer.

Photo 1. Ensiling on the silo trenches in LLP "Amiran", Almaty region (phot.: *Ye. Zhumagaliyev*)

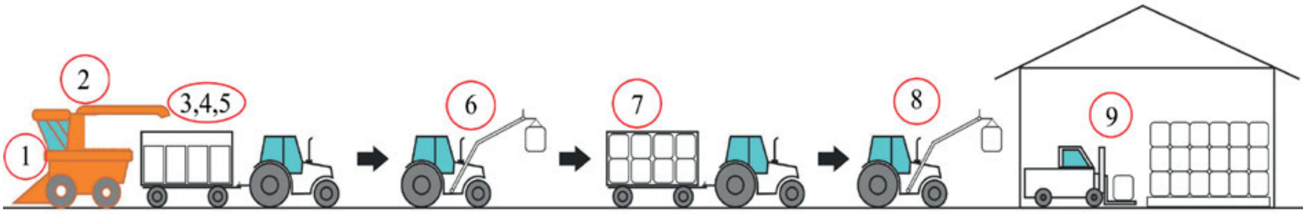

Fig. 1. Harvesting, ensiling, transportation, and storage process of silage in flexible vacuumed containers; 1 = mowing, 2 = grinding, 3 = filling, 4 = vacuuming, 5 = ensiling, 6 = reloading, 7 = transportation, 8 = unloading, 9 = stacking; source: own elaboration

CONVERTING OF FORAGE TRAILER FOR ENSILING SILAGE USING A VACUUMED POLYETHYLENE CONTAINER

The location of basic equipment for ensiling feed on forage trailers that are commonly used in farms (Zhumagaliyev *et al.*, 2021) for transporting feed and cargo is shown in Figure 2.

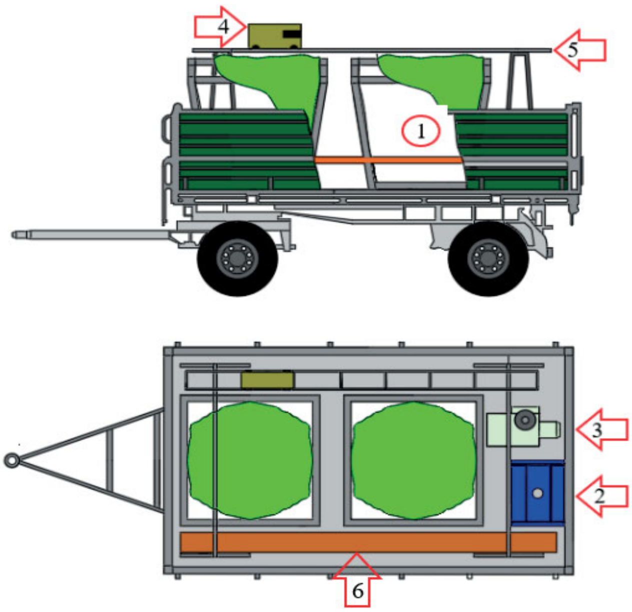

Fig. 2. General view of the basic design of a converted forage trailer for ensiling by vacuum; 1 = matrixes, 2 = power plant up to 6 kW, 3 = vacuum pump, 4 = sealing machine for polyethylene, 5 = rail for movement, 6 = lower deck platform; source: own elaboration

The principle of the conversion of the trailer is carried out by covering the base of the body with an electrically insulating wood board and placing equipment for ensiling: matrixes, power plant up to 6 kW, vacuum pump, and sealing machine for polyethylene with a rail for movement. A lower deck platform was added where the operator could work safely without climbing on the top of the trailer.

OPERATION FOR ENSILING GREEN MASS FOR SILAGE BY VACUUM

The proposed ensiling technology on the converted forage trailer includes several operations. The operations include manual preparation (levelling the surface) of crushed green mass in flexible vacuum containers and closing the vacuum container for sealing and unloading (Fig. 3). During unloading after ensiling, the flexible container is carried out directly at the transport vehicle.

All three operations are performed (on a trailer) by two operators who have undergone laboratory pre-training on a valid prototype. The preparatory operation (on the trailer) of the flexible container includes hanging the flexible intermediate bulk container such as a big-bag inside the metal matrix, and similarly, hanging the flexible container inside the flexible intermediate bulk container.

The overlapping of the sealed surface of the loading neck is performed by means of stretching (excluding the presence of external objects) and contacting these surfaces with a double layer between two holding plates. The operation of sealing the loading neck (double layer) of the flexible container with the help of a sealing machine is performed on a specially designed frame design. The sealing module is moved along the rail by means of two rear drive wheels (arranged on one drive shaft). The two front wheels also move along the rail. The speed of the sealing module and the melting time of the films (loading neck) have a certain dependence on the temperature setting of the heating layers. The movement of the sealing module is controlled by one of the operators along the length of the neck.

After the seal of the flexible container is completed, the sealing module is removed from the rail and the neck of the flexible container is removed from the clamps. The final sealing operation is carried out by connecting a vacuum pump and the valve to the walls of the flexible container via a vacuum pipe. The vacuuming is carried out at a negative pressure of 70 kPa until the juice of the green mass appears in the vacuum pipeline (the vacuum pipeline is transparent for observing the silage juice appearance). When the vacuum is disconnected, the valve is locked automatically excluding air access to the container (Nekrashevich *et al.*, 2019).

THE GEOMETRIC DIMENSIONS OF THE COMPACTED GREEN MASS

The equipment for ensiling the green mass for silage in flexible containers on the tractor-trailer was constructed based on the geometrical dimensions of the compacted green mass, and of the structural and energy parameters of the equipment. The geometric dimensions of the compacted green mass were selected from the conditions of unloading and loading of the compacted green mass in a flexible container. For this purpose, the most common tractor lifting, and other mechanisms used in the Republic's farms up to 1 Mg are used. The geometric dimensions of the ensiled mass are structurally selected and the frame of the matrix for accommodating the flexible intermediate bulk container and the flexible plastic container from the polyethylene sleeve is manufactured (Sagyndykova *et al.*, 2021a).

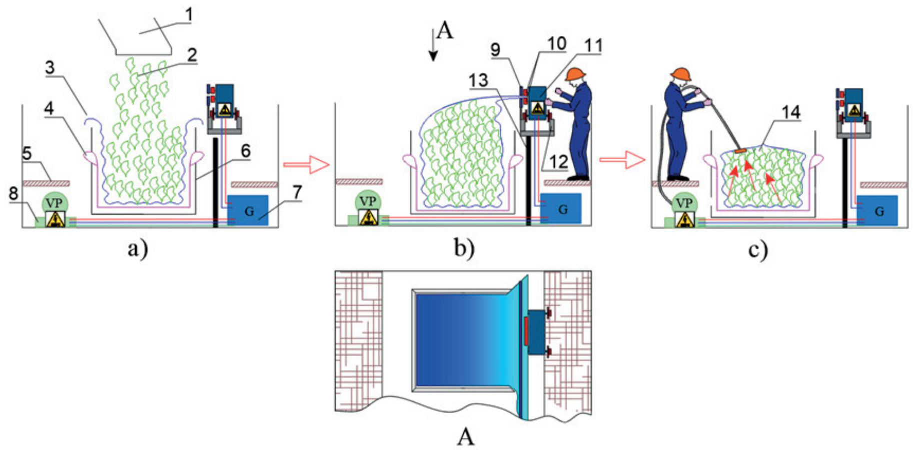

Fig. 3. Structure diagram of the fodder preparation in a flexible container for silage: a) loading of crushed green mass into a container, b) sealing of the container neck by sealer machine, c) vacuuming; 1 = forage harvester, 2 = crushed green mass, 3 = flexible container, 4 = big-bag, 5 = operator's workplace, 6 = matrix for a flexible container, 7 = power plant, 8 = vacuum pump, 9 = clamp, 10 = heating elements, 11 = sealing module, 12 = sealer's platform, 13 = frame, 14 = compacted (pressed) container, A = top view, G = generator, VP = vacuum pump; source: own elaboration

A vacuum pump with a vacuum pressure of up to 70 kPa (3.5 kW) is selected from a mass density condition (650–850 kg·m^{-3}) and a three-phase generator of up to 5 kW is selected for said vacuum pump (Field *et al.*, 2014). The continuous heat sealer module for the polyethylene film is modified by the installation of the drive wheels. A movable bridge rail for moving the sealing module was manufactured. To protect the personnel from electric shock protective cutout device (Rus.: Ustroystvo zashchitnogo otklyucheniya – UZO) on the power transmission line and protective covers made of wood were used. All equipment was attached with special bolts to the wooden cover of the body (Kim *et al.*, 2019). All containers were weighed during unloading by a dynamometer mounted on a hoist. The geometric dimensions of the compacted green mass were measured by a hand tape measure. The geometric dimensions of the sealed flexible containers (in each lot of five containers) were measured prior to storage. Average values and other indicators from these measurements were determined for statistical processing.

The project was funded from 2019 to 2021, the recommended converting method of forage trailer after two preparation years was tested at the "Amiran" farm in 2021 (Karatogan, Almaty region, Kazakhstan (43.691622, 77.330514)) where corn for silage is harvested using the traditional method and the new technology. The field length was 43.7 m (with a combine harvester width of 3 m), silage moisture content was 72%, and the stem height before mowing was 2.33 m. Harvester speed (v) was 4–4.5 km·h^{-1}. In Photo 2, the fragments of the process are shown: positioning of the equipment on the trailer for vacuum sealing of the silage in a flexible container (position 1), loading of the crushed green mass from the harvester into flexible containers when the trailer is in motion (position 2), sealing of the flexible container after loading the silage by sealing the neck (position 3), vacuuming of a flexible container with green mass by sucking air

Photo 2. The fragments of of the vacuum silage process in flexible containers on tractor trailer: 1) silage vacuuming on the trailer, 2) converted trailer equipped with the ensiling system, 2) loading of shredded green mass from the forage harvester, 3) sealing of the container by continuous heat sealers, 4) vacuuming, 5) reloading of containers, 6) stacking behind vacuumed containers (phot.: *Ye. Zhumagaliyev*)

through the built-in non-return valve (position 4), reloading the finished compacted mass in the flexible container by lifting behind the straps of the load-bearing bag "big-bag" (position 5), stacking of ready containers with storage weight (position 6).

The weight and dimensions of green mass in flexible containers were measured before compaction (Photo 3a). During the field test of the green mass vacuuming in the flexible container for silage, the compacted green mass acquired the shape of a big-bag and the dimensions decreased in comparison to the original size (Photo 3b).

Photo 3. Geometric dimensions of the container: a) before vacuuming, b) after vacuuming; (phot.: *Ye. Zhumagaliyev*)

To estimate the energy intensity of the vacuum sealing of the silage in flexible containers on a mobile tractor unit, an energy input calculation was carried out for each operation of the process separately according to standard (Standartniform, 2018).

The prototype adopted the traditional silage harvesting technology under trench conditions and similarly used machine specifications to calculate the energy consumption of operations. To compare the figures, calculations were made to determine the energy consumption (kW·h^{-1}) per unit mass (1 Mg) of green mass for silage harvested.

RESULTS AND DISCUSSION

The main parameters of compacted green mass are presented in Table 1. There are six repeated measurements, each of which is the average of 10 tested flexible containers with silage per day. All containers do not exceed 800 kg in weight. This container mass is convenient for loading and unloading operations and transportation in farms on the basis of loading equipment with a lifting capacity of up to 1,000 kg. The vacuuming time of the flexible container in minutes is recorded when the silage juice appears in the vacuum tract since most of the nutrients are in the silage juice itself. The density of the silage due to the presence of silage juice in the container averaged about 1,000 kg·m^{-3}. This is 30–35% higher than the silage density under trench conditions (650–700 kg·m^{-3}).

As shown, the flexible containers were reduced by 10–15% in length and width, and by 40% in height. A significant change in the height of the container is due to the fact that in addition to vacuum pressure, the force of dimensions gravity of the crushed green mass acts in the vertical direction of the container. This change was studied in the theoretical calculations (Nekrashevich *et al.*, 2020b).

Based on the results of the experiment during vacuum compaction of green mass in a flexible container, time data were obtained (Fig. 4).

As can be seen from the obtained results, the total preparation time for vacuum blocks was 44 min. The longest operation in terms of preparation time was the vacuuming of flexible containers – 14.67 min. The operation of loading the crushed green mass was the fastest – 1.32 min. This indicator depends on the yield of the field and the capacity of the forage harvester. However, the process time can be halved by parallel compaction of adjacent containers when connected to the same vacuum pump since the vacuum pump, according to technical indicators up to 70 kPa in terms of the productivity of the sucked air, completely satisfies this need.

When harvesting for silage, the corn yield was 72,500 Mg·ha^{-1}. The volume of work per 1,000 ha with a mown silage weight of 72,500 Mg is considered the same for the methods to be compared. On the basis of the data presented in columns 3–6 of Table 2, the energy costs for the individual operation in column 7 for the two silage methods were determined.

The total energy consumption is presented accordingly for the traditional method – 797,096 kW·h^{-1} and the vacuum method – 513,042 kW·h^{-1}. When dividing the total energy consumption according to the methods of harvesting by the mass of the harvested silage, respectively, the following specific energy consumption is obtained by types: the traditional method – 10.9 kWh·Mg^{-1}, the vacuum method – 7.076 kWh·Mg^{-1}. The results of the specific energy consumption of the proposed method (by vacuuming) for silage blanks are 35% more economical than the traditional method.

Table 1. Main parameters of compacted green mass in the container

Repetitiveness of the measurement	Container mass (kg)	Vacuuming time (min)	Container length after vacuum (m)	Container width after vacuum (m)	Height of the container (m)
1	771.0	12.80	0.86	0.82	0.92
2	772.0	14.50	0.90	0.91	0.93
3	768.0	13.20	0.84	0.79	0.88
4	775.0	12.80	0.80	0.91	0.87
5	762.0	13.50	0.79	0.84	0.92
6	770.0	12.80	0.91	0.83	0.91
Arithmetic value	769.6	13.27	0.85	0.85	0.90
Standard deviation	4.0	0.70	0.05	0.05	0.02

Source: own study.

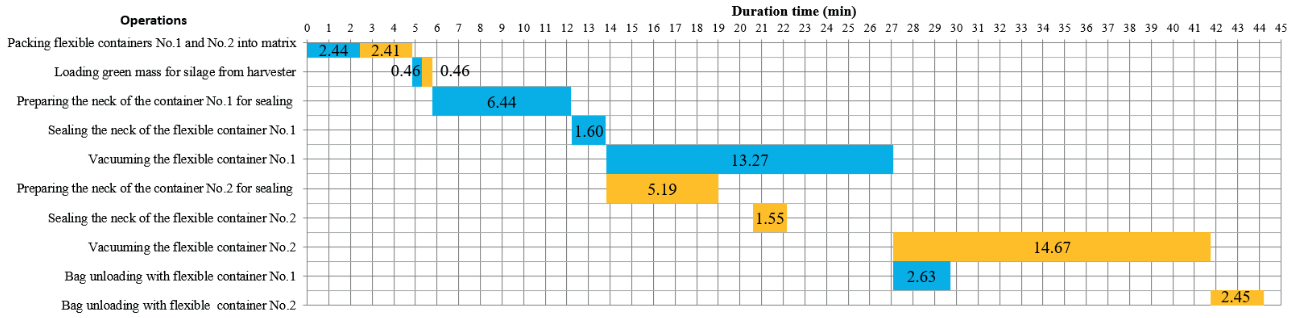

Fig. 4. A diagram of technological operations when preparing silage; source: own elaboration

Table 2. Technology map for traditional and flexible container silage preparation by field vacuuming on a mobile transport unit

Process operation name	Silage method	Technical characteristics of agricultural machinery and tractors			Aggregate quantity (pcs.)	Completion time (h)	Total energy costs (kWh)
		kind of the agricultural machinery and tractors	horsepower (kW)	throughput			
No.	1	2	3	4	5	6	7
Mowing, grinding and loading of silage mass	traditional	Jaguar 830	236	4.6 ha·h^{-1}	1*	217	51,212
	vacuum						
Sealing	vacuum	DBF-900W	0.52	24 Mg·h^{-1}	2*	3,020	1,570
Ensealing	traditional	RZM-2.6	175	26 Mg·h^{-1}	2–3*	2,788	487,980
	vacuum	ZYBW-60F	3	5 Mg·h^{-1}	5*	14,500	43,500
Unloading	vacuum	MTZ-82.1	60	24 Mg·h^{-1}	1*	3,020	181,200
Transporting	vacuum	MTZ-82.1	60	80 Mg·h^{-1}	5–6*	906	54,360
	traditional	MTZ-1221	60	26 Mg·h^{-1}	5–6*	2,788	167,280
Unloading	vacuum	MTZ-82.1	60	24 Mg·h^{-1}	1*	3,020	181,200
Workload	1,000 ha, 72,500 Mg						
Total	traditional						797,096
	vacuum						513,042

Explanations: * = the number of units varies according to the size of the farm and the availability of the machines involved.
Source: own study.

The appearance of easily accessible materials from polyethylene films in the market has made it possible to create technology and equipment for the preparation, storage and transportation of silage in livestock farms using flexible vacuum containers, which improves the quality of the silage and reduces energy and storage costs. Green mass harvested by vacuuming in flexible containers for silage is easily transported and stored in any limited amount with zero losses. The technology does not require high capital investment, can be used with the existing equipment of the enterprise by retrofitting them, and there is no need to build a costly silo storage facility.

CONCLUSIONS

The stated objective of the study on the selection of equipment for a feed trailer using new technology for compacting the green silage mass in a flexible container by vacuuming has been achieved. The technological operations were implemented on a conventional, converted forage trailer. Based on the results of the study, the main time costs for each operation when preparing green mass for silage on a forage trailer were established. The vacuuming process takes most of the time. The use of a high-performance vacuum pump could decrease the time. Further research on this technology should be carried out on low-profile transport trailers equipped with mechanisms that provide operators with ergonomics. Manufacturers, together with scientific institutions in this field, should develop appropriate technical and practical standards for future designs of feed preparation systems. In order to avoid emergency situations, compliance with current applicable standards, the appropriate warnings in the instructions on the operator's checklist and on machines, and the admission control mechanism that can be used to stop all operations should be included. To ensure the safety of operators working in such difficult conditions in agricultural production system, a new mandatory labour safety policy is required.

ACKNOWLEDGEMENTS

The authors would like to thank the "Amiran" farm providing raw material and data which was used in this paper.

FUNDING

This research has been funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP13067761).

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

REFERENCES

ASM (2020) *Proizvodstvo i prodazha traktornoy, sel'skokhozyaystvennoy tekhniki proizvoditelyami Rossii i drugikh stran SNG [Production and sale of tractor and agricultural machinery by manufacturers in Russia and other CIS Countries: An analytical review]*. Moscow: ASM-Holding. Available at: https://asm-holding.ru/services/proizvodstvo-i-prodazha-traktornoy-selskokhozyaystvennoy-tekhniki-proizvoditelyami-rossii-i-drugikh-/ (Accessed: March 15, 2023).

Baillie, C. *et al.* (2020) *Review of technologies, regulations and operating standards for field based autonomous agricultural machinery*. Toowoomba: University of Southern Queensland. Available at: https://research.usq.edu.au/item/q797q/review-of-technologies-regulations-and-operating-standards-for-field-based-autonomous-agricultural-machinery (Accessed: May 10, 2023).

Boyarskiy, L.G. (2001) *Tekhnologiya kormov i polnotsennoye kormleniye sel'skokhozyaystvennykh zhivotnykh [Feed technology and full-fledged feeding of farm animals]*. Rostov-on-Don: Feniks.

Bukatov, S. (2018) "Sredniy nadoy moloka v Kazahstane v proshlom godu sostavil 2341 kg [The average milk yield in Kazakhstan last year was 2341 kg]," *Qazaq Zerno*. Available at: https://kazakhzerno.net/137679-srednij-nadoj-moloka-v-kazakhstane-v-proshlom-godu-sostavil-2341-kg/ (Accessed: March 07, 2023).

CIA (no date) *Kazakhstan: People and Society*. The World Factbook. Last updated: 07 August, 2024. Available at: https://www.cia.gov/the-world-factbook/countries/kazakhstan/#people-and-society (Accessed: March 02, 2023).

Darby, D.E. and Jofriet, J.C. (1993) "Density of silage in horizontal silos," *Canadian Agricultural Engineering*, 35(4), pp. 275–280. Available at: https://library.csbe-scgab.ca/docs/journal/35/35_4_275_ocr.pdf (Accessed: May 17, 2023).

Davydova, S.A. and Starostin, I.A. (2021) "Compliance of modern agricultural tractors presented on Russian market with global emission standard," *IOP Conference Series: Earth and Environmental Science*, 659, 012119. Available at: https://doi.org/10.1088/1755-1315/659/1/012119.

Field, W.E. *et al.* (2014) "Worker hazards associated with the use of grain vacuum systems," *Journal of Agricultural Safety and Health*, 20(3), pp. 147–163. Available at: https://doi.org/10.13031/jash.20.9989.

Karnatam, K.S. *et al.* (2023) "Silage maize as a potent candidate for sustainable animal husbandry development – perspectives and strategies for genetic enhancement," *Frontiers in Genetics*, 14, 1150132. Available at: https://doi.org/10.3389/fgene.2023.1150132.

Khazimov, Z.M. *et al.* (2018) "Development of a dual action planting and mulching machine for vegetable seedlings," *Engineering in Agriculture Environment and Food*, 11(2), pp. 74–78. Available at: https://doi.org/10.1016/j.eaef.2018.02.003.

Khazimov, K.M. *et al.* (2021) "A novel method and device for plastic mulch retriever," *Journal of Water and Land Development*, 49, pp. 85–94. Available at: https://doi.org/10.24425/jwld.2021.137100.

Khazimov, J.M. and Khazimov, M.Z. (2011) "To justification of the parameters of the work wheel of the seedling planting device for soil mulching," *Journal of the University of Chemical Technology and Metallurgy*, 46(1), pp. 99–104. Available at: https://journal.uctm.edu/node/j2011-1/15_Khazimov.pdf (Accessed: June 03, 2023).

Kim, B. *et al.* (2019) "Risk assessment of tractor-related hazards based on accident cases," *Journal of Agricultural Safety and Health*, 25 (3), pp. 133–152. Available at: https://doi.org/10.13031/jash.13076.

Klochkov, A.V., Novitsky, P.M. and Khazimov, M.Z. (2018) *Innovatsionnaya sel'skokhozyaystvennaya tekhnika [Innovative agricultural machinery]*. Gorki: BSHA.

Kovalev, G. (2020) "V kakom napravlenii budet razvivatsya molochnoe proizvodstvo Kazahstana [In what direction will dairy production in Kazakhstan develop]," *Kursiv*. Available at: https://kursiv.kz/news/biznes/2020-01/v-kakom-napravlenii-budet-razvivatsya-molochnoe-proizvodstvo-kazakhstana (Accessed: March 09, 2023).

Muck, R.E. and Holmes, B.J. (2001) "Density and losses in pressed bag silos," *ASAE The Society for engineering in agricultural, food, and biological systems*, 01-1091, pp. 1–20. Available at: https://fyi.extension.wisc.edu/forage/files/2014/01/SiloBagDensity.pdf (Accessed: April 24, 2023).

Nekrashevich, V. *et al.* (2019) *Klapan dlya konteynera primenyayemogo pri silosovanii kormov [Valve for a container applicable for silage]*. RGP "Natsional'nyy institut intellektual'noy sobstvennosti" Ministerstva yustitsii Respubliki Kazakhstan. Patent specification 33425. F16K 15/00 (2006.01). Appl. no. 2017/0767.1. Date of filing 18.09.2017. Date of publ. No. 5, 01.02.2019. Available at: https://gosreestr.kazpatent.kz/Invention/DownLoadFilePdf?patentId=282476&lang=ru (Accessed: April 24, 2023).

Nekrashevich, V. *et al.* (2020a) "Theory and practice of feed silage in containers made of airtight film," *BIO Web of Conferences*, 17, 00041. Available at: https://doi.org/10.1051/bioconf/20201700041.

Nekrashevich, V.F. *et al.* (2020b) "Innovatsionnaya energo i resurso sberegayushchaya tekhnologiya prigotovleniya i khranenya silosa v myagkikh vakuumirovannykh konteynerakh putem ispol'zovaniya mobil'nogo agregata v polevykh usloviyakh (iz pod kombayna) [Innovative energy and resource-saving technology for preparing and storing silage in flexible vacuum containers by using a mobile unit in the field (from under a combine harvester)]," *Issledovaniye, rezul'taty*, 3(87), pp. 380–385. Available at: https://journal.kaznaru.edu.kz/index.php/research/issue/view/2/1/ (Accessed: April 05, 2023).

Niyazbayev, A. *et al.* (2022) "Power need of an implement for removing polymer residues from the soil surface in Kazakh horticulture," *Journal of Agricultural Engineering*, 53(3), 1382. Available at: https://doi.org/10.4081/jae.2022.1382.

Sagyndykova, Zh. *et al.* (2021a) "Research and development of essentials for silage preparation, transport and storage in flexible containers of optimal volume," *Acta Technologica Agriculturae*, 24(2), pp. 72–78. Available at: https://doi.org/10.2478/ata-2021-0012.

Sagyndykova, Zh. *et al.* (2021b) "Opredeleniye effektivnosti tekhnologii prigotovleniya i khraneniya silosa v myagkikh vakuumirovannykh konteynerakh [Determination of the efficiency of the technology of preparation and storage of silage in flexible vacuum containers]," *Herald of Science of the S. Seifullin Kazakh Agrotechnical Research University*, 4(111). pp. 50–57. Available at: https://doi.org/10.51452/kazatu.2021.4(111).780.

Standartniform (2018) *Mezhgosudarstvennyy standart. GOST 34393–2018. Tekhnika sel'skokhozyaystvennaya. Metody ekonomicheskoy otsenki [Interstate standard. GOST 34393–2018. Agricultural machinery. Methods of economic evaluation]*. Moscow: Standartniform. Available at: https://meganorm.ru/Data/705/70500.pdf (Accessed: December 7, 2018).

Zhumagaliyev, Ye.R. *et al.* (2021) "Razrabotka transportnogo sredstva (konteynerovoza) dlya priyomki izmel'chonnoy massy ot silo-souborochnogo kombayna i issledovaniye rezhimov vakuumirovaniya silosnoy massy [Development of a transport vehicle (container carrier) for receiving the chopped mass from the forage harvester and the study of the system vacuuming silage mass]," *Issledovaniya, rezul'taty*, 1(89), pp. 178–187. Available at: https://doi.org/10.37884/1-2021/19.