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Preface

Dear authors and readers,

It is with great pleasure that I present to you a new product - the first issue of the scientific e-journal "Sustainable Food Industry", which is the only journal in Latvia (and the Baltics) in this field.

The journal "Sustainable Food Industry" is an international, peer-reviewed journal published online by the RTU Rezekne Academy, Latvia. The journal aims to provide sound scientific evidence on the science of food production and extraction to create a more sustainable world for future generations. The journal Sustainable Food Industry aims to provide scientists with an international platform to publish research in the field of food science. We believe that the future of food production is closely linked to our ability to adapt and implement sustainable solutions that ensure food security while preserving our planet's resources.

Thank you to the authors for entrusting us with publishing their research in the e-journal "Sustainable Food Industry". Many thanks to the reviewers because, without their input and evaluation, this issue would not have been possible. We hope that the research published in the journal will be useful and interesting to readers. Our journal is a platform where scientists, researchers, farmers, producers, entrepreneurs, and policymakers can share their research, experience, and ideas that will contribute to the sustainability of food production, as well as get acquainted with the experience of other authors.

We also invite other authors to submit works for publication in the e-journal "Sustainable Food Industry": https://journals.rta.lv/index.php/SFI/about/submissions, which covers a wide range of topics, including:

- **Agriculture.** Food production: the cultivation of plants and animals (including insects and aquaculture) for food production and management, including value-added products that affect yield, food quality, and sustainability. The impact of packaging on food. Food waste reduction and recycling. Smart agriculture. Innovative agricultural methods and technologies that improve food quality and are environmentally friendly. Organic farming. Agroecology.
- **Food quality and safety.** Food and beverages. Animal feed development. Food production and processing. Factors affecting product properties that change product characteristics include texture, shelf life, tastes, colors or aromas, etc. The impact of packaging on food. Food waste reduction and recycling. Application of risk assessment (including analytical methods) and risk management techniques.
- **Food processing and food technology.** Food processing to transform raw materials into marketable food products. Development, production, and processing of food and beverages for humans and animal feed. Packaging properties and their impact on food. New or improved production processes that increase product yield or reduce losses between production and consumption. Food waste reduction and recycling. Automation and sensor solutions in food technology.
- **Food distribution and marketing.** Implementation and logistics of sustainable food value chains. Gastronomic tourism. Agritourism. Food systems and marketing. Food chains and supply of consumer goods. Food waste reduction and recycling. Reducing negative impacts by producing and selling food most efficiently and cost-effectively. Food consumer education. The impact of packaging on food. Food policy.

We invite you to become a part of our magazine to jointly build a more sustainable and resilient food system. Your contribution is invaluable, and we look forward to working with you in the future.

Sincerely,
Editor of the e-journal "Sustainable Food Industry",
Liena Poiša

Priekšvārds

Cienījamie autori un lasītāji!

Ar lielu prieku Jūs iepazīstinu ar jaunumu - zinātniskā e-žurnāla "Sustainable Food Industry" pirmo numuru, kas ir vienīgais žurnāls Latvijā (arī Baltijā) šajā jomā.

Žurnāls "Sustainable Food Industry" ir starptautisks, recenzēts žurnāls, ko tiešsaistē izdod RTU Rēzeknes akadēmija, Latvijā. Žurnāla mērķis ir piedāvāt pamatotus zinātniskus pierādījumus par pārtikas ražošanas un ieguves zinātni, lai radītu ilgtspējīgāku pasauli nākamajām paaudzēm. Žurnāla "Sustainable Food Industry" mērķis ir piedāvāt zinātniekiem starptautisku platformu, lai publicētu pētījumus pārtikas zinātnes nozarē. Mēs ticam, ka pārtikas ražošanas nākotne ir cieši saistīta ar mūsu spēju pielāgoties un ieviest ilgtspējīgus risinājumus, kas nodrošina pārtikas drošību, vienlaikus saglabājot mūsu planētas resursus.

Paldies autoriem, ka uzticēja mums publicēt savus pētījumus e-žurnālā "Sustainable Food Industry". Liels paldies recenzentiem, jo bez viņu ieguldījuma un vērtējuma šo izdevumu nebūtu bijis iespējams izdot. Ceram, ka žurnālā publicētie pētījumi būs noderīgi un interesanti lasītājiem. Mūsu žurnāls ir platforma, kurā zinātnieki, pētnieki, lauksaimnieki, ražotāji, uzņēmēji un politikas veidotāji var dalīties ar saviem pētījumiem, pieredzi un idejām, kas veicinās pārtikas ražošanas ilgtspēju, kā arī iepazīties ar citu autoru pieredzi.

Aicinām arī citus autorus iesniegt darbus publicēšanai e-žurnālā "Sustainable Food Industry": https://journals.rta.lv/index.php/SFI/about/submissions, kas aptver plašu tēmu loku, t.sk.:

- **Lauksaimniecība**. Pārtikas ražošana: augu un dzīvnieku (t.sk. kukaiņu un akvakultūru) audzēšana pārtikas ražošanai un apsaimniekošanai, tostarp produktus ar pievienoto vērtību, kas ietekmē ražu, pārtikas kvalitāti un ilgtspējību. Iepakojuma ietekme uz pārtiku. Pārtikas atkritumu samazināšana un pārstrāde. Viedā lauksaimniecība. Inovatīvas lauksaimniecības metodes un tehnoloģijas, kas uzlabo pārtikas kvalitāti un ir draudzīgas videi. Bioloģiska lauksaimniecība. Agroekoloģija.
- **Pārtikas kvalitāte un nekaitīgums (drošība)**. Pārtika un dzērieni. Dzīvnieku barības izstrāde. Pārtikas ražošana un apstrāde. Produktu īpašības ietekmējošie faktori, kas maina produktu īpašības, tostarp tekstūru, uzglabāšanas laiku, garšas, krāsas vai aromātus u.c. Iepakojuma ietekme uz pārtiku. Pārtikas atkritumu samazināšana un pārstrāde. Riska novērtēšanas (ieskaitot analītiskās metodes) un riska pārvaldības metožu pielietošana.
- **Pārtikas pārstrāde un pārtikas tehnoloģija**. Pārtikas pārstrāde, lai pārveidotu izejvielas tirgojamos pārtikas produktos. Cilvēkiem paredzētās pārtikas un dzērienu un dzīvnieku barības izstrāde, ražošana un pārstrāde. Iepakojuma īpašības un ietekme uz pārtiku. Jauni vai uzlaboti ražošanas procesi, kas palielina produkcijas ražu vai samazina zudumus starp ražošanu un patēriņu. Pārtikas atkritumu samazināšana un pārstrāde. Automatizācijas un sensoru risinājumi pārtikas tehnoloģijā.
- **Pārtikas izplatīšana un mārketings**. Ilgtspējīgu pārtikas vērtību ķēžu ieviešana un loģistika. Gastronomiskais tūrisms. Agrotūrisms. Pārtikas sistēmas un mārketings. Pārtikas ķēdes un patēriņa preču piegāde. Pārtikas atkritumu samazināšana un pārstrāde. Negatīvās ietekmes samazināšana, ražojot un pārdodot pārtiku visefektīvākajā un rentablākajā veidā. Pārtikas patērētāju izglītošana. Iepakojuma ietekme uz pārtiku. Pārtikas politika.

Mēs aicinām Jūs kļūt par daļu no mūsu žurnāla, lai kopīgi veidotu ilgtspējīgāku un noturīgāku pārtikas sistēmu. Jūsu ieguldījums ir nenovērtējams, un mēs ceram uz turpmāko sadarbību ar Jums.

Ar cieņu
e-žurnāla "Sustainable Food Industry" redaktore,
Liena Poiša

Content/Saturs

Sustainable Food Industry 2025, 1(1)

Sweetened condensed milk with acorn coffee, a time-forgotten product revival

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Abstract

Sweetened condensed milk is a long-storable concentrated product that can be found worldwide. It is used both directly in food and as a raw material for the production of other food products. Canned milk plays an important strategic role in the food stock reserves of many countries. Mostly canned milk is consumed by countries with poorly developed farming or dairy processing industries or regions where the existence of such branches is not possible. Worldwide, condensed milk is mostly produced in large milk processing plants due to the complexity of technology and the need for large amounts of raw milk and energy for its processing. Nowadays, there are many varieties of condensed milk available on the market, where the most interesting examples are present in post-Soviet regions. This is explainable due to the significance of condensed milk as one of the most strategically important food products of the USSR (especially during the Cold War period), and also due to the cultural impact on its citizens as canned milk was the easily available sweet tasting product. Soviet canned milk production specialists upgraded and developed other varieties, such as sweetened condensed full cream or skimmed milk or cream with coffee or cocoa. Also, there were other taste varieties in development, but due to different factors, only a few of them got to the mass production stage. Most interesting is the use of coffee substitutes for adding to sweetened condensed milk, where you get a coffee-taste-like product, but without caffeine in it. In mass production, there is only one such product available – sweetened condensed milk with chicory, and unfortunately, its selling market is very limited. The objective of this article is to reveal the use of oak tree acorns as a caffeine-free additive for sweetened condensed milk, reinventing it for the modern world market, where demand for traditional and biological food is growing. The article contains sweetened condensed milk with acorn coffee explanation with a historical review, production theory, and prototype creation steps, that were based on original, but time-forgotten technology from 1939, and similar, but still used, sweetened condensed milk with chicory technology.

Keywords: sweetened condensed milk, acorns, coffee substitute, canned milk, forgotten food products and technologies

1. Introduction

Canned milk (condensed or evaporated milk) is a long shelf life dairy product, that is made by vacuum evaporation of excess water and further adding of sugar or high temperature sterilization. Because condensed milk is a concentrate, it has more nutrients than regular whole milk, and adding additives only increases its nutrient value. The canning industry helps to make good use of all processed milk and its by-products, especially in the summer period, when it is not possible to process all milk in the form of whole milk products and sell it to consumers (Mahfuza et al., 2024; Nieuwenhuijse, 2011). There are several industries where condensed milk is widely used: sweets/confectionery, pastry and bread, ice cream and processed cheese production, etc. Canned milk is in demand in regions where animal husbandry is not developed or is not possible. Also, sailors, expeditions, armies, and strategic reserves of various countries are supplied with canned milk. The ordinary end consumer uses this product both directly for food and also for preparing various dishes and desserts (Stern et al., 1971).

The historical reason for the emergence of canned milk can be explained by the need for a high-quality milk product that can be stored for a long time above +6°C, can be easily transported, and used easily (Paludetti et al.,

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2018). The basis of modern condensed milk production was laid in the 19th century thanks to Nicolas Appert, who developed technologies for the preservation of various food products for the Napoleon army (food sterilization), as well as Gail Borden, who, struggling with high child mortality, developed the technology and equipment for the production of condensed milk with sugar, after which he created the first canned milk factory in the world (Barbano, 2017; Ramesh et al., 2016; LaikaPaka, 2023). In Latvia, from 1957 to 2001, canned milk was produced by Rēzeknes Piena Konservu Kombināts (RPKK), which during more than 40 years processed around 8.2 million tons of milk, from which around 3 billion cans of different variety condensed milk were produced. RPKK products were exported all over the world, thus highly appreciated, regularly awarded and nowadays becoming a legend. Nowadays, in Latvia, only one small-scale producer of condensed milk exists – SIA Vajars, but the local market is mostly filled with canned milk from Lithuania, the Netherlands, and Ukraine (LaikaPaka, 2023).

Despite the ancient origin of the product, it still does not lose its relevance and demand (Henchion et al., 2021). Since the 19th century, not only the production technology, equipment and packaging have been improved, but also the varieties of condensed milk have been expanded. Since the use of sweetened condensed milk differs from countries and nations, there is potential for taste variety expansion, but this field is stagnated due to passivity of nowadays condensed milk producers to experiment with new product development (Barbano, 2017). There are small scale producers in Ukraine, Belarus and Russia that present their sweetened condensed milk with different flavourings (banana, peach, strawberry, cherry etc.), but it is usually is obtained by using artificial flavourings and colourings (LaikaPaka, 2023). Modern trends show that there is demand for sugar, lactose free, or plant based milk products, and canned milk producers start to fulfill that demand (Bolshakova et al., 2024; Fang et al., 2023; Guimaraes et al., 2012). Currently existing assortment of condensed milk products consists of:

TABLE 1 VARIATIONS OF CANNED DAIRY PRODUCTS

Sweetened condensed milk (SCM) and other canned milk variations (LaikaPaka, 2023)	
SCM full cream (8-10% fat)	Boiled/caramelized SCM (+cocoa) (5-8.5% fat);
SCM skimmed (1-5% fat);	Sweetened condensed cream (+cocoa or coffee) (19% fat)
SCM with natural additives (cocoa, coffee, chicory)	Evaporated or concentrated milk (without sugar) (7.8-8.6% fat).
SCM with artificial flavorings and colorings or sweeteners	Plant based sweetened canned milk (coconut, oat, palm oil)

Since the article author has free access to historical milk processing and milk product production technology literature, mostly soviet period literature and state standards were used as a base:

TABLE 2 RPKK PRODUCED CANNED MILK CONTENTS

Indicator	**RPKK produced canned milk contents** (Skrebinska et al., 1999)				
	Full cream sweetened	**Skimmed sweetened**	**Sweetened with cocoa**	**Sweetened with coffee or chicory**	**Sweetened cream**
Max. water content %	26,5	30,0	27,5	29,0	26.5
Min. sucrose content %	43.5	44.0	43.5	44.0	38.0
Min. dry matter content of milk and additives %	28.5	24.5	27.5	26.0	34.0
Min. fat content %	8.5	-	7.5	7.0	19.0
Max. dynamic viscosity for fresh product (Pa*s)	2-10	1-10	2-10	2-10	2-10
Max. dynamic viscosity of the product at the end of life (Pa*s)	15	15	17	15-17	17
Max. acidity (°T)	48	60	-	-	40
Max. lactose crystal size for fresh product (µm)	10	15	-	10	10
Max. size of lactose crystals for product at expiration (µm)	15	15	-	15	15

Considering the growing demand for locally produced products, which are mainly produced from local raw materials and materials, as well as the revival of traditional recipes and technologies, it would be useful to develop this direction for the restoration of condensed milk production in Latvia (Pinto-Correia et al., 2021; Henchion et al., 2021). In the territory of Latvia, it is possible to obtain high-quality milk and produce sugar from locally grown sugar beets (historically Latvia had 3 sugar factories) (LaikaPaka, 2023). However, in the production of condensed milk with additives, it will be necessary to abandon cocoa and natural coffee, since it is impossible to grow it freely in our climatic conditions. However, it is possible to use alternative products such as chicory, acorns or cereals, which not only can be grown in our climate, but have become traditional substitutes for coffee (Pouille et al., 2020; Indzere et al., 2018).

Acorn coffee, which is a mixture of roasted, finely ground, sifted and homogeneously mixed acorns, chicory roots and cereals (barley, wheat, rye) (Pasqualone et.al., 2019). Historically, even before coffee and cocoa were brought to the territory of Latvia, our ancestors made acorn coffee from local raw materials, which according to its organoleptic properties is not only similar to natural coffee, but also healthier because it does not contain caffeine. This is especially important for people who are not advised to use caffeine, which is actually considered a very weak poison-stimulant. Caffeine-containing products should be excluded from children's, pregnant and breast-feeding woman diet.al.together, as it can negatively affect child health and development (Reichert et al., 2021). There are several hundred different types of oaks in the world, which are mostly found in the temperate climate zone. For this reason, they are widely found in the territory of Latvia, becoming an integral part of Latvian culture and history. Not only excellent wood and beautiful leaves can be obtained from the oak tree, but also nuts (acorns), which both animals and humans consume. Acorns have always helped people to survive in times of war and famine when the usual food supplies are scarce (Indzere et al., 2018; Pouille et al., 2021; LaikaPaka, 2023).

Condensed milk with sugar and acorn coffee is produced in exactly the same way as condensed milk with sugar and coffee or chicory. Uses the same parameters of raw materials and finished products, as well as calculation formulas. This was concluded after the author discovered the standard ОСТ-НКММП 2 adopted by the USSR on May 4, 1939, and the technical conditions, where condensed milk with sugar and acorn coffee or chicory is described as an alternative product to condensed milk with sugar and natural coffee. It is possible that the beginning of the Second World War did not give a further future for the development of this product, but in the post-war years, natural coffee was already more available and popular. Condensed milk with acorn coffee was mentioned a little in the post-war literature only in a few books published in the USSR on the production of canned milk, but upgraded national standards or technical conditions related to this product were never developed (Kazansky et al., 1955). However, after many years, only condensed milk with sugar and chicory was released in the early 1980s thanks to the Rēzeknes Piena Konservu Kombināts specialists, creating local production standard (ТУ 49 Латв.ССР 1362-85) which later were adopted by other milk canning plants of the USSR (ТУ 10-02-02-9-86) for further mass production (LaikaPaka, 2023).

2. Materials and Methods

Sweetened condensed milk with acorn coffee was experimentally prepared in the food processing laboratory of Rezekne Academy of Technologies using the author's own made small volume vacuum evaporator-crystallizer prototype “Fig. 1”. Also, other available inventory and equipment was used, such as:

- Digital kitchen scales (accuracy +/- 1g, max 5000g);
- Digital thermometer with probe (accuracy +/- 1°C, 0-250°C);
- Refractometer for honey or syrup (accuracy +/- 0,5%, 12-27% water content);
- Induction stove, refrigerator, pots, dishes, spoons, cups and sieves of various sizes.

For experimental sweetened condensed milk with acorn coffee further ingredients and materials were used:

- Pasteurized and normalized milk “Latgale” 3,5% - 4 L; (Latvia);
- Sugar beet refined sugar “Marijampoles”- 880 g; (Lithuania);
- Ground acorn coffee "Zīleja" - 334 g; (Latvia);
- Fine lactose powder - 35 g; (Spain);

• 40 ml glass jars with screw-on metal lids – for packaging and final product storage.

Fig. 1. Small volume vacuum evaporator-crystallizer prototype (authors own designed and made).

The next sequence of operations consists of pre-preparation of 2 main components – sweetened condensed milk and acorn coffee extract. For sweetened condensed milk production, it is necessary to calculate the correct amount of needed ingredients. As mentioned previously, technology of sweetened condensed milk with chicory is taken as a basis because it is most suitable for such coffee substitute variation production (Ozola, 1988; Stern et al., 1971; Kazansky et al., 1955).

The main idea of sweetened condensed milk production is to create a long shelf life dairy product, where an unsuitable environment for microbiological activity must be created. In that case, water removal from the product plays the most important role. To remove excess water, vacuum evaporators are used, as it allows to evaporate water at much lower temperatures, preserving most nutrients in the product. Also, the addition of sugar creates a high osmosis pressure environment, which hinders further life processes of microorganisms (Renhe et al., 2018; Martinez et al., 2017; Park and Darke, 2016). Correct calculation of ingredients is very important, to achieve the desired result in the final product, and it is calculated by equation (Ozola, 1988; Stern et al., 1971; Kazansky et al., 1955):

$$T\_pr/(BS\_pr\,) = T\_m/(BS\_m\,) \;\; or \;\; C\_pr/(BS\_pr\,) = C\_m/(BS\_m\,) \qquad (1)$$

Where:

- T_pr- fat content in the product;
- T_m- fat content in the mixture;
- BS_pr - fat-free content of the product;
- BS_m- fat-free content in the mixture;
- C_pr- sugar content in the product;
- C_m- sugar content in the mixture.

Based on these equations, all calculations in the production of condensed milk are made. However, ready-made normalization tables with the necessary data and parameters exist to facilitate calculations (Stern et al., 1971).

TABLE 3 PRODUCT TYPE

Product Type	**Mixture contents %**		**Mixture amount (kg for 400kg ready product)**	
	Fat	**Non fat solids**	**Summer season**	**Winter season**
Sweetened condensed milk	3.52	8.29	1005	1007

Product Type	Mixture contents %		Mixture amount (kg for 400kg ready product)	
	Fat	Non fat solids	Summer season	Winter season
Sweetened condensed milk with cocoa	4.22	8.24	686	686
Sweetened condensed milk with coffee or chicory	4.36	8.23	682	684

Also, other equations are used for determining necessary parameters (Ozola, 1988; Stern et.al., 1971):

$$B = P(1 - S\_m/S\_g) \qquad (2)$$

The amount of water to be evaporated from the mixture, where:

- B - amount of water to be evaporated (kg);
- P - Weight of raw materials to be thickened (kg);
- S_m - Solids content in the mixture %;
- S_g - Solids content in finished product %

$$G = (S_m * A)/S\_g \qquad (3)$$

Amount of condensed milk to be obtained, where:

- G- Quantity of condensed milk (kg);
- S_m- Solids content in the mixture %;
- Total amount of raw materials for thickening (kg);
- S_g- Solids content in finished product %;

$$C = (M * A * S\_p)/(100 * S\_g) \qquad (4)$$

The required amount of sugar for the mixture, where:

- C - Amount of sugar required for processing (kg);
- M - Amount of mixture required for thickening (kg);
- S_p - Solids content of normalized milk %;
- S_g - Required solids content in the finished product %;
- A - The required amount of sugar in the finished product (kg).

$$\mathrm{E} = (P * K * S)/(100 * G) \qquad (5)$$

Determination of dry coffee or chicory extract amounts, where:

- E - Amount of dry coffee or chicory extracts needed for cooking (kg);
- P - Amount of normalized milk required for cooking (kg);
- K - The dry extract substance is contained in coffee or chicory %;
- S - Dry matter content in normalized milk %;
- G - Dry matter content in the finished product %

As only 30% of the total amount of dry extracts of coffee or chicory enters the extract. Therefore, the total amount of coffee or chicory is determined by (Stern et.al., 1971):

$$K\_k = (100 * E)/30 \qquad (6)$$

where:

- E - Amount of dry coffee or chicory extracts needed for cooking (kg);
- S - Dry matter content in normalized milk %;

- P - Amount of normalized milk required for cooking (kg);
- K - The dry extract substance is contained in coffee or chicory %;
- G - Dry matter content in the finished product %.

Using previously mentioned equations, correct proportions of ingredients were determined, for starting point taking accessible amount and quality of milk. As ready to use pasteurized and normalized milk was used, no detailed explanation of raw milk processing technology and quality indicators is needed (Ozola, 1988; Stern et al., 1971; Kazansky et al., 1955).

Further processing contained preparation of sweetened condensed milk, where prepared mixture of milk and sugar were evaporated to 26% water content at 20 inHg or 508 mmHg vacuum and 75°C +/- 5°C temperature of mixture. During milk-sugar mixture evaporation, acorn coffee extract was prepared according to equation, where dry ground acorn coffee was mixed with required amount of water. Acorn-water mixture was heated to boiling point, where it was further heated and continuously stirred for 5 more minutes. After heating, acorn-water mixture was left to settle and cool down for 30 minutes. After settling, the acorn coffee extract was separated from the solids with the help of a sieve or cheesecloth, repeating the filtration several times. The resulting extract was added to pre-prepared but still hot sweetened condensed milk and mixed together. Complete mix was evaporated to required water content (less than 26%) "Fig. 2" and cooled down to 35°C with active mixing in order to achieve correct crystallization process by adding 0.02% of fine lactose powder (from total product mass). Overall evaporation and crystallization process took around 6 hours. Ready sweetened condensed milk with acorn coffee was filled in pre-sterilized and still hot glass jars and closed with pre-sterilized screw-on metal lids. Completed product was stored in refrigerator at 4°C.

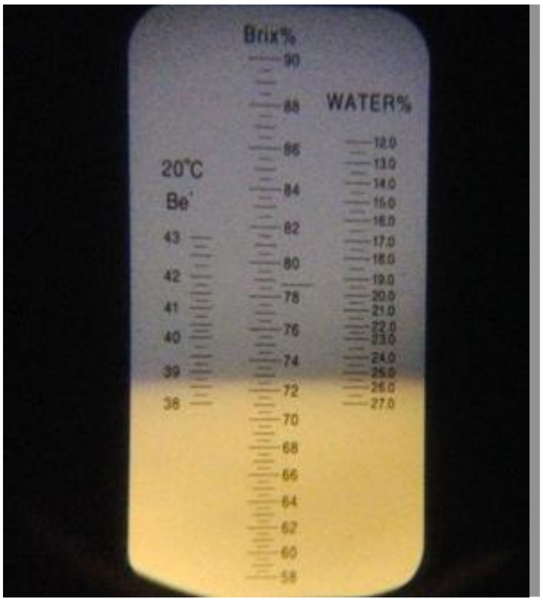

Fig. 2. Water content of sweetened condensed milk with acorn coffee (25,5%).

3. Results and discussion

- Despite certain risks and possibility of failure, as original technology of sweetened condensed milk with acorn coffee from 1939 was not used and developed further, also, complications with seasonality of acorn harvest, research resulted in quite promising new product prototype, that after some more improvements could be used for further mass production.
- From 4 litres of milk, 880 g. beet sugar and 334 g. ground acorn coffee - 1736 g. sweetened condensed milk with acorn coffee was obtained.
- For ease of use, all ingredient amounts for sweetened condensed milk production were calculated using authors own made automatic calculation tables (using Microsoft Excel), that are based on equations, that are mentioned in this article.

- Due to limited product amount, prototype was presented for close circle tasting, where participants (12 woman and 9 man of age 20-75) using method similar to “Hedonic scaling”, valued product organoleptic qualities, emphasizing that it is quite similar to sweetened condensed milk with coffee. Overall, participants enjoyed prototype taste and showed interest to purchase such product when it would be available for sale.
- Product was put in long term shelf life testing (2019-2024), with periods from 1 to 5 years, storing it all this period in refrigerator at 4°C. Product remained its organoleptic features for 12 months without changes (as required in sweetened condensed milk with chicory standard). Further in time, product started to became more viscous with noticeable feeling of sugar grains, but still remained its pleasant taste, no visible or sensible microbiological spoilage was detected (mould, fermentation).
- Visitors of “LaikaPaka” museum show interest in sweetened condensed milk with acorn coffee, as remaining prototype sample and its creation story is a part of exhibition.
- Sweetened condensed milk with additives topic may be a field for further researches, new discoveries and creation of new market product niche.

Obtained sweetened condensed milk with acorn coffee prototype organoleptic features “Fig. 3”:

- Colour - Light brown with small dark dots (fine coffee grounds), uniform throughout the mass;
- Consistency - viscous, homogeneous throughout the mass with small organoleptically felt coffee grounds, without lumps;
- Smell - pleasantly sweet with a pronounced aroma of sweet cream and acorn coffee aromas;
- Taste - moderately sweet with a distinct taste of sweet cream and acorn coffee, pleasant mild aftertaste.
- When dissolved in hot water - the colour and smell remain a little less pronounced.

Fig. 3. Sweetened condensed milk with acorn coffee (prototype).

4. Conclusions

This research shows that the use of oak tree acorns as a coffee substitute for flavouring sweetened condensed milk is possible. Moreover, the organoleptic qualities of the experimental batch of sweetened condensed milk with acorn coffee were pleasurable for persons who tasted it. Since the original 1939 technology of sweetened condensed milk with acorn coffee is time forgotten, and acorn coffee itself is an old Latvian traditional beverage, it could be a potentially new and uncial national product of Latvia, that could be produced from 100% locally producible ingredients and used for other new food product creation (sweets, ice cream etc.). Using biological ingredients may be more challenging, but more attractive for those customers, who care about their and their close one health.

It is clear, that some more prototypes of sweetened condensed milk with acorn coffee should be made for future examination and testing to optimise its production technology. After optimisation and marketing campaign, the product should be produced in considerable amounts (approximately 1500 standard tin cans or 600 kg of product itself) for customer testing, which would determine its liveability on the Latvian market.

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References

Barbano D.M. (2017). A 100-year review: Production of fluid (market) milk. *Journal of Dairy Science*, vol 100, p. 9894-9902.

Bolshakova E.I., Kruchinin A.G., Turovskaya S.N., Illarionova E.E., Yurova E.A., Barkovskaya I.A., Galstyan A.G. (2024). Effects provided by sugar substitutes upon the quality indicators of model systems of sweetened condensed milk in storage. *Journal of Dairy Science*, vol. 107. p. 9110-9123.

Fang R., Jiang H., Lin C., Xia T., Xu S., Chen Q., Xiao G.(2023). Characterization and shelf stability of sweetened condensed milk formulated with different sucrose substitutes during storage. *Food Chemistry*, vol. 404. Part A. 134402.

GOST 2903-78. (1978). Sweetened condensed whole milk. Technical conditions. Moscow.

GOST 719-85. (1985). Sweetened condensed whole milk with natural coffee. Technical conditions. Moscow.

Guimaraes I.C.O., Rocha Leao M.H.M. ,Pimenta C.J., Ferreira L.O., Ferreira E.B. (2012). Development and description of light functional dulce de leche with coffee. *Food Science and Technology*. 36 (2).

Henchion M., Moloney A.P., Hyland J., Zimmermann J., McCarthy S. (2021). Review: Trends for meat, milk and egg consumption for the next decades and the role played by livestock systems in the global production of proteins. *Animal*, vol. 15, Supplement 1. 100287.

Indzere Z., Khabdullina Z., Khabdullin A., Blumberga D. (2018). The benchmarking of chicory coffee's production. *Energy Procedia*, vol. 147, p. 631-635.

Kazansky M.M., Tverdokhleb G.V. (1955).Technology of milk and dairy products. Moscow "Pishchepromizdat".

LaikaPaka. (2023). Latvian food processing history private museum "LaikaPaka" materials. Est.

Mahfuza E.J., Alam M.J., McKenzie A.M. (2024). Demand for milk and milk products in the rural household of Bangladesh: A panel data analysis. *Journal of Agriculture and Food Research*, vol. 18, 101457.

Martinez B.A., Stratton J., Bianchini A. (2017). Isolation and genetic identification of spore-forming bacteria associated with concentrated-milk processing in Nebraska. *Journal of Dairy Science*, vol. 100. p. 919-932.

Nieuwenhuijse J.A. (2011). Concentrated dairy products: Sweetened condensed milk. Encyclopaedia of dairy sciences (second edition). p. 869-873.

Ozola L.(1988). Cheese and canned milk production technology. Whey processing. Riga.

Ozola L., Ciprovīča I. (2002). Milk processing technology. Jelgava, R. LLU, Faculty of Food Technology.

Paludetti L.F., Kelly A.L., O'Brien B**.**, Kieran J., David G. (2018). The effect of different precooling rates and cold storage in milk microbiological quality and composition. *Journal of Dairy Science*, vol. 101. Issue 3. p. 1921-1929.

Park C.W., Darke M. (2016). Condensed milk storage and evaporation affect the flavour of non-fat dry milk. *Journal of Dairy Science*, vol. 99, p. 9586-9597.

Pasqualone A. , Makhlouf F.Z., Barkat M., Difonzo G., Summo C., Squeo G., Caponio F. (2019). Effect of acorn flour on the physico-chemical and sensory properties of biscuits. *Heliyon*, vol. 5, e02242.

Pinto-Correia T., Rivera M., Guarín A., Grivins M., Tisenkopfs T., Hernández P.A. (2021). Unseen food: The importance of extra-market small farm's production for rural households in Europe. *Global Food Security*, vol. 30. 100563.

Pouille C.L., Jegou D., Dugardin C., Cudennec B., Ravallec R., Hance P., Rambaud C., Hilbert J-L., Lucau-Danila A. (2020). Chicory root flour – A functional food with potential multiple health benefits evaluated in a mice model. *Journal of Functional Foods*, vol. 74, 104174.

Ramesh C., Chandan R.C., Kilara A., Shah N.P. (2016). Dairy Processing and Quality Assurance. Second edition.

Reichert C.F., Veitz S., Bühler M., Gruber G., Deuring G., Rehm S.S., Rentsch K., Garbazza C., Meyer M., Slawik H., Lin Y-S., Weibel J. (2021). Wide awake at bedtime? Effects of caffeine on sleep and circadian timing in male adolescents – A randomized crossover trial. *Biochemical Pharmacology*, vol. 191. 114283.

Renhe I.R.T., Pereira D.B.C., Sa J.F.O., Santos M.C., Teodoro V.A.M., Magalhaes F.A.R., Perrone I.T., Silva P.H.F. (2018). Characterization of physicochemical composition, microbiology, sensory evaluation and microscopical attributes of sweetened condensed milk. *Food science and technology*. 38 (2).

Ryabova A.E., Tolmachev V.A., Galstyan A.G. (2022). Phase Transitions of Sweetened Condensed Milk in Extended Storage Temperature Ranges. *Food Processing: Techniques and Technology*, vol. 52.

Skrebinska T., Nazarova A., Lempa I., Karabeška L. (1999). Dairy product technology, part 2. Ozolnieki.

Stern A.A., Barbayanov K.A., Barmash A.I., Lungern V.G. (1973). Handbook of canned food production, volume 3. Moscow "Food Industry".

ОСТ НКММП 2. (1939). Acorn coffee with condensed milk and sugar. Moscow.

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Innovative Soil Liming and Fertilizer Means Production Technology

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Abstract

In addition to numerous factors, organic waste has a significant impact on increasing environmental pollution, which is an imperative for its solution. The goal of the work was to use the by-products of biogas production plants and cogeneration plants for soil fertilization, which allows to create a new innovative product from their mixtures. The preparation of the best mixtures applied and evaluated in greenhouses under production conditions was carried out at the companies JSC "Ziedi JP" and "Pampali". The production scheme of soil liming and fertilizer was developed and approved at both companies. The effectiveness of the composition of the mixtures was first tested on soils of different acidity in a greenhouse. The set of machines and aggregates required for the preparation and spreading of the new type of fertilizer on the field was made. Digestate, after complete development in bioreactors, is fed to the mechanical screw press separator, where it is divided into solid (dry matter 25 %<) and liquid (dry matter 3%>) fraction. The digestate of solid fractions is mixed with wood ash in portions in a screw-type mixer equipped with electronic scales. The ingredients are poured in parts so that the mixer mixes a uniform mass. After mixing, the new fertilizer is discharged from the mixer onto a conveyor belt and then into a pile, which is covered with a cover to reduce ammonium emissions. The use of the innovative soil fertility enhancer can be an effective way of recycling both products and can also be an environmentally friendly alternative to mineral fertilizers.

Keywords: digestate, wood ash, mixtures

1. Introduction

Anaerobic digestion and biogas production plants are considered the center of the circular economy, where anthropogenic organic residues previously considered as waste can be converted into energy, organic fertilizers and other value-added components and materials (Adekunle et al., 2019).

The post-fermentation residue is called digestate and spreading the digestate on fields is a common practice in agricultural enterprises. Digestate spreading norms in nitrate-sensitive areas are limited to 170 kg N ha-1 per year. (Commission of the European Communities, 1991). Phosphorus spreading norms are not directly included in the Nitrates Directive, but many European countries have different phosphate spreading limits. Depending on the species of cultivated plants, the amount of phosphorus in the soil, and other variable factors, its spread is in the range of 0 - 250 kg P2O5 ha-1 per year (Amery et al., 2014). If there are already enough nutrients in the soil, but the amount of digestate is more than necessary, it may be necessary to transport the digestate to further fields. Long transport distances justify economic investments in mechanical separation of the digestate. During separation, the digestate is divided into solid and liquid fractions. Sometimes the liquid fraction still contains high solids (up to 10% dry matter) and the solid fraction still has high moisture (15-45% dry matter) (Guilayn et al., 2019). Dividing the digestate into fractions allows to reduce the moisture content in the solid fraction, thereby reducing the costs of transporting and storing the solid fraction. The liquid fraction is easy to pump and can be easily incorporated directly into the soil in the fields, thus significantly reducing nitrogen losses (Fuchs et al., 2013).

In the mechanical separation of digestate, nitrogen usually remains more in the liquid fraction, while phosphorus and potassium remain in the solid fraction. This leads to better nutrient management (Möller et al., 2012).

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Burning woody biomass for energy is of interest to many countries as they want to reduce their consumption and dependence on fossil fuels (Perkiomaki et al., 2005). Wood-fired cogeneration plants and other biomass-fired boiler houses generate more and more ash. Ash in wood cogeneration plants is a by-product (Silva, 2018). Wood ash consists of inorganic compounds from burned biomass, sand and very small, incompletely burned organic parts (Ingerslev, 2011). As a by-product of burning wood, phosphorus (P), potassium (K) is retained in the ash, but most of the nitrogen (N) is lost during combustion in the form of NOx compounds, while the remaining N is strongly associated with organic, unburned residues and is in a non-absorbable form for microorganisms. During the combustion of biomass, various oxides are formed and the subsequent aeration leads to the formation of carbonates in the wood ash, making the ash very alkaline with a pH of 8 to 13 (Augusto, 2008). If the ash is not disposed of in landfills, but processed into plant fertilizers, all the ash is returned to the soil existing nutrients, and the pH of the soil is increased (Pittman, 2006).

The aim of this research was (I) to create a technology to prepare an innovative fertilizer using two production by-products, biogas post-fermentation digestate and biomass cogeneration ash, (II) determine the efficiency of novel mixture fertilizer creation by available agricultural tools on the experimental farm

2. Materials and Methods

The initial stage of the research is to check the chemical composition of the digestate and wood ash of different origins. Wood ash was mixed with digestate according to certain proportions, which are based on laboratory studies guided by the chemical composition of the raw materials.

The preparation of the best mixtures applyed and evaluated in greenhouses under production conditions was carried out at the companies JSC "Ziedi JP" and "Pampali" in Latvia. The production scheme of soil liming and fertilizer was developed and approved at both companies. The effectiveness of the composition of the mixtures was first tested on soils of different acidity in a greenhouse, using fast-growing plant species lettuce and cucumber. The set of machines and aggregates required for the preparation and spreading of the new type of fertilizer on the field was made.

Biogas post-fermentation digestate from cattle dung obtained by JSC "Ziedi JP" and "Pampali" was used for the experiments. Digestates were separated into solid and liquid fractions before preparing the new fertilizer mixtures. Wood ash from the cogeneration stations of LLC "Gren Jelgava" and LLC "Dobeles Eko" was used for the experiments analyses. The characteristics of solid fractions of separated digestates and wood ash are presented in Table 1.

TABLE 1 THE RESEARCH USED THE COMPOSITION OF DIGESTATE AND WOOD ASH

Indicators	**Cattle manure digestate**		**Wood ash**	
	From JCS "Ziedi JP"	***From JCS "Pampali'***	***Table column subhead***	***From JCS "Ziedi JP"***
Moisture, %	74.3	76.7	0.16	0.14
Total nitrogen, %	0.57	0.48	0.00	0.00
Total phosphor, %	0.46	0.53	3.50	3.46
Total potassium, %	1.24	1.47	11.6	8.52
pH	9.05	9.03	13.9	13.5

The content of macronutrients and heavy metals was also tested using standard methods and analyzed. The macronutrient content of the soil was also tested The tests were carried out before and after the use of the digestate. The analyzes were carried out by the Latvia University of Life Sciences and Technologies Biotechnology Scientific Laboratory (LBTU BZL).

3. Results and discussion

So far, only a few studies have been conducted to mix biogas digestate with wood ash in a specific ratio.

To prepare the new fertilizer from biogas digestate and wood ash, the equipment available on farms was used. After the correct technology, the number of days the digestate is kept in fermenters is long enough so that the digestate is fully developed and, leaving the post-fermentation, biogas is no longer released or comes close to it. An innovative technological scheme for the preparation of digestate and wood ash mixtures is shown in Fig. 1.

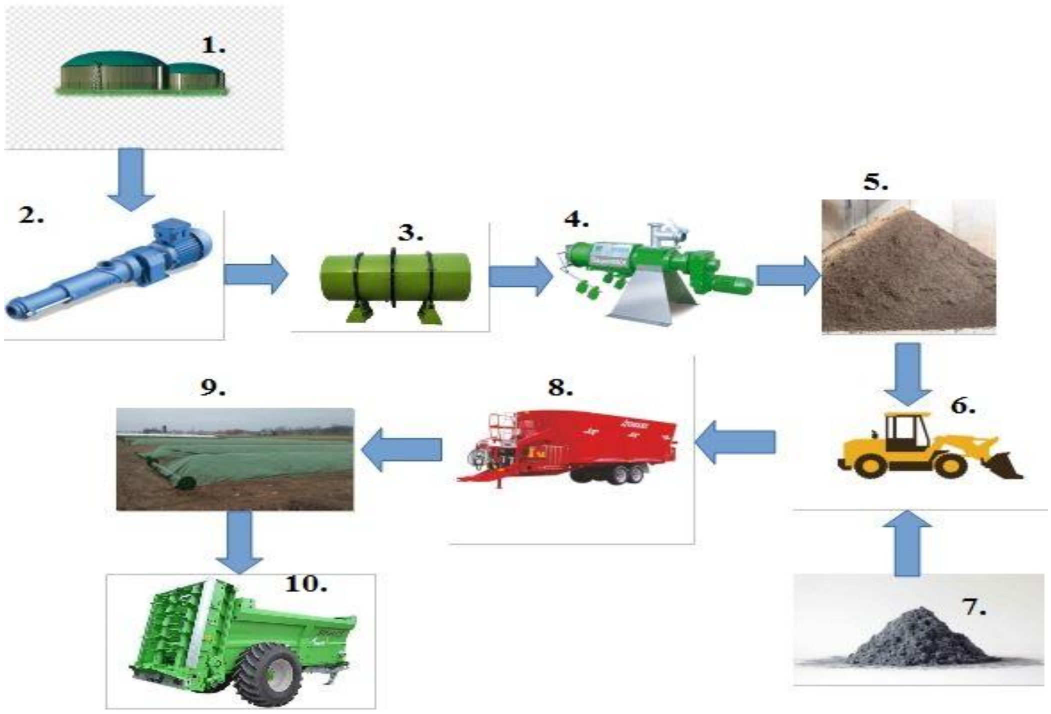

Fig. 1. Scheme of the new fertilizer preparation technology, where 1. Biogas fermenters; 2. Digestate pump; 3. Digestate intermediate storage; 4. Separation of digestate into fractions; 5. Digestate solid fraction storage; 6. Digestate and ash loading; 7. Ash storage; 8. Mixing machine Trioliet with scales and tractor; 9. Application of mixed fertilizer in stirring and covering; 10. Spreading the new fertilizer on the field.

The post-fermentation digestate, which has a dry matter content of up to 7.5%, is pumped with a VANGEN screw-type pump. Pumping takes place through a 150 mm pipeline for optimal digestate flow. The digestate is pumped to the 10m3 intermediate storage of the digestate separator. The buffer acts as a buffer to ensure a steady and continuous supply of digestate to the separator, as well as to prevent the siphon effect. The liquid manure separator EYS SP600 operates in continuous operation mode, as it is equipped with a liquid digestate intermediate storage in a volume of 10 m3, which is always in level.

A single-stage sieve with a holes size of 0.75 mm was used in the separator. After separation, the liquid fraction of the digestate, in order not to consume additional energy, flows to the liquid digestate storage. In the liquid fraction, the dry matter content remains within 2%, because they are particles with a size smaller than 0.75 mm and the separator sieve cannot retain them. The solid fraction of the digestate from the separator falls into a warehouse created under the separator room, so that the digestate is sheltered and easily collected. This is necessary so that in the event of precipitation, another fraction of the digestate does not change the dry matter content, which after separation is 25.7%.

After separation, the solid fraction of the digestate was loaded into the Trioliet mixing machine with the bucket of the front loader. The mixing machine is equipped with electronic scales so that it is possible to observe the proportions of the mixture. The Trioliet mixing machine used is equipped with 3 augers, placed 1 meter apart from each other, which ensure uniform mixing of the ingredients throughout the volume. It is possible to prepare 8 t of mixture in each mixing portion of the new fertilizer. The agitator is driven by gimbal transmission from the tractor PTO. A 130 PS John Deere 6430 is used to drive the PTO. Digestate with wood ash should be added to the mixer alternately to make the mixture faster. After filling the entire preparation dose of fertilizer into the mixer, the mixing process takes place for 15 minutes. The operator carefully watches the process to ensure that the ingredients are thoroughly mixed. During the mixing process, the operator uses personal protective equipment to protect himself from physico-chemical damage.

After mixing, the new fertilizer is discharged from the mixer into the stirrups with the help of an integrated conveyor. The height and width of the stirrups are designed in such a way that the maximum bevel angle is formed. The stirrups are quickly covered with a gas-tight cover to delay ammonia emissions. The pH of the new fertilizer is 11.5, so nitrogen release is rapid. Due to the high pH, the resulting mixture neutralizes the microorganisms present in the digestate. Without a long wait, the mixed mixture is loaded into the JOSKIN manure spreader with the front loader. The spreader is equipped with accurate dosing of fertilizer from the tractor cab and also has its own scales. Spreading width is 24m. The basic elements of the technology are visually shown in Fig. 2.

Preparation of raw materials for mixtures - digestate and wood ash, using front loader JCB 434S.

Loading the raw materials of the mixtures into the mixer.

Mixing raw materials of mixtures in a mixer.

Unloading the digestate and wood ash mixture mixed in certain proportions from the mixer.

Loading prepared means for improving soil fertility into transport.

Spreading of digestate and wood ash mixture on the field.

Fig.2. Production technology of soil liming and fertilizer (some elements of technology).

To prevent the fertilizer from compacting after transportation to the fields, the spreader has 2 auger conveyors and a conveyor belt.

4. Conclusions

Wood ash is a by-product from biomass cogeneration plants and boiler houses, while digestate is a by-product from biogas plants. Together, this is a valuable mixture of nutrients that add value to production by-products. Wood ash is produced by burning wood, while digestate is produced in the biogas fermentation process. The choice of such fertilizer raw materials is based on solving the problems related to reducing waste accumulation and more efficient use of existing resources. As a result, the benefit is not only from the environmental aspect, but also from the operation of farms in the circular circulation economy or bringing them closer to working in accordance with the environment.

The rational use of such by-products was realized by the application of the used technology.

References

Adekunle A.S., Ibitoye S.E., Omoniyi P.O., Jilantikiri L.J., Sam-Obu C.V., Yahaya T., Mohammad B.G., Olusegun, H.D. (2019) Production and Testing of Biogas Using Cow Dung, Jatropha and Iron Filins. *J. of Bioresources and Bioproducts*. vol.4, I. 3, 143-148. https://doi.org/10.12162/jbb.v4i3.002.

Amery F., Schoumans O.F. (2014). Agricultural Phosphorus Legislation in Europe. Institute for Agricultural and Fisheries Research ILVO. 45 P.Augusto, L., Bakker, M.R., Meredieu, C. (2008). Wood ash applications to temperate forest ecosystems - potential benefits and drawbacks. *Plant Soil*, 181–198 https://doi.org/10.1007/s11104-008-9570-z.

Comission of the European Communities, (1991). Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Off. J.EUR Union.

Fuchs W., Drosg, B. (2013). Assessment of the state of the art of technologies for the processing of digestate residue from anaerobic digesters. *Water Sci. Technol*. 67, p. 1984–1993.

Guilayn F., Jimenez J., Martel J.-L., Rouez M., Crest, M., Patureau D. (2019). First fertilizing-value typology of digestates: a decision-making tool for regulation. *Submitted to Waste Manag*, p. 67-79. DOI: 10.1016/j.wasman.2019.01.032

Ingerslev M., Skov, S., Sevel, L., Pedersen L.B. (2011). Element budgets of forest biomass combustion and ash fertilisation – a Danish case-study. *Biomass Bioenergy*, 35, p. 2697–2704. ttps://doi.org/10.1016/j.biombioe.2011.03.018.

Möller K., Müller T. (2012). Effects of anaerobic digestion on digestate nutrient availability and crop growth: a review. *Eng. Life Sci*. 12, p. 242–257.

Perkiomaki J., Fritze H. (2005). Cadmium in upland forests after vitality fertilization with wood ash - a summary of soil microbiological studies into the potential risk of cadmium release. Biol. Fertil. Soils 41, p. 75–84. https://doi.org/10.1007/s00374-004-0816-5.

Pitman R.M. (2006). Wood ash use in forestry - a review of the environmental impacts. *Forestry.* https://doi.org/10.1093/forestry/cpl041.

Silva F.C., Cruz N.C., Tarelho L.A.C., Rodrigues S.M. (2019). Use of biomass ash-based materials as soil fertilisers: critical review of the existing regulatory framework. *J. Clean. Prod*. 214, p. 112–124. https://doi.org/10.1016/j.jclepro.2018.12.268.

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The Efficiency of Using Innovative Soil Liming and Fertilizer Means in Winter Wheat Sowings

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Abstract

Field trials were conducted at the Study and Research Farm "Peterlauki" of the Latvia University of Life Sciences and Technologies from 2020 to 2023. Soil characteristics: sod - stagnogley soil Luvisols (according to FAO classification); granulometric composition – heavy dusty sand clay. Winter wheat sowings were established using different variants of a fertilizer mix with cattle (from JSC "Ziedi JP") manure digestate (D) and wood ash (P) (from LLC "Gren Jelgava") in different ratios. The norms of the innovative mixed fertilizer for cattle manure digestate and wood ash were 5, 10, and 20 t per ha. Unfertilized winter wheat plots were used as a control. Variants in the two-factor trial were randomized in triplicate. In the experiment, the influence of the researched factors on winter wheat grain yield, the content of protein, starch and gluten in grains, Zeleny index, grain volumetric weight (kg per hL), and the mass of 1000 grains were determined. The aim of the study was to determine the impact of biogas fermentation by-product (digestate) and cogeneration plant and boiler house residues (wood ash) on the yield and quality of winter wheat. Depending on the study variant, the winter wheat yield varied on average three years from 6.29 to 7.39 t per ha. It was established that the average winter wheat grain yield in the control variant was 5.05 t per ha, which is significantly ($p<0.05$) lower than in the variants using fertilizers of digestate and wood ash mixtures. Using digestate and wood ash mixtures, sufficiently high and high-quality winter wheat yields can be obtained without the use of mineral fertilizers. The mixtures of digestate and wood ash are an innovative fertilizer way for improving soil fertility, which is also suitable for winter wheat.

Keywords—digestate, wood ash, mixtures, winter wheat

1. Introduction

Winter wheat (*Tricum* aestivum L.) is considered to be one of the most important grain crops. Due to its high yielding and grain quality they are widely grown and used in food products all over the world. In general winter wheat productivity and yield quality can be affected by a variety of biotic, abiotic and anthropogenic factors, for example meteorological conditions, soil fertility, soil reaction, fertilizer use and various agricultural treatments. The most important measures for improving the productivity and yield quality of winter wheat are soil reaction improvements and plant fertilization. Proper use of various fertilizers not only ensures improvements in yield but also can reduce environmental pollution, thereby improving general quality of life (Hejcman et al., 2011; Jakab et al. 2019). Currently, to produce heat and energy biogas plants and solid fuel boilers are widely used with generating digestate and wood ash as by-products. In normal circumstances, these by-products need to be stored and disposed of which is a complex task that can often pose various environmental pollution risks. Both wood ash and biomass digestate are used as liming and fertilizing agents in agricultural sectors.

Agricultural production must be carried out in accordance with environmental protection requirements. It is important to maintain the safe use of fertilizers, especially nitrogen fertilizers, in the agricultural environment. About 180 million tons of anaerobic digestion digestate is produced in the European Union annually, most of which is used as organic fertilizer (Corden et al., 2019).

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Digestate, or fermentation residue, is produced as a by-product under anaerobic conditions in biogas plants and is considered one of the most valuable types of organic fertilizer. It contains valuable macro- and microelements and is a good fertilizer (Dubrovskis et al., 2012; Koszel et al., 2015).

Anaerobic digestion residues are products from various sources of organic raw materials, which include sewage treatment, plant sludge, agri-food industry waste (a part of household solid waste, including fruit and vegetable by-products, canteen waste, kitchen waste), green waste (agricultural and horticultural waste), animal waste (pig, cattle, etc., manure), and food waste (animal fat, used cooking oil, degreasing waste from restaurant tanks) (Bhatt et al., 2020). Digestate is rich in nutrients and can provide a large part of the nutrients needed by plants during the vegetation period, as well as improve soil structure.

The nutrients present in the digestate are in a form that is easily utilized by plants. Approximately 35–81% of the total nitrogen content in digestate is ammonia (NH_4) in a form available to plants. Also, digestate is a plant fertilizer competitive to mineral fertilizers. The organic substances present in digestate have a positive effect on the physical and chemical properties of soil and on the soil fertility in general (Comparetti et al., 2013).

Digestate performs several functions and plays a beneficial role in both improving the soil properties and promoting the plant growth. First of all, digestate contains nutrients necessary for plant growth and serves as a fertilizer that improves plant productivity. Secondly, digestate significantly affects the overall soil fertility and other important soil parameters. Digestate plays an important role in improving soil efficiency by ensuring the cycle of nutrients in the soil, carbon transformation, and maintenance of soil structure (Przygocka-Cyna et al., 2018). Field application of digestate could have less short-term results due to the slow mineralization or microbial activity (Abubaker et al., 2015).

In order to use digestate as an organic fertilizer, it is usually divided into a solid (dry) and a liquid fraction. They differ in dry matter content and chemical composition, which in turn can affect biomass production differently (Hjorth et al., 2010). In agricultural practice, digestate is often used as a fertilizer for crops grown for biomass production, especially for the production of biogas.

As a result of anaerobic fermentation processes, digestate can have higher nitrogen and other nutrient content compared to unfermented manure (Alburquerque et al., 2012; Li et al., 2018), which in turn can affect fertilizer efficiency and yield. Some short-term studies have found lower nitrogen use efficiency for organic fertilizers (slurry, digestate) compared to mineral fertilizers (Schröder, 2005), which is probably related to the risk of nitrogen losses due to leaching and ammonium emissions (Gutser et al., 2005; Sänger et al., 2014). However, long-term studies have observed a positive effect of organic fertilizer on crop yield, which depends not only on the amount of nitrogen applied to plants, but also on other aspects of organic fertilizer use related to changes in soil fertility (Sørensen, 2004; Schröder et al., 2007).The different results of studies on the effect of digestate on wheat yield are explained by the interaction of many factors, including dose and substrate type (Koszel et al., 2016; Abubaker et al., 2017). The effect of digestate on crop yield depends on many factors, such as soil properties, climatic conditions during the growing season, chemical composition of the digestate and application methods (Riva et al., 2016; Panuccio et al., 2018). Studies in England compared the effects of digestate and mineral fertilizers on winter wheat yield: the nitrogen rate for both types of fertilizer were N250 kg ha^{-1}. No significant differences in biomass and grain yield were found between the use variants of digestate (respectively 19.2 t ha^{-1} and 11.3 t ha^{-1}) and mineral fertilizers (respectively 19.6 t ha^{-1} and 11.6 t ha^{-1}). Also, when analyzing the protein content in grains, no significant differences were found between the use variants of digestate and mineral fertilizers (11.52% and 11.06%, respectively) (Udall et al., 2017). In other studies, when digestate fertilizer was used, a higher protein content was found in wheat grains compared to the mineral fertilizer variant, but no significant differences in starch content were found (Różylo et al., 2015). Due to the significant increase in the cost of mineral fertilizers and their more difficult availability, it is necessary to find alternatives to the use of mineral fertilizers and improve soil fertility as soon as possible.

Wood ash, a by-product of biomass combustion, can return important nutrients to the soil and prevent its acidification. Soil pH can be regulated by using various soil liming materials (e.g. dolomite flour, lime) or wood ash. In recent years, due to the increase in the volume of biomass combustion for heat production, the production of wood ash as a by-product has increased significantly. Wood ash consists of inorganic compounds from the obtained biomass, sand residues and a very small part of unburned organic material (Ingerslev et al., 2011). Thus, wood ash contains all inorganic macro- and microelements present in plant biomass, except N (Augusto et al., 2008; Demeyer et al., 2001). During combustion, various oxides are formed, and subsequent aeration leads to the formation of carbonates in the wood ash, which makes the ash highly alkaline, with a pH of 8 to 12 (Augusto et al., 2008). Unlike landfilling ash, recycling ash as a soil amendment returns important nutrients to the soil and prevents acidification (Pitman, 2006).

The aim of the study was to determine the impact of biogas fermentation by-product (digestate) and cogeneration plant and boiler house residues (wood ash) on the yield and quality of winter wheat.

2. Materials and Methods

A field trial was conducted at the “Peterlauki” Study and Research Farm (56°53' N, 23°71' E) of the Latvia University of Life Sciences and Technologies (LBTU) from 2020 to 2023. Soil characteristics: sod calcareous soil Luvisols (according to FAO classification); granulometric composition: heavy dusty sand clay. Soil agrochemical parameters: pH KCL 6.7 (LVS ISO 10390: 2006); organic matter content: 26 g kg^{-1} (by Tyurin method, LV ST ZM 80-91), the phosphorus (P_2O_5) and potassium (K_2O) level – 60 mg kg^{-1} and 144 mg kg^{-1}, respectively (according to Egner-Rhym method, LV ST ZM 82-97).

A two-factor experiment was set up: 1) mixtures of cattle manure digestate (from JSC “Ziedi JP”) (D) and wood ash (from LLC “Gren Jelgava”) (P) with different component proportions (D+P 1:0; D+P 1:1; D+P 2:1; D+P 3:1; D+P 3:1 + NPK 8-20-30 200 kg ha^{-1}, in autumn; D+P 3:1 + N 64 kg ha^{-1}, in spring; D+P 4:1); 2) different norms of mixtures used for fertilization (5 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1}). The nutrient content of the digestate and wood ash mixtures are given in Table 1.

TABLE I. TABLE 1 NUTRIENT CONTENT OF THE DIGESTATE AND WOOD ASH MIXTURES

Nutrients	Content in dry matter, %			
	D+P 1:0	*D+P 1:0*	*D+P 1:0*	*D+P 1:0*
Nitrogen in the natural sample (N)	0.29	0.27	0.30	0.51
Ammonium nitrogen (N/NH_4), g kg^{-1}	1.20	0.43	0.40	0.76
Phosphorus (P),	0.74	0.90	0.89	0.83
Potassium (K),	1.70	2.90	2.92	2.73

D –*cattle manure digestate*; P –*wood ash*

Winter wheat fields fertilized only with digestate were used as control variants. Variants in the experiment were arranged randomly, in three replications. The size of each individual plot in the replications was 30 m^2. Winter wheat pre-crop – fallow. All previously prepared mixtures of cattle digestate and wood ash were spread in the plots prepared before sowing. The mixtures were incorporated into the soil with the combined soil tiller “Farmet Kompaktomat K400”, which simultaneously crumbles and levels the soil while applying fertilizer. The winter wheat variety ‘Zeppelin’ was used for sowing; sowing rate – 500 germinating seeds per m^2. Sowing depth – 3–4 cm; row spacing – 12.5 cm. The experimental plots were sown with a seed-drill "Wintersteiger plotseed H”. In the spring, when vegetation was restored, 200 kg ha^{-1} ammonium nitrate (N 34.4%) was incorporated into the plots of the trial variant D+P 3:1+N.

Fig 1. Winter wheat sowings in field trials

Harvesting was carried out with a small-sized combine harvester "Sampo". After threshing of the experimental plots, the yield of each plot was weighed and cleaned using the "PFEUFFER SLN3" sample cleaning device. Qualitative indicators were determined at the Biotechnology Scientific Laboratory (BSL) of the Latvia University of Life Sciences and Technologies (LBTU). Using the express analyser "Infratec NOVA Foss", the moisture content of the samples, the total nitrogen and starch content in the grains (%), and the bulk density (kg hL^{-1}) were determined. Using the obtained result, the obtained yield (t ha^{-1}) was calculated at 14% standard moisture and complete (100%) sample purity. For the samples, the weight of 1000 seeds, in grams, was also determined using the standard method (LVS EN ISO 520).

The meteorological conditions in all three trial years differed from the long-term average. Autumn 2020 was long and cool, 2021 was relatively warm and dry, and 2022 was similarly warm and dry. All winters during the trial period were mild and favourable for winter wheat. Vegetation re-emerged in all years in early April.

Spring 2021 was warm with sufficient moisture; summer was rainy, especially with high precipitation in July, but precipitation decreased in August.

Spring 2022 was moderately warm and humid; however, summer in June and August was dry, with high precipitation in July.

Spring 2023 was warm with low precipitation, but summer in June and August was dry.

The data were statistically analysed using a two-way analysis of variance (ANOVA) with different norms of mixtures and different component proportions in mixtures as factors, and the difference among means was detected by LSD at the $p < 0.05$ probability level (Excel for Windows, 2003).

3. Results and discussion

Winter wheat grain yield. All studied factors showed a significant effect on grain yield. All used digestate and wood ash rates, starting from the lowest (5 t ha^{-1}) to the highest (20 t ha^{-1}), significantly affected the increase in grain yield compared to the control. On average, the winter wheat yield in the study variants over the three years was 6.29-7.39 t ha^{-1}. This was 1.24 -2.34 t ha^{-1} or 24.6-46.3% more than in the control variant (without fertilizer). During the research years, winter wheat yield, depending on the research variants, varied from 4.26 to 9.40 t ha^{-1} (Table 2).

TABLE 2 THE EFFECT OF DIGESTATE AND WOOD ASH MIXTURES ON WINTER WHEAT GRAIN YIELD, T HA^{-1}

Fertilizer rate, t ha^{-1} (FA)	Digestate and wood ash ratio in the mixture, D+P (FB)	Years of field trials			On average in three trial years
		2021	*2022*	*2023*	
5	1: 0	7.40	4.83	4.26	5.85

Fertilizer rate, t ha^{-1} (FA)	**Digestate and wood ash ratio in the mixture, D+P (FB)**	**Years of field trials**			**On average in three trial years**
		2021	***2022***	***2023***	
	1: 1	7.30	5.33	4.28	5.86
	2: 1	7.40	5.92	4.69	6.11
	3: 1	7.20	5.05	4.55	6.14
	3: 1+NPK	7.40	6.10	4.69	6.32
	3: 1+N	8.50	7.88	7.39	7.96
	4:1	7.40	5.36	4.31	5.79
	On average	**7.51**	**5.78**	4.88	**6.29**
10	1: 0	8.50	4.78	5.06	5.76
	1: 1	8.30	5.00	5.69	6.11
	2: 1	8.50	5.15	5.59	6.30
	3: 1	8.60	5.28	5.38	5.88
	3: 1+NPK	8.60	5.67	5.41	6.30
	3: 1+N	9.20	7.29	7.79	8.06
	4:1	7.90	5.16	5.31	6.02
	On average	**8.51**	**5.48**	**5.75**	**6.35**
20	1: 0	7.90	5.02	6.53	6.48
	1: 1	8.00	5.76	6.58	6.78
	2: 1	7.90	6.63	6.60	7.04
	3: 1	7.90	6.89	7.12	7.30
	3: 1+NPK	8.10	7.02	7.38	7.50
	3: 1+N	9.40	8.31	9.03	8.91
	4:1	7.80	8.33	7.10	7.74
	On average	**8.14**	**6.85**	**7.19**	**7.39**
Control	0 :0	**6.80**	**4.31**	**4.03**	**5.05**
$LSD_{0.05}$ A		0.24	0.53	**0.39**	**0.39**
$LSD_{0.05}$ B		0.39	0.86	**0.59**	0.61
$LSD_{0.05}$ AB		0.68	1.49	1.02	1.06

D- cattle manure digestate, P- wood ash

The results showed that the average yield of wheat grain in all three years of the study was very high at all studied fertilizer rates, when mineral nitrogen was added to the digestate and wood mixture, variant 3:1+N., The grain yield in this variant was on average 7.96-8.91 t ha^{-1} but the lowest yields were obtained in the variant with a digestate-ash ratio of 1:0, in which ash was not used (Table 2). This can be explained by the fact that digestate and wood ash mixtures, as fertilizer, provide plants mainly with phosphorus and potassium and a nitrogen deficiency is observed. The trends in the influence of the ratio of digestate and wood ash in the mixtures on wheat grain yield were the same in all years of the study. Better results were obtained when this ratio was 3:1.

Grain yield depended on the amount of fertilizer used, as well as the digestate and wood ratio in the mixture (Table 2). The fertilizer rate significantly ($p<0.05$) increased the winter wheat yield in 2021 – on average by 0.71-1.34 t ha^{-1} or 5,20-19,70 %, compared to the unfertilized control variant. In this year, significant grain yields were obtained in all studied variants compared to 2022 and 2023. The lower grain yield in these years is explained by unfavorable meteorological conditions, when a very severe drought was observed precisely during the grain formation period. Using wood ash and digestate mixtures, it is possible to significantly ($p<0.05$) increase the grain yield of winter wheat.

Wheat grain's chemical composition makes it a staple crop with versatile uses in various food products worldwide. Wheat grain consists primarily of carbohydrates (70–75%), mainly in the form of starch, followed by protein (10–15%), fats (1–2%), vitamins (such as B-vitamins), minerals (like iron and magnesium), fiber (2–3%), and water (10–15%) (Simon et.al.,2020; Khalid et. al.2023).

The applied fertilizer rate had a significant ($p<0.05$) effect on the following wheat quality indicators: protein content, gluten content, starch content in dry matter, Zeleny index, volume weight and 1000-grain weight.

Protein (CP) content of winter wheat grain. Protein content in grain is the most important indicator of wheat grain quality. Wheat proteins, particularly gluten, play a significant role in determining the dough's strength, elasticity, and extensibility, which ultimately determine the quality of baked products (Ooms et al., 2019). The gluten proteins contribute to the structure of bread by forming a strong and elastic network that traps gases produced by yeast during fermentation, leading to a well-risen and airy bread.

The control variant had an average protein content of 9.52% versus the average protein content of wheat grain was significantly higher ($p<0.05$) with any fertilizer variant, ranging from 10.02% to 11.94%. The highest protein content – was obtained from plots fertilized with D+P 3:1 + N 64 kg ha^{-1}. Among fertilized rates significantly higher average protein content of 12.4% was obtained from plots fertilized with variant of 10 t ha^{-1}.

Significantly higher protein content in dry matter was found when using lower (5 and 10 t ha^{-1}) fertilizer rates, while the lowest indicators were found when using a 20 t ha^{-1} fertilizer rate (Table 3).

TABULA 3 EFFECT OF DIGESTATE AND WOOD ASH MIXTURE ON PROTEIN CONTENT IN WINTER WHEAT GRAINS, %

Fertilizer rate, t ha^{-1} (FA)	Digestate and wood ash ratio in the mixture, D+P(FB)	Years of field trials			On average in three trial years
		2021	*2022*	*2023*	
5	1: 0	11.00	11.07	9.40	10,49
	1: 1	11.40	10.23	9.50	10,38
	2: 1	10.70	10.83	9.40	10,31
	3: 1	11.00	10.90	9.27	10,39
	3: 1+NPK	10.70	10.67	9.13	10,17
	3: 1+N	14.60	10.57	10.53	11,90
	4:1	10.80	10.83	9.40	10,34
	On average	**11.46**	**10.73**	**9.52**	**10,57**
10	1: 0	12.10	10.17	8.50	10,26
	1: 1	12.00	9.90	9.07	10,32
	2: 1	12.20	10.90	8.40	10,50
	3: 1	12.10	9.93	9.17	10,40

Fertilizer rate, t ha^{-1} (FA)	**Digestate and wood ash ratio in the mixture, D+P(FB)**	**Years of field trials**			**On average in three trial years**
		2021	***2022***	***2023***	
	3: 1+NPK	12.80	9.97	8.53	10,43
	3: 1+N	14.30	10.37	10.77	11,81
	4:1	11.60	10.63	8.17	10,13
	On average	**12.44**	**10.27**	**8.94**	**10,55**
20	1: 0	10.50	10.67	9.63	10,27
	1: 1	10.50	9.80	10.00	10,10
	2: 1	10.30	9.97	9.80	10,02
	3: 1	10.70	10.50	10.33	10,51
	3: 1+NPK	11.10	10.17	9.87	10,38
	3: 1+N	13.80	10.80	11.23	11,94
	4:1	10.90	10.13	10.07	10,37
	On average	**11.11**	**10.29**	**10.13**	**10,51**
Control	0 :0	**10.4**	**10.13**	**8.02**	**9.52**
LSD $_{0.05}$ A		0.31	0.24	0.21	**0.24**
LSD$_{0.05}$ B		0.50	0.31	0.29	0..32
LSD $_{0\text{-}05}$ AB		0.68	0.42.	0.38	0.44

D- cattle manure digestate, P- wood ash

The standards for food quality wheat grain CP content are from 12% (https://dzirnavnieks.lv/lv/graudu-piegadatajiem). To achieve higher protein more nitrogen is required to fulfil the higher demand. Grain protein with optimum N for yield in feed wheat is consistently around 11% (equivalent to 1.9% N). However, bread making wheat optimizes for yield at around 12% protein and will often need extra nitrogen to achieve a market specification of over 13%. Low grain protein i.e. less than 10% for feed varieties, indicates sub-optimal nitrogen use.

Conditions of growing season affected significantly the grain protein content. In all studied variants, on average, the highest protein content was observed in growing season 2020/2021 (11.11- 11.46 %). In this year, the plants were better secured with moisture and contributed to better use of the nutrients from the soil. Lower protein content in the grains was observed during the growing season 2021/2022 (10.27- 107.3%) and 2022/2023 (8.94 - 10.13%).

Gluten content of winter wheat grain. An important indicator of the baking properties of bread is the gluten content in wheat grains. Wheat grains with a gluten content higher than 23% are suitable for baking bread. The gluten and its resulting functions are essential to determining the dough quality of bread and other baked products such as pasta, cakes, pastries, and biscuits. Gluten is heat stable and has the capacity to act as a binding and extending agent and is commonly used as an additive in processed foods for improved texture, flavor, and moisture retention (Biesiekierski, 2017).

The amount and quality of gluten are one of the physical indicators of the quality requirements of cereals, for example, for good white bread, wheat flour with at least 23% gluten is required. The quality of wheat gluten is determined by the ratio of the amino acid groups gliadin and glutenin, which should be optimally 1:1.2. Of these, gliadin provides the dough with stretchability, and glutenin — elasticity and firmness (Zarins et al., 2015).

Gluten content (%) in grains significantly ($p<0.05$) differed depending on the year of the study, and a trend for differences depending on the fertilizer rates and mixture composition was observed. Gluten content had a significant close relationship with protein content. Significant differences in gluten content existed between all study years, the highest gluten content was in 2021 – 24.01-27.19%, followed by 2022 – 18.14-19.58%, and 2023 – 15.53 -17.77 percent. The highest gluten content was in variant 3: 1+N at all fertilizer rates. The average for the three years was 23.46 percent (Table 4).

TABLE 4 EFFECT OF DIGESTATE AND WOOD ASH MIXTURE ON GLUTEN CONTENT IN WINTER WHEAT GRAINS, %.

Fertilizer rate, t ha^{-1} (FA)	Digestate and wood ash ratio in the mixture, D+P (FB)	Years of field trials			On average in three trial years
		2021	***2022***	***2023***	
5	1: 0	22.90	20.67	16.10	19.89
	1: 1	24.10	18.13	16.27	19.50
	2: 1	22.10	20.17	16.07	19.45
	3: 1	22.90	20.00	15.63	19.51
	3: 1+NPK	21.80	19.43	15.73	18.99
	3: 1+N	32.20	19.03	18.80	23.34
	4:1	22.10	19.60	15.93	19.21
	On average	**24.01**	**19.58**	**16.36**	19.98
10	1: 0	26.80	17.93	14.67	19.80
	1: 1	25.60	17.13	15.77	19.50
	2: 1	27.00	20.00	14.53	20.51
	3: 1	25.60	17.00	15.47	19.36
	3: 1+NPK	28.80	17.27	14.53	20.20
	3: 1+N	32.00	18.47	19.53	23.33
	4:1	24.50	19.20	14.23	19.31
	On average	**27.19**	**18.14**	**15.53**	20.29
20	1: 0	21.30	19.23	16.73	19.09
	1: 1	21.20	16.80	17.40	18.47
	2: 1	20.40	17.33	16.97	18.23
	3: 1	21.60	18.70	18.10	19.47
	3: 1+NPK	23.30	18.10	16.97	19.46
	3: 1+N	30.50	19.93	20.70	23.71
	4:1	22.50	17.83	17.50	19.28
	On average	**22.97**	**18.27**	**17.77**	19.67
Control	0 :0	**21.3**	**17.04**	14.01	**17.45**
$LSD_{0.05}$ A		0.94	0.81	**0.74**	**0.86**

Fertilizer rate, t ha^{-1} (FA)	Digestate and wood ash ratio in the mixture, D+P (FB)	Years of field trials			On average in three trial years
		2021	*2022*	*2023*	
$LSD_{0.05}$ B		1.15	1.02	**1.13**	1.18
LSD $_{0\text{-}05}$ AB		1.85	1.54	1.97	1.74

D- cattle manure digestate, P- wood ash

The required amount of gluten and/or the optimal ratio of gliadin to glutenin in grains may not be formed due to adverse weather conditions, lack of nutrients, plant diseases, premature grain harvesting, and other reasons (Kunkulberga et al., 2010).

The results of our trial show that the control variant had a gluten content of 17.45%, while the different fertilizer treatments had significantly ($p<0.05$) higher average gluten content of winter wheat grain, ranging from 19.67 to 20.29% depending on fertilizer rate and mixture composition ($p<0.05$). Similarly to protein content, also gluten content in grain increased significantly fertilizer rate 5 t ha^{-1} and the next significant increase was secured by10 t ha^{-1}. The lowest border of food demand of gluten content was obtained when fertilizer rate 20 t ha^{-1} was used. The highest gluten content was obtained for the variants fertilized with fertilizer mixtures D+P 3:1 + N 64 kg ha^{-1}.

These results are in agreement with other studies that determined nitrogen fertilization has a positive impact on gluten content of grain and the content of nitrogen substances is closely related to the gluten content in grain (Kozlovsky et al., 2009).

Results show that the growing season also had a significant impact on gluten content, and explanation can be the same as for protein content.

Zeleny index. Zeleny index or sedimentation value, determines quantity and quality of gluten proteins (Kozlovsky et al., 2009). Evaluation of the data regarding Zeleny index showed that in the control variant the Zeleny index was 24.32 mL and with the addition of any fertilizer variants the Zeleny index increased significantly ($p<0.05$) from 20.58 to 41.60.1 mL (Table 5). In all the study years, the highest Zeleny index, on average 37.06 mL, was obtained from the D+P 3:1 + N 64 kg ha^{-1} fertilizer variants. Among the fertilizer norms of 5, 10 un 20 t ha^{-1} a significantly higher ($p<0.05$) mean Zeleny index compared to control plots was obtained, while the highest mean Zeleny index value 37.66 mL was obtained from fields where 10 t ha^{-1} fertilizer norms were used.

The growing season affected the Zeleny index significantly. More favorable conditions for higher Zeleny index formation were in 2020/2021 when also the highest average protein content in grain accumulated.

TABULA 5 EFFECT OF DIGESTATE AND WOOD ASH MIXTURE ON ZELENY INDEX IN WINTER WHEAT GRAINS, ML

Fertilizer rate, t ha^{-1} (FA)	Digestate and wood ash ratio in the mixture, D+P (FB)	Years of field trials			On average in three trial years
		2021	*2022*	*2023*	
5	1: 0	33.3	26.15	26.00	28.48
	1: 1	34.6	20.6	26.15	27.12
	2: 1	31.3	24.09	26.08	27.16
	3: 1	31.9	24.06	25.94	27.30
	3: 1+NPK	31.4	23.36	25.74	26.83
	3: 1+N	55.5	21.68	32.80	36.66
	4:1	31.5	23.57	26.39	27.15
	On average	**35.64**	**23.36**	**27.01**	28.67

Fertilizer rate, t ha^{-1} (FA)	Digestate and wood ash ratio in the mixture, D+P (FB)	Years of field trials			On average in three trial years
		2021	***2022***	***2023***	
10	1: 0	39.3	19.88	22.99	27.39
	1: 1	37.9	18.85	25.04	27.26
	2: 1	40.2	23.86	24.08	29.38
	3: 1	38.9	18.68	24.41	27.33
	3: 1+NPK	43.7	19.38	23.99	29.02
	3: 1+N	55.1	22.58	35.29	37.66
	4:1	36.1	22.66	21.85	26.87
	On average	**41.60**	**20.84**	**25.38**	29.27
20	1: 0	31.1	22.15	28.75	27.33
	1: 1	30.0	17.9	29 .50	23.95
	2: 1	29.3	19.41	28.04	25.58
	3: 1	31.0	21.55	31.16	27.90
	3: 1+NPK	32.6	19.91	28.06	26.86
	3: 1+N	49.8	23.42	37.35	36.86
	4:1	32.8	19.69	29.94	27.48
	On average	**33.80**	**20.58**	**30.55**	28.31
Control	0 :0	**29.60**	**19.04**	**21.14**	24.32
$LSD_{0.05}$ A		1.62	1.34	1.69	1.52
$LSD_{0.05}$ B		2.64	2.07	2.58	2.34
$LSD_{0.05}$ AB		4.57	3.89	4.47	4.15

D- cattle manure digestate, P- wood ash

Starch content. Starch constitutes the major carbohydrate in the endosperm of wheat grains and serves as a multifunctional ingredient for the food or nonfood industries. Starch plays a significant role in the texture, stability, appearance, and nutritional value of food products. (Ai et al., 2018; Shevkani et al., 2017). Starch, as the main component of wheat comprising about 60–75 % of grain and 70–80 % of flour, has a number of food and industrial applications (Shevkani et al., 2017). Starch comprises the main source of calories in bread and other wheat-based food products.

In all the years of the study, the effect of the composition of the digestate and wood ash mixtures and the fertilizer rates did not differ significantly between the studied variants. The total starch content in analysed wheat fertilizer variants ranged from 66.35 to 70.80%, with an average 69.70 percent (Table 6).

Analysis of the results of winter wheat grains showed that the starch content in the control variant was 70.32%, while the use of any fertilizer variant minimally changed the starch content in the range from 61.68 to 71.60 percent.

TABULA 6. EFFECT OF DIGESTATE AND WOOD ASH MIXTURE ON STARCH CONTENT IN WINTER WHEAT GRAINS, %

Fertilizer rate, t ha^{-1} (FA)	**Digestate and wood ash ratio in the mixture, D+P (FB)**	**Years of field trials**			**On average in three trial years**
		2021	***2022***	***2023***	
5	1: 0	70.97	67.53	71.40	69.97
	1: 1	70.63	68.57	71.37	70.19
	2: 1	71.27	67.53	71.47	70.09
	3: 1	71.10	67.67	71.43	70.07
	3: 1+NPK	71.07	68.20	71.50	70.26
	3: 1+N	66.33	61.68	71.03	66.35
	4:1	71.20	69.57	71.63	70.80
	On average	**70.37**	**67.25**	**71.40**	**69.67**
10	1: 0	70.33	68.47	71.60	70.13
	1: 1	69.93	68.93	71.23	70.03
	2: 1	69.77	67.43	71.93	69.71
	3: 1	69.77	68.90	71.30	69.99
	3: 1+NPK	69.10	68.73	71.50	69.78
	3: 1+N	66.60	62.54	70.87	66.67
	4:1	70.67	68.96	70.83	70.15
	On average	**69.45**	**67.71**	**71.32**	**69.49**
20	1: 0	71.53	67.90	71.07	70.17
	1: 1	71.40	68.70	71.10	70.40
	2: 1	71.70	68.90	71.20	70.60
	3: 1	71.40	68.03	70.80	70.08
	3: 1+NPK	71.10	68.10	70.87	70.02
	3: 1+N	67.53	67.60	70.07	68.40
	4:1	71.27	68.03	70.70	70.00
	On average	**70.85**	**68.18**	**70.83**	**69.95**
Control	0 :0	**71.60**	**68.10**	**71.25**	**70.32**
LSD $_{0.05}$ A		0.29	0,18	0.25	0.22
LSD$_{0.05}$ B		0.48	0.31	0.39	0.37
LSD $_{0\cdot05}$ AB		0.83	0.48	0.67	0.59

D- cattle manure digestate, P- wood ash

The lowest average starch content of 66.8% was obtained from fertilizer variant D+P 3:1 + N 64 kg ha^{-1}. Addition of mineral nitrogen to the digestate and wood mixture fertilizer in all years of the trial reduced the starch content in wheat grains. Our study confirmed the negative relationship between protein and starch content in grain once more: protein content decreased if starch content increased. All obtained starch results depending on mentioned factors were opposite to protein content.

Among the fertilizer rates applied, lower starch content was in the trial fields where norm of 10 t ha^{-1} was used. Starch constitutes the major carbohydrate in the endosperm of wheat grains and serves as a multifunctional ingredient for the food or nonfood industries. Starch plays a significant role in the texture, stability, appearance, and nutritional value of food products. (Ai, Jane, 2018; Shevkani et al., 2017). Starch, as the main component of wheat comprising about 60–75 % of grain and 70–80 % of flour, has a number of food and industrial applications (Shevkani et al., 2017). Starch comprises the main source of calories in bread and other wheat-based food products.

Volume mass. It is an indicator of flour outcome at milling enterprise (Kozlovsky at al., 2009). Grain volume indicates grain density. This is mainly determined by the genetic characteristics of the varieties, but improper fertilization of the plants can reduce it. Higher volume weight indicates better grain maturation and richness with nutrients.

Our experiments have shown that using digestate and wood ash mixtures for fertilizing wheat crops can produce high-quality grains with a bulk density of 73-75 kg hL^{-1}, which is comparable to the bulk density of wheat.

Weight of 1000 grains. In the control variant, the weight per 1000 seeds was 39,9g and using different type of fertilizers it is possible to increase 1000 seed weight. Fertilized fields had 1000 seed weight of 40.8 till 43.5g. Significantly ($p<0.05$) higher 1000 seed weights were obtained with 10 or20 t ha^{-1} fertilizer norms.

4. Conclusions

Mixtures of digestate and ash can be used to produce high quality fertilizers, which can increase the productivity of various crops, including winter wheat.

The mixtures of digestate and wood ash are an innovative way for improving the soil fertility.

The results of the study showed that using digestate and wood ash mixtures, sufficiently high and high-quality winter wheat yields can be obtained without the use of mineral fertilizers. Significantly higher ($p<0.05$) winter wheat grain yield was obtained in the variant D+P 3:1 + N and D + P 3:1 + NPK.

It has been observed that to improve the quality of the winter wheat harvest, in addition to this fertilizer, it is recommended to use nitrogen mineral fertilizers.

It has been found that among the studied variants, significantly higher protein and gluten content, as well as Zeleny index, was provided by the fertilizer mixture D + P 3:1 + N, regardless of the fertilizer rate.

References

Abubaker J., Elnesairy N., Ahmad S. (2017). Effects of non-digested and anaerobically digested farmyard manures on wheat crop cultivated in desert soil. *Journal of Arid Land*, 3, p. 1–10.

Abubaker J., Risberg K., Jönsson E., Dahlin A.S., Cederlund H., Pell M. (2015). Short-term effects of biogas digestates and pig slurry application on soil microbial activity. *Applied and Environmental Soil Science*. Available: https://www.hindawi.com/journals/aess/2015/658542/ (viewed 18.02.2024).

Ai Y., Jane, J. (2018). Understanding starch structure and functionality. In Starch in Food, p. 151-178. Woodhead Publishing. https://dx.doi.org/10.1016/B978-0-08-100868-3.00003-2

Alburquerque J. A., Fuente C., Ferrer-Costak A., Carrasco L., Cegarra J., Abad M. (2012). Assessment of the fertiliser potential of digestates from farm and agroindustrial residues. *Biomass Bioenergy*, 40, p. 181–189.

Augusto, L., Bakker M. R., Meredieu C. (2008). Wood ash applications to temperate forest ecosystems—potential benefits and drawbacks. *Plant and Soil*. Vol. 306, No. 1/2, Part I: Special Issue, p. 181-198.

Biesiekierski J. R. (2017). What Is Gluten? J. Gastroenterol. Hepatol. 32 (Suppl. S1), p. 78–81. doi: 10.1111/jgh.13703.

Bhatt A.H., Tao L. (2020). Economic perspectives of biogas production via anaerobic digestion.

Demeyer A., Nkana J.C.V, Verloo M.G. (2001). Characteristics of wood ash and influence on soil properties and nutrient uptake: an overview. *Bioresour Technol*, Vol.77, p. 287–295

Comparetti A., Febo P., Greco C., Orlando S. (2013). Current state and future of biogas and digestate production. *Bulgarian Journal of Agricultural Science*, 19, p. 1–14.

Corden C., Bougas K., Cunningham E., Tyrer D., Kreißig J., Crookes M. (2019). Digestate and Compost as Fertilisers: Risk Assessment and Risk Management Options. Wood Environment & Infrastructure Solutions UK Limited; Aberdeen, UK. Available: https://ec.europa.eu/environment/chemicals/reach/pdf/40039 Digestate and Compost RMOA—Final report i2_20190208.pdf. (viewed 20.02.2024).

Dubrovskis V., Adamovics A. (2012). Bioenerģijas horizonti. Jelgava. p. 352.

Gutser R., Ebertseder T., Weber A., Schraml M., Schmidhalter U. (2005). Short-term and residual availability of nitrogen after long-term application of organic fertilizers on arable land. *Journal of Plant Nutrition and Soil Science*, 168, p. 439–446.

Ingerslev M., Skov S. Sevel L and. Pedersen L. B. (2011). Element budgets of forest biomass combustion and ash fertilization – A Danish case-study. *Biomass and Bioenergy*. Vol. 35(7), p. 2697-2704.

Hjorth M., Christensen K. V., Christensen M. L., Sommer S. G. (2010). Solid-liquid separation of animal slurry in theory and practice. *Agronomy for Sustainable Development*, 30, p.153–180.

Hejcman M., Ondracek J., Smrz Z. (2011). Ancient waste pits with wood ash irreversibly increase crop production in Central Europe. *Plant and Soil*. Vol. 339 (1), p. 341 – 350.

Jakab P., Festo D., Zoltan G., Komarek L. (2019). The effect of different fertilizer tratments on the yield and quality of winter wheat. *Review on Agriculture and Rural Development*. Vol. 6 (1 – 2), p. 182 – 187.

Kozlovský O., Balík J., Černý J., Kulhánek M., Kos M., Prášilová M. (2009). Influence of nitrogen fertilizer injection (CULTAN) on yield, yield components formation and quality of winter wheat grain. *Plant, Soil and Environment*. 55 (12), p. 536-543

Koszel M., Kocira A., Lorencowicz E. (2016). The evaluation of the use of biogas plant digestate as fertilizer in alfalfa and spring wheat cultivation. *Fresenius Environmental Bulletin*, 25, p. 3258–3264.

Kunkulberga D., Segliņš V. (2010). Maizes ražošanas tehnoloģija (Bread production technology). Rīga : RTU izdevniecība, p. 53—54. (in latvian)

Li X., Yun S., Zhang C., Fang W., Huang X., Du T. (2018). Application of nano-scale transition metal carbides as accelerants in anaerobic digestion. International Journal of Hydrogen Energy, 43, p.1926–1936.

Ooms N., Delcour J.A. (2019). How to Impact Gluten Protein Network Formation during Wheat Flour Dough *Making. Curr. Opin. Food Sci*. 25:88–97.

Panuccio M.R., Papalia T., Attina E., Giuffre A., Muscolo A. (2018). Use of digestate as an alternative to mineral fertilizer: effects on growth and crop quality. Archives of Agronomy and Soil Science, 65, p. 700–711.

Pitman R. M. (2006). Wood ash uses in forestry – a review of the environmental impacts. Forestry, Vol. 79, p. 563 – 586.

Przygocka-Cyna K., Grzebisz W. (2018). Biogas digestate – benefits and risks for soil fertility and crop quality – an evaluation of grain maize response. Open Chemistry, 16 (1), p. 258-271.

Riva C., Orzi V., Carozzi M., Acutis M., Boccasile G., Lonati S., Tambone F, D'Imporzano G., Adani F. (2016). Short-term experiments in using digestate products as substitutes for mineral (N) fertilizer: agronomic performance, odours, and ammonia emission impacts. *Science of The Total Environment*, 547, p. 206–214.

Różyło K., Gawlik-Dziki U., Swieca M., Różyło R., Pałys E. (2015). Winter wheat fertilized with biogas residue and mining waste - yielding and the quality of grain. *Journal of the Science of Food and Agriculture*, 96 (10), p. 3454–3461.

Sänger A., Geisseler D., Ludwig B. (2014). C and N dynamics of a range of biogas slurries as a function of application rate and soil texture: a laboratory experiment. *Archives of Agronomy and Soil Science*, 60, p.1779–1794. Available: https:10.1080/03650340.2014.907491 (viewed 06.09.2023).

Schröder J., Uenk D., Hilhorst G.J. (2007). Long-term nitrogen fertilizer replacement value of cattle manures applied to cut grassland. Plant Soil, 299, p. 83–99.

Shevkani K., Singh N., Bajaj R., Kaur A. (2017). Wheat starch production, structure, functionality and applications—a review. *International Journal of Food Science & Technology*, 52(1), p. 38-58.

Sørensen P. (2004). Immobilisation, remineralisation and residual effects in subsequent crops of dairy cattle slurry nitrogen compared to mineral fertiliser nitrogen. *Plant Soil*, 267, p. 285–296.

Udall D., Rayns F., Charlesworth S. (2017). The Potential of Biochar and Anaerobic Digestate use in a Temperate Conventional Wheat Production System. *International Journal of Research in Agriculture and Forestry*, 4(10), p. 44-49.

Zariņš Z., Neimane L., Bodnieks E. (2015) Uztura mācība (6. pārstrādātais un papildinātais izd.) (Nutrition education (6th revised and supplemented ed.)). Rīga: LU Akadēmiskais apgāds, p.113. (in latvian)

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Honey production in Latvia

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Abstract

The geographical position of Latvia is favorable for obtaining high-quality honey. The beekeeping industry is one of the modern agricultural production sectors in Latvia. Honey from various flowers can be obtained in Latvia. The aim of the study is to assess the potential for honey production in Latvia. Research methods: 1) analysis of honey production data, 2) review of various information sources. On average, 1256.811±0.426 tons of honey are obtained in Latvia per year (time period 1923-1937 and 1997-2023). Since 2019, honey exports in Latvia have exceeded imports. The greater the amount of honey produced in Latvia, the greater the amount of honey exported. The amount of honey exports increased, especially in 2021. It is possible that this was also facilitated by the formation of beekeepers' cooperatives. The amount of imports also increased, which could be explained by the decrease in the solvency of the population, i.e., imported honey is much cheaper than local honey. In Latvia (2018), honey was exported at a price 2.1 times higher than imported, but in 2019, the difference between export and import prices was only 1.3 times. There is a trend in Latvia where there are many small beekeepers in the honey extraction sector, for whom it is an additional source of income or a hobby. However, both the number of bee colonies and the amount of honey produced are increasing every year. Latvian beekeepers can produce high-quality products, but honey production can be increased by moving bees to nectar-rich pastures and diversifying production types by developing monofloral honey production.

Keywords: honey yield, tips of honey, Latvia, export, import

1. Introduction

The beekeeping industry is not only one of the modern agricultural production sectors in Latvia, but also an occupation rich in traditions, and one of the oldest (LR ZM, 2024). In Latvia, colonies of various subspecies of Western honeybees (Apis mellifera L.) are used in beekeeping (LR ZM, 2021). The Latvian native honeybee (Apis mellifera mellifera L.), or the European (Western European) dark bee, appeared 8,000 years ago (Liepniece et al., 2017). Bumblebees can also collect honey, which has a much higher content of enzymes, microelements, and vitamins compared to bee honey, i.e., 100 g of bumblebee honey replaces 1 kg of bee honey when comparing the content of enzymes, microelements, and vitamins (Dimiņš et al., 2022). In addition, in northern regions, including Latvia, during the short flowering period of nectar plants, nectar is released more concentrated and richer in biologically active substances than in southern regions (LR ZM, 2021). Honey contains antioxidants, which are higher in bee honey than in bumblebee honey (Dimiņš et al., 2022). The main components of honey are various carbohydrates, the most important of which are glucose and fructose (Šteiselis, 2024: 157). However, it should be noted that for beekeeping products, impurities that occurred during product collection are not desirable (Jayapal et al.,). Honey obtained in Latvia is polyfloral, containing a wide spectrum of biologically active substances (ZM, 2022). Bees can also collect so-called honeydew honey, which is a sweet liquid of plant origin that oozes through leaves, branches or plant stems (Ritmanis, 1992; 222). Honey is a natural product that has a wide range of applications, for example, in food, apitherapy. In recent years, beekeepers have also used honey to feed bees. Various by-products are also obtained from the honey production process, such as bee bread and beeswax candles.

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According to the information provided by the Agricultural Data Center (LDC), in 2023, there were 4,723 registered beekeepers with 117,657 bee colonies. Compared to 2022, the number of beekeepers has increased by 35% and the number of bee colonies by 12% (LR ZM, 2024).

Research problem: Analysis of the potential for honey production in Latvia is an important factor in assessing the volume of honey production in Latvia and possible sales opportunities. Research object: honey production in Latvia. Research subject: honey production potential in Latvia. Research question: What is the potential for honey production in Latvia. The aim of the research is to assess the potential for honey production in Latvia. The medicinal and gastronomic properties of honey are an important factor in its application in various sectors. There is a trend in Latvia where there are many small beekeepers in the honey extraction sector, for whom it is an additional source of income or a hobby, because in Latvia (LR ZM, 2024)) in 2023, most (28%) were beekeeping establishments with 21 to 50 bee colonies, 22% were establishments with 11–20 bee colonies, 20% were establishments with 6–10 bee colonies and 21% of establishments with one to five bee colonies. It is important to assess the real potential for honey extraction in Latvia. Otherwise, a shortage of supply may arise, as a result of which it will not be possible to ensure demand. However, there is also a risk of the opposite situation, that supply will exceed demand, therefore it is important to also explore possible sales opportunities and how to increase honey sales.

2. Materials and Methods

A literature review was chosen as a research method because it can summarize and synthesize previous research. The study collected information on honey harvest in Latvia (time period 1923-1937 and 1997-2023), exports, imports (Fig. 2 - Fig. 5), using the Latvian Statistics Portal (Latvijasportāls, 2025), (Statistikas portals, 2019), the Ministry of Agriculture's Agricultural Annual Reports (LR ZM, 2001)-(LR ZM, 2024), as well as to find out what honey is (Table 1) and what are its types (Fig. 1), because a literature review is also equivalent to practical research (Snyder, 2019).

Data processing was performed using aprakstošas statistikas elementi (mean values, standard deviation, regression coefficient, regression equation) in the “Microsoft Excel” computer program.

3. Results and discussion

In Latvia, since 1937, both the number of bee colonies, the total honey yield (Fig.2), and honey consumption per person per year have been decreasing. In 1936, one person ate an average of 1.8 kg of honey, but in 2016, a rural person – 0.62 kg and a city person – 0.92 kg of honey per year, but in 2009 – 1.2 kg. (Statistikas portāls, 2019) (LR ZM, 2010).

Honey has different definitions both in regulatory acts, in various dictionaries, and in scientific publications (Table 1). Definitions 1-5, 7, 11-13 indicate that honey is a sweet substance, while definitions 6, 9, 10 indicate that honey is a food product, and definition 8 indicates that it is a source of energy.

TABLE 1 DEFINITIONS OF HONEY

No.	Honey is…	Information source
1.	...a sweet, aromatic sugar substance that honey bees have collected from living plants, carried into cells and sealed; nectar is the main raw material for honey	(Latviešu konversijas vārdnīca, 2002: 26305)
2.	…a sweet, firm or viscous product created by bees when processing flower nectar	(Latviešu valodas vārdnīca, 2013; 613)
3.	…sweet liquid	(Ritmanis, 1992)
4.	…a sweet additive or sugar substitute in a person's daily diet, a natural product with a liquid or semi-liquid, viscous consistency	(Vincēviča-Gaile, 2010)
5.	…a natural, sweet substance produced by the bee (Apis mellifera) from plant nectar or secretions of living parts of plants, or from secretions of sucking insects on living parts of plants, which it collects and transforms, adding its own special substances, deposits, dehydrates, stores and leaves in honeycombs to mature and ripen	(LR ZM, 2015)
6.	...a well-known food product worldwide due to its sweet taste, aroma and health benefits	(Keke et. al., 2020)
7.	….a natural sweetener, expensive compared to other sweeteners	(Labsvārds et. al., 2021)

No.	Honey is…	Information source
8.	….an important source of energy, 100 g of which consists of approximately 80 g of carbohydrates and 20 g of water	(BIOR, 2019: 5)
9.	…a complex product consisting of more than 300 different groups of substances: sugars, organic acids, enzymes, vitamins, essential oils, flavonoids, sterols and phospholipids, which also determine the taste, colour and aroma of honey	(BIOR, 2019: 5)
10.	…a product that inhibits the growth of foodborne pathogens	(Bikheet et. al., 2024)
11.	...the main and most popular bee product. It is widely used in food, as a natural sweetener, and as a pharmaceutical product.	(Pokojevicz et.al., 2024)
12.	…a sweet, nutritious, and stable food that honeybees produce from plant nectar or the excrement of plant-sucking insects found on living plant parts.	(Washkoo et.al., 2024)
13.	…nectar, which is a sugar solution in water that also contains small amounts of other substances (amino acids, organic acids, proteins, minerals)	(Šteiselis, 2024:151)

Summarizing the definitions of honey (Table 1), it can be stated that honey is clearly a natural and sweet product, which is a good source of energy, and with its positive properties has been widely known in Latvia and the world since ancient times. Honey is a sweetness that has taste properties that are not found in any other sweet substance (Šteiselis, 2024:426). This means that honey can be used as a sugar substitute.

Honey can be divided into nectar or flower honey (it is obtained from plant nectar) and honeydew-leaf honey (it is mainly obtained from the secretions of sucking insects on the living parts of plants or from the secretion of the living parts of plants (LR MK, 2015) (Fig.1). In Latvia, various flower honeys can be obtained (various flowers, wildflowers, linden flowers, phacelia flowers, sweet flowers, heather flowers, meadow flowers and buckwheat flowers, etc.) (Dimins et al., 2008). The quality of honey can be characterized by various chemical and physical parameters (Kūka et al., 2002). Latvian beekeeping production meets EU requirements in terms of both price and quality (ZM, 2022). In order to support Latvian honey producers, scientific research has been underway for several years on the authenticity, quality and safety of honey of Latvian origin. As a result of the research, a database has been created, with the help of which it will be possible to distinguish honey of Latvian origin from products of other countries, as well as to assess the quality of Latvian honey and monitor the spread of pesticide residues (ZM, 2022). Honey samples obtained in Latvia have been of high quality, natural and matured (Kūka et al., 2002).

Honeydew-leaf honey is produced by bees from sweet secretions left on plants by various insects. This honey is darker and thicker than flower honey, with a pronounced taste and aroma. The fructose and glucose content (total) in honeydew-leaf honey, in a mixture of honeydew-leaf and flower honey, the sugar content must be at least 45 g/100 g, and in flower honey - at least 60 g/100 g (BIOR, 2019), (LR MK, 2015). If honey is produced from the flowers of different plants, it is called polyfloral honey. If honey is produced from the flowers of one plant species, it is called monofloral honey.

Honey from various flowers is most widely available in Latvia, however, nectar from a specific plant is becoming increasingly popular (Labsvārds et al., 2021). The following monofloral types of honey are most commonly obtained in Latvia:

- Linden honey: light, mild, with a distinct linden blossom aroma.
- Buckwheat honey: dark, with a specific taste and aroma, rich in iron.
- Rapeseed honey: light, with a mild flavor, crystallizes quickly.
- Heather honey: dark, with a bitter taste, jelly-like consistency.

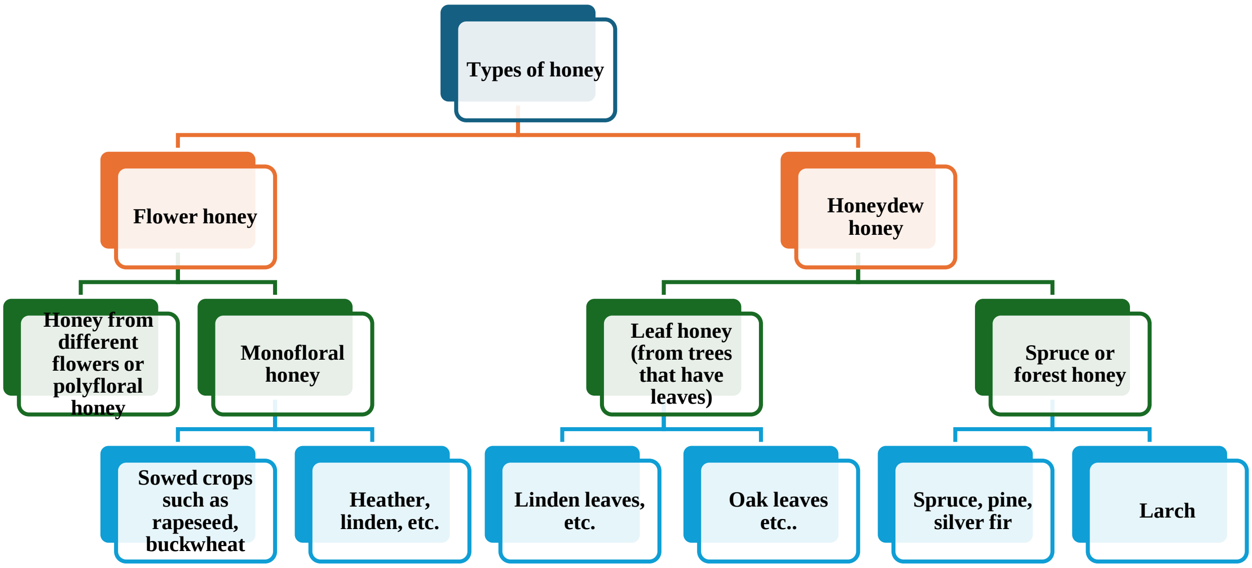

Fig.1. FTypes of honey (Šteiselis, 2024:153), (ZM, 2022), (BIOR, 2019), (LR MK, 2015), (LR ZM, 2024) (Labsvārds et.al., 2021).

In 2000, the trademark "Ievākts Latvijā" was created in Latvia and applied for registration with the Patent Office, which designates beekeeping products collected in Latvia and prepared for sale. The trademark was created with the aim of highlighting products produced in Latvia in the general range of goods and supporting local producers. The trademark project envisages extensive popularization of beekeeping products, as well as training of beekeepers to improve their professional skills and produce high-quality products. The project has earned recognition and received state support for 2001 (LR ZM, 2001).

Honey is the third most counterfeited product in the world (Eiropas Parlaments, 2018), so honey labelling is important so that consumers of honey products know the country and place of origin of honey. Any product labelled as honey that is not a joint product of bees, and a living plant is counterfeit (Latviešu konversijas vārdnīca, 2002, 26305). The geographical location of Latvia is favourable for obtaining high-quality honey. The mixed forests of the temperate climate zone, which alternate with wide meadows, natural and floodplain meadows, shrubs, bogs and heaths, are an excellent home for nectar plants. The diversity of nectar plants and their quality are the main prerequisites for the quality of the harvested honey.

In Latvia, honey consumption has decreased to 576.8 tons in 2000 (LR ZM,2001). If we compare the statistics for four years (1996-2000), then the number of bee colonies has tended to decrease, which has affected the amount of honey produced and caused its decrease from 700.2 t in 1997 to 333.3 t in 2000. However, in 1999, 362.3 t were produced, which is more than in 2000. The reason is indicated that it was a rainy summer in 2000 (LR ZM, 2001). It is positive that the total honey yield in Latvia has tended to increase in recent years (Fig. 2), which is an important factor, especially considering the changes in the environment, when, due to weather conditions, many farms suffered losses due to floods, rain, heat, etc. This phenomenon of not only not decreasing but even increasing honey yield can be explained not only by the increase in the number of apiaries, but also by the suitability of the bee species in Latvia for the geographical location of Latvia. The increase in the total honey yield in Latvia can serve as a good basis for the sale of honey not only in Latvia, but also outside Latvia. It is positive that Latvia has a trademark "Ievākts Latvijā", which, by developing it, implementing various distribution methods, advertising it, depicting its positive qualities and uniqueness, can bring the name of Latvia to distant lands, thus increasing its distribution opportunities outside Latvia. Many Latvians also live in other countries and the trademark "Ievākts Latvijā" can cause nostalgia and when planning a marketing strategy, attention should also be paid to this aspect.

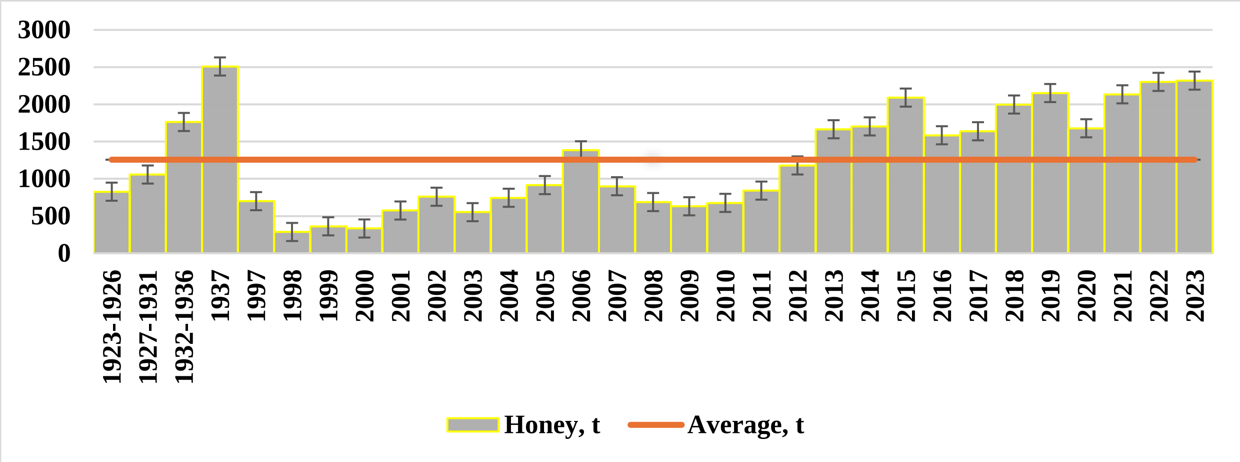

Fig.2. Total honey production in Latvia depending on the year of production, tons (Statistikas portāls, 2019), (LR ZM, 2001) - (LR ZM, 2024), (LR,2022), (LR MK, 2015).

In 2021, Latvia produced 2,135 tons of honey (Fig.2), which is 27.2% more than in the previous year. This could be explained by Covid-19 restrictions, when people had to spend more time at home, as well as be near their apiaries and pay more attention to their bee colonies, while monitoring their health.

The value of honey exports increased especially in 2021 (Fig.3). It is possible that this was also facilitated by the activities of beekeepers' cooperatives. The value of imports also increased, which could be explained by the decrease in the solvency of the population, i.e. imported honey is much cheaper than local honey. In Latvia (2018), honey is exported at a price 2.1 times higher than imported, but in 2019 the difference between export and import prices was only 1.3 times. The value of honey exports in the reporting period from 2021 to 2023 decreased by 21% overall, but in 2023 compared to 2022 – by 26%. The value of honey imports increased by 2% in the reporting period, while in 2023 it decreased by 25% compared to the previous year. The average price of honey exports in 2023 increased by 11% compared to 2021 and the average price of imports – by 19%.

Since 2019, there has been a trend in Latvia that honey exports exceed imports (Fig.3, Fig.4), which can be assessed positively from an economic point of view. Despite the fact that the largest increase in the total honey yield was observed in 2018 (Fig.2), the sharpest increase in exports was observed only in 2021 (Fig.3, Fig.4). Which could be explained by caution on the part of beekeepers, restrictions introduced due to Covid-19, or sufficient demand in the domestic market. Despite the good total honey yield in 2023 (Fig.2), honey exports decreased in that year compared to previous years. The decrease in imports is also more likely due to the fact that Latvia had a good total honey yield in that year. It can be unequivocally stated that Latvia has a good environment for honey production and there is also potential for its distribution.

After joining the European Union, Latvian honey producers had the opportunity to sell their products in other EU member states, thus expanding the range of consumers. In very small quantities, honey was exported to Estonia and Malta in 2005, but the largest percentage of honey imports came from Hungary and Ukraine, even up to 99% of all imports (LR ZM, 2006:111). In 2019, honey was mainly exported to Estonia (36% of the total value of honey exports), Germany (29%), Poland (17%) and Lithuania (11%), while the honey importing countries were Lithuania (40% of the total value of honey imports), Poland (35%), China (16%), etc. (LR ZM, 2020:73). At the end of 2022, the European Commission also approved the Latvian Beekeeping Society's program "EU honey - delicious and environmentally friendly", the operation of which began in Latvia and Estonia in 2023. The aim of the project is to promote honey consumption in everyday life and public awareness of the possibilities of using honey and its connection with natural diversity in Latvia and Estonia. When implementing the project, information campaigns are organized to popularize honey harvested in the European Union as a delicious and environmentally friendly food product (LR ZM, 2024).

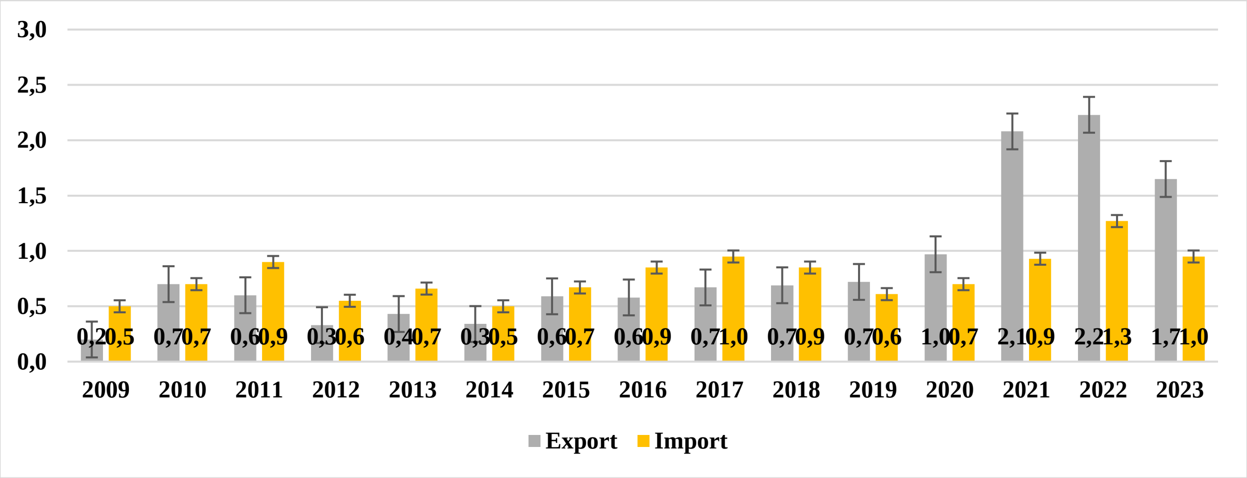

Fig. 3. Honey export and import in Latvia depending on the year of production, million, euros (LR ZM, 2010) - (LR ZM, 2024).

In 2015, the number of farms with more than 150 bee colonies also increased rapidly (an increase of 29%), as well as the number of professional beekeepers (LR ZM, 2016; 63). The structure of the honey market has changed significantly since 2013 – direct sales to consumers have decreased, the volume of honey sold to retail companies and producers has slightly increased, and exports have begun. This means that honey producers are becoming more professional, the volume of wholesale honey sales is increasing, and large producers do not threaten beekeepers of small farms who are engaged in direct sales to consumers with their products.

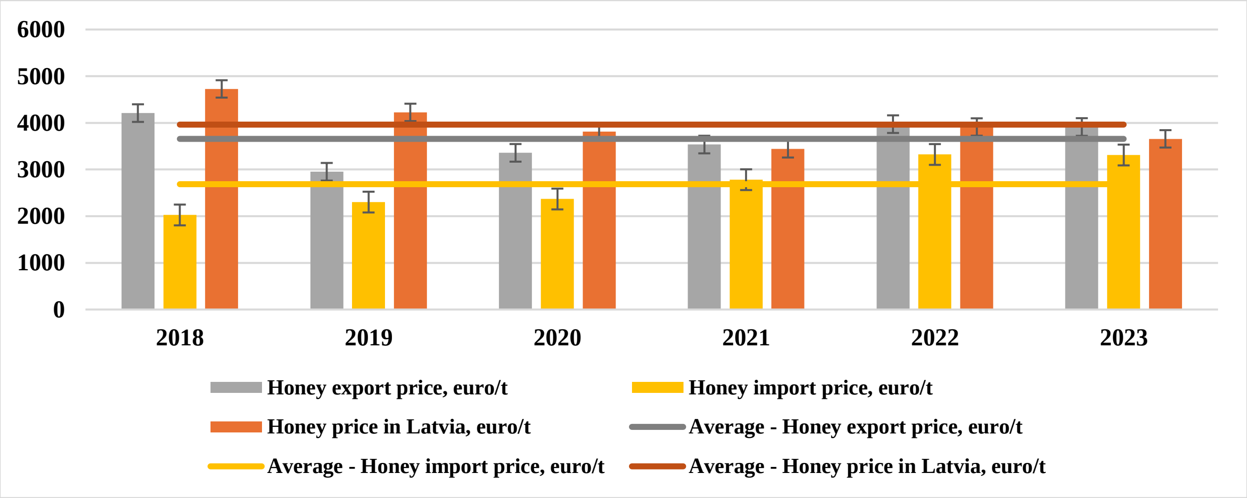

Fig. 4. Honey export and import price in Latvia depending on the year of production (LR ZM, 2019) - (LR ZM, 2024).

The large import of honey, despite the large honey harvest in Latvia, can be explained by the price of imported honey (Fig.4, Fig.5). Although the price of imported honey increases every year, except for 2023, when it remained at the previous year's level, it is still cheaper than local honey. It should be noted that since 2021, the price of honey consumed by Latvians has been lower than the price of exported honey, which indicates the interest of Latvian residents in purchasing local products. In previous years, honey was exported at a significantly lower price than it was offered to local consumers in Latvia. The larger the amount of honey produced in Latvia, the larger the amount of honey exported (Fig.5).

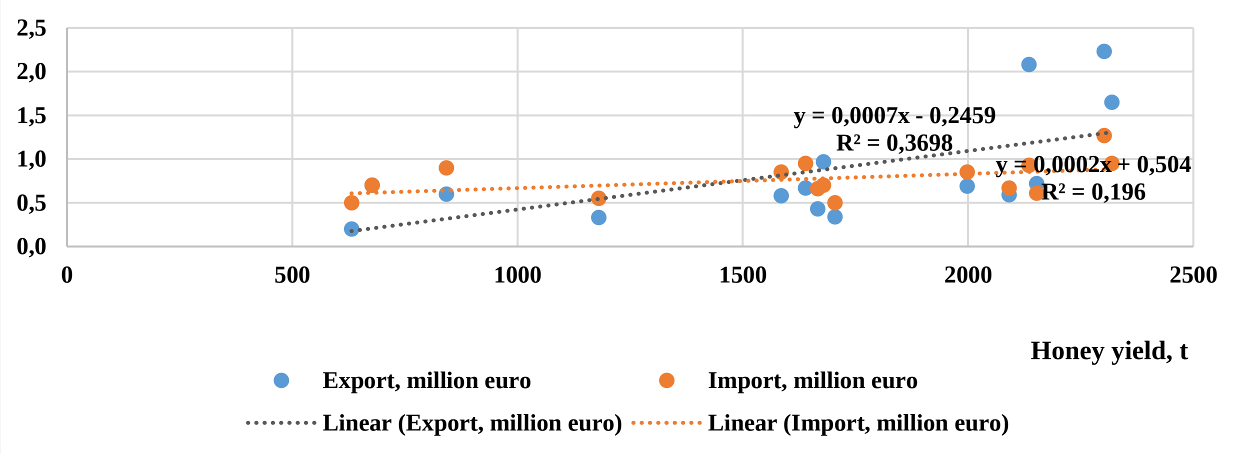

Fig. 5. Relationship between export/import and honey production in Latvia 2009-2023 (LR ZM, 2010) - (LR ZM, 2024).

In the future, honey consumption could possibly increase, not only in markets and shops, but also in restaurants and cafes and other public catering establishments. Reducing the price of the product is currently not possible due to the political situation in the world, and therefore an increase in consumption can be ensured by educating consumers, offering new and suitable packaging types and sizes, as well as using honey and its products in other industries, such as medicine, cosmetics, confectionery, etc.

4. Conclusions

Both the number of bee colonies and the amount of honey produced are increasing every year. Latvian beekeepers are able to produce high-quality products, but there are additional opportunities in honey production, both in increasing productivity by moving bees to nectar plants and by diversifying production types - by developing monofloral honey production.

The price of honey produced in Latvia is higher than the price of imported honey. The large import of honey, despite the large honey harvest in Latvia, can be explained by the price of imported honey. Since 2019, honey exports in Latvia have exceeded imports. Both the number of bee colonies and the amount of honey produced are increasing every year.

The increase in the total honey yield, price stability, and the development of the beekeeping industry are key factors that indicate that the honey yield in Latvia is sufficient to satisfy both the needs of local consumers and suffice for export, making a greater contribution to Latvia's economic growth and development of the national economy.

References

Bikheet M., Shaban M.S. (2024). Duality Effect of Bee Products in Dealing with Yoghurt Starter, *Probiotics and Food Borne Pathogenic Bacteria*. *April 2024 International Journal of Scientific Research in Agricultural Sciences*, No. 6 (2535-1796), p.166-184. DOI:10.21608/sjas

BIOR. (2019). *Latvijas izcelsmes medus autentiskuma, kvalitātes un nekaitīguma novērtējums un prasmes pārbaužu organizēšana*. Gala atskaite. p.80. Available: Available:https://bior.lv/sites/default/files/inline-files/Medus%20atskaite%202019.pdf (viewed 01.07.2018.)

Dimiņš F., Cinkmanis I., Augšpole I., Ķeķe A. (2022). *Dažādu fenolu savienojumu saturs kameņu un bišu medū*. In: Zinātniski praktiskā konference "Līdzsvarota Lauksaimniecība 2022", LLU, Jelgava, Latvija, p. 103 – 107.

Dimins F., Kuka P., Cakste I. (2008). *Content of Carbohydrates and Specific Rotation Angle of Honey*. In: 3rd Baltic Conference on Food Science and Technology FOODBALT-2008. Conference proceedings, Straumite, LLU, 2008. Baltic Conference on Food Science and Technology FOODBALT-2008, 3, Jelgava (Latvia), p. 121-125

Eiropas Parlaments. (2018). *Bišu aizsardzība un cīņa pret viltota medus importu Eiropā*. 24-01-2018. Available: https://www.europarl.europa.eu/news/lv/headlines/economy/20180122STO92210/bisu-aizsardziba-un-cina-pret-viltota-medus-importu-eiropa (viewed 01.07.2018.) sk.16.04.2023

Jayapal P., Anandhabhairavi N., Arivarasan S., Sruthi A.B. (2024). *Therapeutic Implications of Honeybee Venom*: A Holistic Approach. Chapter 1.

Keke A., Cinkmanis I. (2020). a-Amylase Activity in Freeze-Dried and Spray-Dried Honey. Research for Rural Development, vol. 35, DOI: 10.22616/rrd.26.2020.017

Kūka P., Dimiņš F., Kūka M., Čakste I. (2002). Usage of physical methods in the characterization of the quality of honey. *LLU Raksti*, 6 (301), p. 29-32.

Labsvārds K.D., Rudoviča V., Vīksna A, (2021). Latvijas medus izcelsmes pētījumi. Biškopis (biškopības žurnāls) 2021 (6) p. 21-22. Available: https://www.lu.lv/fileadmin/user_upload/LU.LV/Apaksvietnes/Fakultates/www.kf.lu.lv/Biskopis__1_.pdf (viewed 05.07.2024.)

Latviešu konversijas vārdnīca XIII. (2002). Eds. Švābe A., Būmanis A., Dišlers K. Rīga: izdevniecība Antēra (Faksimilizdevums), p.26620.

Latviešu valodas vārdnīca. (2013). *30000 pamatvārdu un to skaidrojumu*. Eds. Guļevska D., Rozenštrauha I., Šnē D. Rīga: Izdevniecība Avots, p. 1216.

Liepniece M., Trops J. (2017). *Latvijas vietējās medus bites saglabāšanas darbs*. Rakstu krājums: Ražas svētki „Vecauce – 2017": Lauksaimniecības zinātne Latvijas simtgades gaidās. p.45-48.

LR MK. (2015). *Latvijas Republikas Ministru kabineta noteikumi Nr. 251. Kvalitātes, klasifikācijas un papildu marķējuma prasības medum (2015., 26. maijā)*. Available: https://likumi.lv/ta/id/274304 (viewed 01.07.2021.).

LR ZM. (2001). *Lauksaimniecības gada ziņojums*. p. 157. Available: https://www.zm.gov.lv/lv/media/4620/download?attachment (viewed 14.07.2024.)

LR ZM. (2002). *Lauksaimniecības gada ziņojums*. p. 168. Available: https://www.zm.gov.lv/lv/media/4623/download?attachment(viewed 14.07.2024.)

LR ZM. (2003). *Lauksaimniecības gada ziņojums*. p. 188. Available: https://www.zm.gov.lv/lv/media/4626/download?attachment (viewed 14.07.2024.)

LR ZM. (2004). *Latvijas lauksaimniecības un lauki*. p. 92. Available: https://www.zm.gov.lv/lv/media/4560/download?attachment (viewed 14.07.2024.)

LR ZM. (2005). *Latvijas lauksaimniecības un lauki*. p. 129. Available: https://www.zm.gov.lv/lv/media/4626/download?attachment (viewed 14.07.2024.)

LR ZM. (2006). *Latvijas lauksaimniecības un lauki*. p. 151. Available: https://www.zm.gov.lv/lv/media/4566/download?attachment (viewed 14.07.2024.)

LR ZM. (2007). *Latvijas lauksaimniecības un lauki*. p. 152. Available: https://www.zm.gov.lv/lv/media/4569/download?attachment (viewed 14.07.2024.)

LR ZM. (2008). *Latvijas lauksaimniecības un lauki*. p. 116. Available: https://www.zm.gov.lv/lv/media/4572/download?attachment (viewed 14.07.2024.)

LR ZM. (2009). *Latvijas lauksaimniecības un lauki*. p. 94. Available: https://www.zm.gov.lv/lv/media/4578/download?attachment (viewed 14.07.2024.)

LR ZM. (2010). *2010. gada ziņojums par 2009*. gadu. p. 110. Available: https://www.zm.gov.lv/lv/media/4581/download?attachment (viewed 14.07.2024.)

LR ZM. (2011). *2011. gada ziņojums par 2010. gadu*. p. 148. Available: https://www.zm.gov.lv/lv/media/4584/download?attachment (viewed 12.07.2014.)

LR ZM. (2012). *Latvijas lauksaimniecība*. p.133. Available: https://www.zm.gov.lv/lv/media/4587/download?attachment (viewed 01.07.2024.)

LR ZM. (2013). *Latvijas lauksaimniecība*. p.157. Available: https://www.zm.gov.lv/lv/media/4590/download?attachment (viewed 01.07.2024.)

LR ZM. (2014). *Latvijas lauksaimniecība*. p.156. Available: https://www.zm.gov.lv/lv/media/4593/download?attachment (viewed 01.07.2024.)

LR ZM. (2015). *Latvijas lauksaimniecība*. p.156. Available: https://www.zm.gov.lv/lv/media/4596/download?attachment (viewed 01.07.2018.)

LR ZM. (2016). *Latvijas lauksaimniecība*. p.155. Available: https://www.zm.gov.lv/lv/media/4599/download?attachment (viewed 01.07.2024.)

LR ZM. (2017). *Latvijas lauksaimniecība*. p.170. Available: https://www.zm.gov.lv/lv/media/4602/download?attachment (viewed 01.07.2024.)

LR ZM. (2018). *Latvijas lauksaimniecība*. p. 180. Available: https://www.zm.gov.lv/lv/media/4605/download?attachment (viewed 01.07.2024.)

LR ZM. (2019). *Latvijas lauksaimniecība*. p. 188. Available: https://www.zm.gov.lv/lv/media/4608/download?attachment (viewed 01.07.2024.)

LR ZM. (2020). *Latvijas lauksaimniecība*. p. 197. Available: https://www.zm.gov.lv/lv/media/4611/download?attachment (viewed 01.07.2024.)

LR ZM. (2021). *Latvijas lauksaimniecība 2020*. p. 207. Available: https://www.zm.gov.lv/public/files/CMS_Static_Page_Doc/00/00/02/12/76/2021_lauksaimniecibas_gada_zinojums.pdf (viewed 05.10.2024.)

LR ZM. (2022). *Latvijas lauksaimniecība 2021*. Available: https://www.zm.gov.lv/lv/media/4617/download?attachment (viewed 05.10.2024.)

LR ZM. (2023). *Latvijas lauksaimniecība 2022*. Available: https://www.zm.gov.lv/lv/media/12006/download?attachment (viewed 05.10.2024.)

LR ZM. (2024). *Latvijas lauksaimniecība 2023*. Available: https://www.zm.gov.lv/lv/media/14880/download?attachment (viewed 05.10.2024.)

Pokajewicz K., Lamaka D., Hudz N., Adamchuk L., Wieczorek P.P. (2024). Volatile profile of bee bread. *Sci Rep* 14, 6870. https://doi.org/10.1038/s41598-024-57159-y.

Ritmanis Z. (1992). *Bišu ceļi*. Rīga: Zvaigzne, 400 lpp.

Snyder H. (2019). Literature review as a research methodology: An overview and guidelines, *Journal of Business Research,* Vol. 104, p. 333-339.

Statistikas portāls. (2019). Medus kopraža. Latvijas oficiālā statistika 17.05.2019. Available: https://stat.gov.lv/lv/statistikas-temas/noz/lauksaimn/publikacijas-un-infografikas/651-medus-kopraza-statistikai100 (viewed 01.07.2024.)

Statistikas portals. (2025). Available: https://www.csp.gov.lv/lv (viewed 21.12.2024.)

Šteiselis J. (2024). *Biškopība*. Latvijas Biškopības biedrība. p.439.

Vincēviča-Gaile Z. (2010). Makro- un mikroelementu saturs medū. *LLU Raksti*, 25 (320), p. 54-66. Available:https://llufb.llu.lv/proceedings/n25/6/LLU-raksti-nr25-54-66.pdf (viewed 22.08.2024.)

Wachkoo A.A., Nayik G.A., Uddin J. Ansari M.J. (2024). Honey Bees, Beekeeping and Bee Products. CRC Press is an imprint of Taylor & Francis Group, LLC, p.36.

ZM. (2022). Biškopības nozare. Available: https://www.zm.gov.lv/lauksaimnieciba/statiskas-lapas/lopkopiba-un-ciltsdarbs/biskopibas-nozare?nid=588#jump (viewed 01.02.2025.)

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Rice-Legume Flour as an Alternative to Gluten-Containing Flour in Bread Baking

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Abstract

The article describes the development process of a new product - rice bean flour bread. The product is a functional alternative to classic wheat flour bread. The development of the new product is based on literature research and experiments. The ingredients of alternative flour bread are characterized. The most difficult thing in the development of alternative flour bread is the imitation of gluten, in connection with which gluten alternatives are studied. For its imitation, such groups of raw materials as hydrocolloids and proteins are offered. Conclusions are drawn about the importance of ingredients in alternative bread and the possibilities of gluten imitation. Bread made with just rice flour was crumbly, dry, and had a bad texture. Although adding potato starch decreased crumbling and increased cohesiveness, it also added an unwanted aftertaste. Tapioca starch lessened the aftertaste of potato starch and enhanced texture. Using eggs as a source of protein enhanced crumb structure and bread growth.

Keywords: alternative flour, alternative flour bread technology, bread, home production

1. Introduction

One of the main sources of carbohydrate extraction in the human diet is bread. Bread is not only a basic element of the nutritional pyramid, but also an important symbol in Latvian culture. Bread is a product with a rich history. It is a symbol of respect and prosperity, brought to the table at any meal, so it has always been a topical product.

Consumers are more likely to appreciate the healthiness aspect of food products. Primarily, the choice of buyers between products that are products of the same category is influenced by price, but the results of studies show that the impact of a product on the health of the consumer and the environment does not lag far behind the price as an influencing factor. (Grivin, 2023) Due to the fact that people are starting to think more often about their health and the well-being of the planet, the number of vegetarians in the world is increasing. For vegetarians, protein is an important group of nutrients, since excluding meat from the diet excludes a significant source of protein. (Dulman, n.y.) Legumes are considered an excellent source of protein and an analogue of meat, in connection with this, the importance of proteins from legumes and oilseeds in the production of various functional foods is growing, since they have a high protein content (Kumar, 2016).

2. Materials and Methods

The development of the new product is based on literature research and experiments. The goal is to develop a product - an alternative to classic wheat flour bread, which does not contain yeast, dairy products, naturally gluten-containing products, sugar. Since naturally gluten-containing products are excluded in the development of the new product, information that is relevant to gluten-free products is initially selected. However, the product is not positioned as gluten-free. By studying the literature, several main potential ingredients are identified and characterized, with which experiments are conducted. During the experiments, the final ingredients for the new product - alternative flour bread are determined.

Selection of alternative raw materials for flour bread, characteristics.

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When determining raw materials, it is primarily necessary to find out what alternative flour is. Initially, the author defines alternative flours: flours that are naturally gluten-free. Alternative flours can include flour such as: buckwheat, quinoa, amaranth, corn, rice, sorghum, millet. (Šmídová et al 2022). Alternative flour mixtures usually contain a mixture of starch, water-soluble polysaccharides and rice flour, which are more neutral, light and tender in taste, they have more easily digestible carbohydrates. (Ren, 2020). The study of the literature is also attributed to gluten-free production, since the main difference between gluten-free and alternative flour bread is the presence of gluten-free cross-contamination, which is not permissible in gluten-free production, but is permissible in alternative flour bread.

The biggest challenge in developing alternative flour bread is the imitation of gluten, which is a wheat protein, since it plays an important role in the preparation of any flour product, so its role in bread is being studied. Gluten proteins form a continuous network in the dough. This net ensures the unity, bonding of substances, as well as the viscous elasticity of the dough, which is necessary for the preparation of bread. (Shewry, 2019) The absence of gluten in gluten-free production resulted in bread with poor texture and colour, characterized by a smaller specific volume. As well as such bread has a shorter shelf life, great dryness, unpleasant taste. The volume of such bread is often less. (Capelli et al., 2020) Gluten plays an important role in tying water into the product. This eliminates such adverse properties as crumbling and dryness. The gluten network contributes to the retention of gases in the product, which, in turn, increases the volume of the product. (Capelli et al., 2020) To create a successful alternative flour bread, it is necessary to find a substitute for gluten. Given that gluten provides several quality-enhancing properties to a product, it is not possible to replace it with just one ingredient. Hydrocolloids and proteins are cited as the main substitutes for gluten. (Arendt et al., 2008a), (Arendt et al., 2008b).

Hydrocolloids are polysaccharide polymers. Their main property is the ability to absorb and retain water in the product, as they are hydrophilic. In the food industry, they are usually used as thickeners and gelling agents. These can include resins, starches, pectin, agar-agar. (sperohope.com, 2025) Their high-water binding capacity means that they can provide stability to products undergoing freezing-thawing processes. (Capelli et al., 2020) In many literary sources it is mentioned that hydrocolloids are used in the production of gluten-free bread, as the main and most widespread is psyllium. Psyllium is a natural source of fibre; it is insoluble in water. This creates the effect of a clinging gel in the product. (Ren, 2020)

Starch is a unique carbohydrate of plant origin, as it is naturally present in the form of dense and relatively insoluble, semi-crystalline granules. Starch is a water-insoluble polysaccharide. It plays several roles in the processing of food products. It affects the rheology and stretchability of the dough, the texture of the bread. Heating of starch suspensions in water leads to changes at the molecular level, as a result of which crystallinity decreases and starch granules irreversibly swell. This process is called gelatinization. Gelatinization is also associated with a decrease in starch dissolution, which determines an increase in the viscosity of the starch suspension. Gelatinization of starch can be provided only if there is enough water. (Capelli et al., 2020) During heat treatment, starch wanders in the presence of water, but without the presence of water, it turns into dextrin's, which gives the products a brown colour. (Gavrilenko, 2001)

When starch is cooled after heating, another phenomenon occurs, which is called retrogradation. Here, starch polysaccharides are associated again, forming a more orderly, crystalline state. Retrogradation is influenced by several factors. The most notable are associated with the presence of other molecules, such as sugars, salts, lipids. (Capelli et al., 2020)

There are several sources of starch that do not naturally contain gluten. These include rice, potatoes, tapioca and cornstarch. Potato starch is the most promising, as it has desirable properties that are significantly different from other starches. A small amount of potato solids helps to preserve the freshness of the bread and gives it a characteristic, pleasant taste, improving the taste characteristics. The study also notes that high molecular weight amylose and phosphate groups esterified to amylopectin contribute to the high transparency, swelling, water-binding ability and freezing and thawing stability of potato starch. (Capell et al., 2020)

Tapioca starch (also called cassava starch) is referred to in the scientific literature as starch, which produces the most acceptable indicators for gluten-free bread. When comparing starch, cassava-sorghum and rice-sorghum bread have better crumb properties than corn-sorghum or potato-sorghum bread. The formula, which contains 50% cassava starch, retains the best overall texture. Potato and cassava starches are classified as starches with high swelling, as they have a weak intermolecular bond and are easily gelatinized, forming a mass of high viscosity. (Onyango et al., 2011) Tapioca starch granules are slightly larger than corn and range from 7.1 to 25.0 μm. Starches differ in the shape and size of the granules, ranging from large (potatoes) to small (corn and tapioca) and oval (potatoes) to multifaceted (corn) or spherical with some shortened (tapioca) granules. Small grooves were also observed in some tapioca starch granules. It is observed that the pH of tapioca is lower (4.80) than that of corn and potato starch, whose values: 6.24 and 7.15, respectively. Among corn, potato and tapioca starch, tapioca starch has the lowest degree of whiteness, 87%, while corn starch, for example, has 99%. Tapioca starch has a lower amylose content, 16.27%, while corn starch has a 25.60%. Also, the moisture content of tapioca starch is lower -7.54% than that of potato or corn starch. Potato and tapioca starch have a lower lipid content than corn starch. The increase in solubility at high temperature (70 °C) is more for potato and tapioca starch. Since tapioca starch has a lower content of amylose, then it gels in a higher concentration compared to potato starch. Tapioca starch jelly is softer, less elastic, resinous and chewable compared to potato and corn starch. Tuber and root starch contains a lower content of proteins, lipids and ash than cereal starch. (Mishra et al., 2006)

Xanthan gum, also known as bean resin, is a polysaccharide with a wide range of applications. It is obtained by fermentation of sugars or small polysaccharides (various starches) using the bacterium Xanthomonas campestris. It is a very popular ingredient in gluten-free products to obtain a dough consistency that is more like gluten-containing products. Food is usually used in concentrations of up to 0.5 % (Lerochem.eu.). The addition of xanthan gum to the dough leads to the greatest increase in viscoelasticity modules and the lowest hardness of the bread. Of the hydrocolloids, they have the highest water-retaining ability. They increase the elasticity of the dough and the viscosity, consistency and strength of the dough, increase the strength of the gas cells in batters made with rice, corn and buckwheat flour. Bread with xanthan gum has a larger specific volume, reduced hardness of crumbs, improved colour, larger gas cells and improved porosity of the crumbs, increased moisture content, reduced water loss, improved sensory perception. The addition of xanthan gum gives the highest results of elasticity and resistance of the dough to deformation. (Capelli et al 2020) Gel formation or an increase in the viscosity of the solution is a frequent result of the interaction of xanthan resins in solutions (Larrosa et al., 2013).

In gluten-free production, both animal and plant products, such as legumes, eggs, etc., are used to provide protein. Like other improvers, the purpose of adding protein is to strengthen the structure of the dough. An additional benefit is the improved nutritional content. (Capelli et al., 2020)

Egg albumins have a relatively small molar mass and high absorption abilities of carbon dioxide, which is significant in the process of its binding. An important factor that has a positive effect on the volume of loaves is the low denaturation temperature of albumin, which is responsible for the formation and stabilization of the structure during frying. (Ziobro et al., 2015)

Legumes are a source of protein that has been widely studied in the literature. One study emphasized that the addition of lupine and pea protein isolates improved dough rheology, increased loaf volume, cell pores, and produced softer crumbs. (Horstmann et al., 2017) Lupine protein reduces the hardness of the crumbs and slightly increases the storage module. (Ziobro et al., 2015)

Chickpea protein is recognized as an excellent improver of the dough. The addition of 5% chickpea flour significantly improves ancient wheat flour, in terms of increased stability of the dough and the volume of bread. (Capelli et al., 2020) Chickpeas have proven to be able to enhance gluten-free dough and bread. (Capelli et al 2020)

Beans have a low glycemic index and, as a result, can raise blood glucose levels after eating at a relatively low level. (Wesley et al 2021) The moisture content of legume flour ranges from 7.9% to 10.8%. (Wilman, 2015) White beans are the most important nutritional legume in many countries around the world. It has a high content of protein, dietary fibre and minerals. Bean protein is rich in lysine. Beans are an important source of minerals such as iron, phosphorus, magnesium, manganese and vitamins A, C, E, K and PP, vitamin B and folic acid, as well as soluble and insoluble dietary fibre, which have a beneficial effect on health. Bread made with bean flour; the water absorption capacity of the dough increases with the increase in bean flour. (Hoxha et al., 2020)

Water is an important source of life, which is involved in the production of almost every product. It, by its chemical structure, is a very universal substance. Water is the basis of chemical reactions. Water is a very important ingredient in a large part of products, including gluten-free products, just as its absorption is of great importance. Water affects the structure, taste of bread also in volume and baking processes. (Capelli et al 2020) The amount of water determines the consistency of the dough and affects its fermentation. It plays a key role in the gelatinization of starch. Most gluten-free bread has a higher water level, and the dough has a more liquid-like structure. Less hydrated gluten-free doughs have less ability to retain the gases released during fermentation, while highly hydrated doughs need to be fermented longer, improving the specific volume. (Capelli et al., 2020)

As substitutes for basic wheat flour in scientific publications, rice flour, cornmeal or buckwheat, amaranth flour are mentioned. (Capelli et al 2020) But an evaluation of the literature leads to the conclusion that rice is mentioned more often as a base ingredient, so rice flour is being studied. It has been proven that in combination with starch and an appropriate hydrocolloid, rice flour is suitable to produce gluten-free bread. Breads with rice flour form even, elongated pores with thin walls. (López et al., 2004) When comparing rice flour produced from two different rice varieties, Basmati and Bomba, with amylose lengths of 699 and 978, Basmati rice flour produces a harder crumbly texture than Bomba, with no significant differences in amylose content. The study concludes: the length of amylose is a decisive factor affecting the quality of rice bread. (Ronie et al,.2022)

Although salt is added to batters in small quantities (1.2-1.8% of the amount of flour), it plays an important role in the preparation of bakery products. It improves the properties of the dough, regulates the fermentation processes and affects the taste of bread. The dough without salt is sticky, fuzzy, rapidly ferments and does not hold its shape, the bread has a pale, hard crust and a flabby taste. An excessive amount of salt (above 2% of the amount of flour) in the dough delays the fermentation processes, sometimes the dough does not ferment at all, it is wet, difficult to process, but the products have an unpleasantly salty taste. In the production of bread, different types of salt can be used – coarse, fine, vacuum salt, fluorosal or iodal. (Latvian Rural Advisory and Education Centre.)

Fat. Gluten-free bread is characterized by a higher fat content than gluten-containing bread. (Tres et al., 2020) Many industrial manufacturers use cheap vegetable fats such as palm or palm kernel oil to produce gluten-free products, but local producers are inclined to use quality vegetable fats, such as olive oil. (Maggio et al., 2018) Among the most used oils in gluten-free breads are sunflower oil and olive oil. Olive oil is characterized by a higher content of oleic and lower linoleic acid compared to sunflower oil. Also, phytosterols by composition in sunflower oil are more than in olive oil, but there are more of them in olive oil than in coconut oil. (Tres et al., 2020) The main ingredients in olive oil, which have healthy properties, are triterpene dysalcohols and acids, squalene, tocopherols, sterols, fatty alcohols and phenolic compounds. The refining process significantly reduces the content of phenolic compounds, while the rest of the smaller components remain in concentrations that can have a positive effect on health, especially cardiovascular health. (Mateos et al 2019) Adding oil to bread dough increases its specific volume and volume. (Mokar et al., 2022) As well as oil can increase the humidity of bread and reduce acidity and brittleness. (Evlash et al., 2019)

3. Results and discussion

When evaluating potential ingredients, experiments are conducted to develop the new product. Initial experiments are carried out with a minimum amount of raw materials, evaluating the characteristics of each raw material. During the process, several experiments are conducted, but those during which there is a strong progress in the development of a new product are characterized.

The purpose of the first experiment is to test what properties rice flour has. The following are taken as raw materials: water, rice flour, rice starter, salt, linseed, baking powder. The result of the experiment is shown in Fig. 1. and Fig. 2.

Fig. 1. Rice bread from above.

Fig. 2. Rice bread in cross section.

In the Fig.1 we can see that the dough lacks binders, the bread bribe is very cracked, which indicates that its crumb, which will also confirm when cutting it. Figure 2. shows that the bread does not stick together when it is cut, especially in places where there are cracks. The flesh itself for bread, when eaten, seems dry. The bread is dense, it has practically no pores. The author concludes that rice flour alone forms an unstable product that is stirring. It is necessary to add to the present raw materials that would bind the product.

In the next experiment, potato starch is added to the raw materials and linseed is removed, since the need to include them in the recipe is not observed. This is an important experiment, since this product is already beginning to resemble bread more and is more acceptable in terms of taste.

Fig. 3. Rice bread with starch in cross section.

By the cross-section of rice bread, it can be judged that now it does not crumble so much, pores have appeared that are not pronounced but are. The flesh is soft, when tasted, a slightly wandering sensation in the mouth occurs, and there is also an aftertaste of potato starch. In general, the bread resembles more something queer.

Fig. 4. Rice bread with starch from above.

On the outside, on the other hand, the bread is light brown, the crust is not thick, it is more like shortbread in consistency. The author marked a drawing before baking bread in the dough to be sure of the properties of the dough. It is concluded that during baking, the dough expands minimally, its fluidity is low, since the drawing has largely survived. This bread hardens quickly.

In the next experiment, protein sources are compared, and tapioca starch is added to reduce the aftertaste of potato starch. Lupine flour and egg are chosen as sources of protein. Fig.5 on the left shows bread with lupine flour, Fig. 6 on the right shows bread with egg.

Fig. 5. Bread with lupine flour

Fig. 6. Bread with egg

Comparing the pictures above, it is concluded that bread with lupine flour is much denser, has less pronounced pores, and also grows worse. When you taste lupine flour bread, an unpleasant aftertaste remains in the mouth, but this bread is moister than bread with egg. In turn, the bread that is with the egg is better grown it has more pronounced and even pores. This bread also has a more pronounced crust. In both breads, the aftertaste of potato starch is no longer felt. However, the bread that is with the egg is not yet the desired result, since the bread seems dry.

To ensure additional hydration of the bread, the addition of hydrocolloids to the bread recipe is tried. In this case, it is psyllium powder. Fig.7 and 8 show the result of the experiment.

Fig. 7. Bread with psyllium in cross section.

As can be seen from Figure 7, the product is palpable, compacted.

Fig. 8. Bread with psyllium from above.

When creating a dough with psyllium, it is very jelly-like, heavy, cracks and holes form in the dough, but when baked, as can be seen in the above pictures, these cracks have smoothed out. Due to the severity of the dough, it is observed that the bread ferments poorly. The crust is thin, breaking. When cutting bread, the jelly-like structure has been preserved, the author concludes that psyllium does not give the desired result.

One of the last experiments is devoted to making bread wetter, more elastic and improving nutritional value. Applying the knowledge gained during the studies, considering the analysed literary sources, the author decides to add fatty substances and additional proteins and other hydrocolloids to the recipe.

Vegetable fats are put forward as a raw material, which would be a source of fatty substances, more precisely, olive oil. To increase the proportion of protein in the product, bean flour is put forward as a potential raw material. To improve the general acceptability and elasticity of the product, xanthan gum is added. The raw materials of the final product are water, rice flour, bean flour, potato starch, tapioca starch, egg, olive oil, rice flour starter, baking powder, xanthan gum, salt.

4. Conclusions

- Gluten is an important binder in bread, which is missing in alternative flour bread, it is impossible to replace it with 1 ingredient, therefore, to replace it, it is necessary to use a combination of several components, basically: hydrocolloids, starches, proteins.
- Experimentally determined raw materials of alternative flour bread: water, rice flour, bean flour, tapioca starch, potato starch, egg, olive oil, rice starter, baking powder, xanthan gum, salt.
- Alternative flour bread dough has a liquid consistency compared to a bread dough that contains gluten.
- Psyllium fibre is most common hydrocolloid used in gluten-free bread production, it adds moisture to the gluten-free bread dough.

References

Arendt E.K., Morrissey A., Moore M. M., Bello Dal F. (2008a). 13 - Gluten-free breads. *Food Science and Technology*, p 289-319, VII. Available: https://www.sciencedirect.com/science/article/abs/pii/B9780123737397500150 (viewed 10.11.2024.)

Arendt E. K., Bello Dal F. (2008b). 19 - Functional cereal products for those with gluten intolerance. Woodhead Publishing Series in Food Science, *Technology and Nutrition*, p. 446-475. Available: https://www.sciencedirect.com/science/article/abs/pii/B9781845691776500199 (viewed 04.11.2024.)

Capelli A. Olivia N., Bonaccorsi G., Lorini C., Cini E. (2020). Assessment of the rheological properties and bread characteristics obtained by innovative protein sources (Cicer arietinum, Acheta domesticus, Tenebrio molitor): Novel food or potential improvers for wheat flour? LWT, Volume 118, 108867 Available:https://www.sciencedirect.com/science/article/pii/S0023643819312095?casa_token=QVMq3xmELI4AAAAA:azxqk30iq0t_hWrGyrvHwUC9ksWrbISXUrph1eRN0jVXNCwCdN4hIzVzEj5nbOJc4l2-zmtRyg (viewed: 11.12.2024.)

Capelli A., Olivia N., Cini E. (2020). A Systematic Review of Gluten-Free Dough and Bread: Dough Rheology, Bread Characteristics, and Improvement Strategies. *Appl. Sci*. 10 (18), 6559. Available: https://www.mdpi.com/2076-3417/10/18/6559 (viewed 12.11.2024.)

Dulman I. (n.y.). Vegetarianism. Available: https://www.kotuedisi.lv/vegetarisms/ (viewed: 06.01.2025.)

Evlash V., Tovma L., Tsykhanovska I., Gaprindashvili N. (2019). Innovative Technology of the Scoured Core of the Sunflower Seeds After Oil Expression for the Bread Quality Increasing. *Modern Development Paths of Agricultural Production*, p. 665–679, Available: https://link.springer.com/chapter/10.1007/978-3-030-14918-5_65 (viewed 31.10.2024.)

Gavrilenko E. (2001). Cooking technology, Riga: Turiba Business School, p.128.

Grivins M. (2023). Centre for Baltic and East European Studies, CBEES, Södertörn University, Ecological Concerns in Transition A Comparative Study on Responses to Waste and Environmental Destruction in the Region, Available: https://www.researchgate.net/profile/Sara-Persson-2/publication/370230710_Narrating_an_oilfield_in_transition/links/64479d58d749e4340e37f857/Narrating-an-oilfield-in-transition.pdf#page=162 (viewed 15.12.2024.)

Horstmann S. W., Foschiaa M., Arendt E. K. (2017). Correlation analysis of protein quality characteristics with gluten-free bread properties. *Food & Function*; Issue 7. Available: https://pubs.rsc.org/en/content/articlelanding/2017/fo/c7fo00415j/unauth (viewed 07.11.2024.)

Hoxha I., Xhabiri G., Deliu R. (2020). The Impact of Flour from White Bean (Phaseolus vulgaris) on Rheological, Qualitative and Nutritional Properties of the Bread. Open Access Library Journal, Vol.7 No.2. Available: https://www.scirp.org/journal/paperinformation?paperid=98121 (viewed 09.11.2024.)

Kumar S. (2016). Meat Analogues: Plant based alternatives to meat products- A review. International Journal of Food and Fermentation Technology. 5(2):107-119. Available: https://www.researchgate.net/profile/SatishKumar178/publication/305317336_Meat_Analogues_Plant_based_alternatives_to_meat_products-_A_review/links/5787c35008aecf56ebcb51ff/Meat-Analogues-Plant-based-alternatives-to-meat-products-A-review.pdf (viewed 06.01.2025.)

Larrosa V., Lorenzo G., Zaritzky N., Califano A. (2013). Optimization of rheological properties of gluten-free pasta dough using mixture design. lJournal of Cereal Science Volume 57, Issue 3, p. 520-526. Available: https://www.sciencedirect.com/science/article/abs/pii/S0733521013000428 (viewed 06.11.2024.)

Latvian Rural Advisory and Education Centre. A guide to home production. Ozolnieki: SIA "Latvian Rural Consulting and Education Centre". Available: https://www.pvd.gov.lv/lv/media/507/download?attachment (viewed 28/10/2024.)

Lerochem.eu. GASANTHAN RESIN, (E415 food quality). Available: https://lerochem.eu/lv/sakums/92-460-ksantana-sveki-e415-partikas-kvalitates-kg.html?srsltid=AfmBOorP6OxIJXOSKfnhODhXvcpkYmph_RwO287YeQ6B5mO10opT48Q5&utm_ (viewed 06.11.2024.)

López B. C. A., Junqueira R. G., Pereira A. J. G. (2004). Flour mixture of rice flour, corn and cassava starch in the production of gluten-free white bread. Food Science and Technology. *Braz. arch. biol. technol*. 47 (1). Available: https://www.scielo.br/j/babt/a/v5XjmMVwSVvrj8NYXzSPtpz/?lang=en&format=html (viewed 12.11.2024.)

Maggio A., Orecchio, S. (2018). Fatty Acid Composition of Gluten-Free Food (Bakery Products) for Celiac People. Foods 2018, 7(6), 95. Available: https://www.mdpi.com/2304-8158/7/6/95 (viewed 31.10.2024.)

Mateos R., Sarria B., Bravo L. (2019). Nutritional and other health properties of olive pomace oil. Critical Reviews in Food Science and Nutrition Volume 60, Issue 20.) Available:

https://www.tandfonline.com/doi/abs/10.1080/10408398.2019.1698005 (viewed 31.10.2024.)

Mikolasova L., Ivanisova E., Tokar M., Snirc M., Lidikova J., Balazova Z. (2022). The Effect Of The Addition Of Various Types Of Oils On The Technological Quality Of Wheat Dough And Bread. *Journal of microbiology, biotechnology and food sciences*. Vol. 12 No. 2. Available: https://office2.jmbfs.org/index.php/JMBFS/article/view/5703 (viewed 31.10.2024.)

Mishra S., Rai, T. (2006). Morphology and functional properties of corn, potato and tapioca starches. Food Hydrocolloids Volume 20, Issue 5, p. 557-566. Available: https://www.sciencedirect.com/science/article/pii/S0268005X0500010X?casa_token=Qa3ykDewqckAAAAA:9PvsLdEea2xtjD1Yxy0INwz7D8of2lT65ntC0pkZRkaW-rXNlBn5I3D9bbZ7JCWo-qTDqcmFXc (viewed 05.11.2024.)

Onyango C., Mutungi C., Unbehend G., Lindhauer M. G. (2011). Modification of gluten-free sorghum batter and bread using maize, potato, cassava or rice starch. LWT - Food Science and Technology. Volume 44, Issue 3, pages 681-68.6. Available: https://www.sciencedirect.com/science/article/pii/S0023643810003087 (viewed: 05.11.2024.)

Ren, Y. (2020). A comprehensive investigation of gluten free bread dough rheology, proving and baking performance and bread qualities by response surface design and principal component analysis. *Food Funct*. 11, p. 5333-5345. Available: https://pubs.rsc.org/en/content/articlehtml/2020/fo/d0fo00115e (viewed 11.11.2024

Ronie M.E., Mamat, H. (2022). Factors affecting the properties of rice flour: a review. *Food Research* 6(6), p. 1-12. Available: https://www.researchgate.net/profile/Macdalyna-R/publication/365135511_Factors_affecting_the_properties_of_rice_flour_a_review/links/636bc98d431b1f53008410dd/Factors-affecting-the-properties-of-rice-flour-a-review.pdf (viewed 12.11.2024).

Shewry P. (2019). What Is Gluten—Why Is It Special? Sec. Nutrition and Food Science Technology Volume 6. Available: https://www.frontiersin.org/journals/nutrition/articles/10.3389/fnut.2019.00101/full (viewed: 12.11.2024.)

Sperohope.com. (2025). Hydrocolloids: properties, types, application and examples. Available: https://lv.sperohope.com/hidrocoloides-propiedades#menu-14 (viewed: 13.11.2024.)

Šmídová Z., Rysová J. (2022). Gluten-Free Bread and Bakery *Products Technology*. *Foods*, 11(3), 480. Available: https://www.mdpi.com/2304-8158/11/3/480 (viewed 11.11.2024.)

Tres A., Tarnovska N., Varona E., Quintanilla-Casas B., Vichi S., Gibert A., Vilchez E., Guardiola F. (2020). Determination and Comparison of the Lipid Profile and Sodium Content of Gluten-Free and Gluten-Containing Breads from the Spanish Market. Plant Foods for Human Nutrition. Vol. 75, p. 344–354. Available: https://link.springer.com/article/10.1007/s11130-020-00828-w (viewed 30.10.2024)

Wesleya S. D., Andréa M. H. B., Clerici S. P. T. M. (2021). Gluten-free rice & bean biscuit: characterization of a new food product. Heliyon, Vol. 7, Issue 7. Available: https://www.cell.com/heliyon/fulltext/S2405-8440(21)00061-X (viewed 09.11.2024.)

Wilman L. (2015). The study of gluten-free flour and its products. Doctoral thesis. p. 21. Available: https://llufb.llu.lv/dissertation-summary/food-science/Laila_Vilmane_prom_darba_kopsavilk2015_LLU_PTF.pdf?utm_ (viewed: 09.11.2024.)

Ziobro R., Juszczak L., Witczak M., Korus J. (2015). Non-gluten proteins as structure forming agents in gluten free bread. Journal of Food Science and Technolgy; 53(1):571–580. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC4711467/?utm_source= (viewed 07.11.2024.)