UDC 637.52:635.11:664.834.1:637.56:664.951.7
DOI: 10.15587/1729-4061.2023.286323

SAUSAGE TECHNOLOGY FOR FOOD SUSTAINABILITY: RECIPE, COLOR, NUTRITION, STRUCTURE

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Food sustainability is a new concept of sustainability, which is complemented by the criteria of culture, eating traditions and food availability. However, the technology of sausage products was not created for the criteria of food sustainability. Technology was developed using dietary, local, seasonal and economically available semi-finished products with a long shelf life, which is a component of food sustainability, public health and zero hunger. Dried semi-finished products from beets and snails are used as a food coloring, a source of nitrites, complete protein, unsaturated fatty acids and minerals. Research shows the technology of red sausages, which is based on white sausages in Poland (Biała kiełbasa) and Germany (Weißwurst) and its analysis in terms of food sustainability. Dried beetroot was added to recipe in amount of 0 % (B0), 0.5 % (B1), 1.0 % (B2), 1.5 % (B3), 2.0 % (B4) and 2.5 % (B5) to chicken fillet. Pork rind is replaced in recipe with snail powder 0 % (B0), 15 % (B1), 30 % (B2), 45 % (B3), 60 % (B4) and 75 % (B5). Color of red sausages for B3 was best combined with Ukrainian cuisine. Texture profile analysis for B3 had similar values to B0 for chewiness at 306.6. Overall acceptability of B3 was higher than B0 by 8.92 % and amounted to 8.67. Physicochemical indicators for B3, such as pH 5.81, peroxide value 0.248 g/100 g and thiobarbituric acid reactive substances 0.667 mg/100 g were better than B0. For B3 moisture content was 57.81 %, protein 15.72 %, ash 3.36 % and fat 3.40 %. This research is development of method for production of other food products to meet the criteria of food sustainability. Red sausages can be used for food in households, restaurants, fairs and festivals

Keywords: sustainability, food systems, European cuisine, dried beet, snail powder, recipe optimization, meat products

Received date 09.06.2023
Accepted date 18.08.2023
Published date 30.08.2023

***How to Cite**: Liu, Y., Helikh, A., Filon, A., Duan, Z. (2023). Sausage technology for food sustainability: recipe, color, nutrition, structure. Eastern-European Journal of Enterprise Technologies, 4 (11 (124)), 47–58. doi: https://doi.org/10.15587/1729-4061.2023.286323*

1. Introduction

In light of global climate change, the relevance of sustainable food consumption is increasing, but access to it is not evolving accordingly [1]. While there is consensus on the need to move towards more sustainable food systems, the transition from a conceptual approach to a more practical understanding of food systems remains a research frontier [2]. The sustainable development of the food system is a cornerstone of the global survival and development of humankind. Ways to transform the food system include creating a global food system with benefit sharing, cleaner production, and equitable participation, improving the innovative capacity of the food system, and creating an effective organizational system of guarantees [3]. Issues of health and sustainable development have become a central topic of dialog both in the scientific community and among the public. Individual human choices have profound, favorable or unfavorable effects on their health and ecological footprint [4].

Food security, when viewed from a global perspective, encompasses both the sustainable production of high-quality food and the reduction of food waste. The production of foods should be resource-saving and contribute to economic growth due to the sustainable use of natural capital [5]. A significant part of plant raw materials, used only for animal feed and classified as food waste, does not have technologies for processing into food products [6, 7]. Improper use of these raw materials worsens food sustainability of the population, causes food shortages, and slows down the transition to plant nutrition [8]. There are many studies on the processing of agricultural products, such as press cake and meal of oil crops, but the studies do not directly specify the processing of food waste. While the technology for obtaining protein isolate from press cake and meal is very effective and involves their use during food production. Markers of such studies as sustainable would be a navigator for the food industry [9]. Global warming and malnutrition are two important aspects that are addressed in sustainable development. On the one hand, global warming has had a serious negative impact on the quality of life and the efficiency of several productive sectors. On the other hand, malnutrition is a complex problem worldwide, affecting about 60 % of the planet's population [10]. Despite various food management studies structured around alternative food systems, analysis of the main characteristics that contribute to food system sustainability has not yet been comprehensively explored [11]. Food systems include the production, transportation, processing, and consumption of food, including food loss and waste. They currently do not provide what is expected or needed to ensure a full contribution to societal well-being and environmental sustainability [12]. The focus on new food production methods and the advancement of sustainable foundations has changed the definition of sustainable foundations themselves. Cultural and technological sustainability is becoming an increasingly important addition to the traditional concept of sustainability. In addition, new technologies and food production systems are influenced by ancient production methods, as well as beneficial crop selection [13].

Food sustainability is unique to each country, culture, and eating habit, requiring individual point-by-point analysis. Therefore, research aimed at the development of food products for food sustainability and methods of their production is relevant.

2. Literature review and problem statement

Food industry is integrating environmental, social, and health dimensions to increase its sustainable impact. To this end, they use new tools to calculate the potential performance of food products with a lower environmental impact. The search, improvement, and introduction into production of new tools for sustainable development remains the front of research [14]. Despite accumulated evidence that the current agricultural model is unsustainable, scientists are far from understanding the consequences of the loss of functional diversity for the functioning and provision of ecosystem services, as well as the potential long-term threats to food security and human well-being [15]. Both technological changes and institutional features, including regulatory and cultural-cognitive rules, can cause the transition of agriculture to sustainable development [16]. The industrial food system is considered unsustainable due to its undesirable impact on the climate and human health. One of the proposed alternatives to these problems is a more local food supply system. This means involving individuals, households, and communities in the cultivation and purchase of food products such as vegetables and livestock products to ensure the concept of "food self-sufficiency" [17]. The concept of "food self-sufficiency" includes the ease of growing plants or breeding animals that are local to the region, resistant to climate change, and ensure gender equality. Failure to adhere to these concepts is one of the main causes of food insecurity in Africa, which requires the development of private households and sustainable strategies to reduce women's vulnerability [18]. A variety of wild species can be cultivated at private farms and households for food self-sufficiency, and their shortages can be supplemented from natural ecosystems to ensure food sustainability. Specific examples of growing wild species and introducing them into the diet of the population are not enough to create a sustainable concept of "food self-sufficiency" [19].

Beet semi-finished products, which are an excellent food additive, play an important role in food sustainability, as their production is organic, local, and seasonal for most countries of the world [20]. Beetroot is widely used in cooking due to its high content of nutrients [21]. Not only beets but also other local products can be used to ensure the food sustainability of the region. A great example is the pumpkin, which can be processed into food products under the conditions of zero-waste production. Pumpkin pulp is used to prepare traditional culinary dishes, or it is dried to obtain food coloring and a source of nutrients. However, pumpkin is mostly orange in color, which limits its use as a food coloring, especially in meat products, unlike beets. Oil is obtained from pumpkin seeds, and press cake is processed into a protein isolate used in plant diets, due to its content of all essential amino acids [22]. Protein isolate from pumpkin seed press cake will complement dried beets to create food coloring that are universal in their nutrient composition. Beetroot is part of the traditional cuisine of Europe, but understanding of its practical value in food sustainability is limited. A large number of experiments proved that beets have various biological activities that have medicinal potential and can be used in the food industry as a bioactive ingredient [23, 24]. Beets contain a large number of bioactive phytonutrients, such as betalains, polyphenols, betains, saponins, flavonoids, and nitrates [25]. The results show that the carotenoid content of beets can vary depending on the species, variety, geographical location of production (region, ground), and time of harvest. This should be considered when finalizing data for nutrient composition databases [26]. 5-methyltetrahydrofolate is the main form of folate in beets. Differences in varieties and growing conditions have a pronounced effect on the content of folic acid in beets. Processing results in significant losses of folate, while losses during storage were found to be moderate [27]. These substances, useful for human health, are also present in beetroot powder and have antioxidant properties [28]. A diet rich in natural antioxidants improves health and heals a human [29].

One of the important food additives applied in the food industry is betalain, which is used as a natural colorant. Red beetroot is the most common source of betalain, so research into its drying and encapsulation methods is constantly being conducted to improve quality characteristics and shelf life [30]. Beet is widely used in the food industry to obtain betalain, which is confirmed by studies of effective extraction from beet powder [31]. Betalains occur in two forms, namely betacyanin (red-purple pigment) and betaxanthin (yellow-orange pigment) and are commercially known as food coloring [32]. Beet betaine is a trimethyl derivative of the amino acid glycine, which promotes human health [33]. Not only root crops are suitable for betalain biosynthesis, but also beetroot leaves, which is confirmed by research of betalain content in variously colored beetroot leaves [34]. Beet chips and beet powder have the highest antioxidant potential among other semi-finished products based on them [35]. Beetroot juice is obtained, which is a rich source of irreplaceable phytochemicals. Beetroot pomace is a rich source of essential phytochemicals. Beet pomace powder has various functional properties, widely used in food products and has significant benefits for human health [36]. Due to the biologically active compounds of beets and their ability to model the intestinal microbiota and improve the health of the gastrointestinal tract, it classify beetroot as value-added functional foods [37].

Pretreatment is widely used before drying agricultural products to inactivate enzymes, accelerate the drying process, and improve the quality of dried products [38]. Damage to the cell membrane and changes in pectin structure in cell walls due to freeze-thaw pretreatment significantly affected the permeability and drying rate of the samples. The high rate of drying of freeze-thawed samples is also explained by the formation of ice crystals, which promote water migration [39]. Freeze-thaw pretreatment reduced drying time and energy consumption due to water loss, increased free water, and formation of porous structures. Freeze-thaw pretreatment improved the thermal stability, antioxidant activity of polysaccharides, taste, and chemical composition of dried products [40]. Destruction of the structure, decrease in volume, mechanical resistance, and skin thickness during freezing/thawing promoted heat and moisture exchange during drying of vegetables, which reduced drying time and energy consumption [41]. To improve the quality of freeze-thawed products and increase the energy efficiency of their production, it is possible to apply innovative technologies that are not widely used in the food industry [42].

Many types of food raw materials that are common in Ukraine but are not used in the traditional diet of the population. A comprehensive analysis of a non-traditional food product from cultivation technology to nutritional value allows its use as a full-fledged food product and raw material for culinary products. On the other hand, traditional raw materials of Ukrainian cuisine, such as spices, are not grown in Ukraine and are imported from other countries. Traditional meat raw materials have many disadvantages during cultivation. This is due to the general technology of livestock breeding, which in many cases is harmful to human health and has a high impact on the climate of planet. Traditional meat raw materials, such as pork and beef, do not meet the criteria of food sustainability (dietary and economically affordable). Therefore, unconventional food raw materials common in Ukraine require comprehensive research [43]. Snails of marine, aquatic, and land origin have been eaten by humans since prehistoric times and remain a delicacy in many parts of the world [44]. Thanks to cost-effective growing conditions with low carbon emissions and high nutritional value of snail meat, it is possible to classify them as a sustainable food source [45]. Models of waste-free processing of food products used in the bioeconomy make it possible to increase the economic efficiency and sustainability of food production [46]. Snails (land and freshwater) are a food product that can solve the problem of future global food shortages [47]. However, Roman and other edible snails are threatened with extinction in Europe due to overexploitation, habitat destruction, climate change, and the impact of predators and parasites [48]. To preserve snails in nature, it is necessary to expand their cultivation under Heliciculture conditions and investigate changes in natural and farm habitats [49]. Land snails are highly productive, take up relatively little space, are easy to breed, their maintenance does not require large financial costs, and they are promising animals for Heliciculture in Europe [50]. Meat of land snails has high protein quality, which is confirmed by the balanced composition of essential amino acids and the value of the protein efficiency coefficient, which is close to egg protein [51]. The amino acid composition of snail meat is qualitatively and quantitatively similar to the meat of freshwater bivalves [43]. Snail meat contains about 48 % polyunsaturated fatty acids and a significant amount of monounsaturated fatty acids, which is beneficial for human health [52].

Food sustainability for developing and least developed countries has not been adapted to the goals of sustainable development, and there are currently no effective methods for researching and improving it. Sustainable and innovative food ingredients do not have ways of effective implementation in the technology of sustainable food systems. Dried beetroot, pretreated by freeze-thaw method has a better nutritional composition and is more economically available due to the optimization of the drying process, which ensures its increased food sustainability. Snails have a high content of complete protein, unsaturated fatty acids, and minerals. Despite the high nutritional sustainability of snails, they are not processed into food semi-finished products and are not used in the daily diet of the population. Dried beetroot, pretreated by freeze-thaw method and snail powder are not used in sausage technology. Therefore, using the example of a meat product and several innovative ingredients, dried beetroot, pretreated by freeze-thaw method and snail powder, it is necessary to investigate its technology to meet the criteria of food stability.

3. The aim and objectives of the study

The purpose of our research is to create a technology of sausage products for food sustainability. It will make possible to obtain a high-quality food product developed from dietary, local, seasonal, and economically available raw materials that meet the criteria of food sustainability.

To achieve the goal, the following tasks are performed:

– to create a sustainable recipe and technology of culinary processing of sausage products to ensure food sustainability criteria using innovative and sustainable ingredients: beets pretreated by freeze-thaw and dried by microwave vacuum drying, and snails dried by solar drying and ground into powder;

– to investigate the color analysis of the developed sausage products;

– to determine the organoleptic properties, physico-chemical parameters and nutritional value of the developed sausage products;

– to analyze the texture profile of the developed sausage products.

4. Materials and methods

4. 1. The object and hypothesis of the study

The object of our research is the technology of sausage products, which corresponds to the concept of sustainable development and food systems sustainability. The hypothesis of the study suggests that creation of new recipe and technology of culinary processing of sausage products, using innovative and sustainable ingredients, will allow to develop a food product that meets the criteria of food sustainability.

4. 2. Materials, chemicals, and reagents

Fresh beetroot (*Beta vulgaris L. subsp. vulgaris var. conditiva Alef.*), fresh snail meat without shell (*Helix pomatia*) were purchased from a local market in Xuzhou, China. Beets and snail meat were stored in a refrigerator (4 °C) until further use. Ingredients for sausages are chicken breast, dried beetroot, snail powder, pork rind, potato starch, ice, salt, dried garlic, ground mustard, dried marjoram, nutmeg, white pepper, white cooking wine, tripolyphosphate, sodium isoascorbate, casings (salted pork intestines), and fermented alcohol (for steam cooking).

Main reagents. Analytical reagents were petroleum ether, trichloromethane, glacial acetic acid, potassium iodide, sodium thiosulfate, potassium hydroxide, sodium chloride, copper sulfate, potassium sulfate, sulfuric acid, ether, hydrochloric acid, and thiobarbituric acid.

4. 3. Instruments and Equipment

Texture analyzer (TA.XT PLUS, Stable Micro Systems Ltd., London, UK), colorimeter (CR-400, Konica Minolta Sensing, Inc., Tokyo, Japan), hot air drying oven (DHG-9245A, Shanghai Yiheng Scientific Instrument Co., Ltd, Shanghai, China), pH meter (FE20, Mettler Toledo Co., Ltd, Switzerland), microwave vacuum dryer (WBZ-10, Guiyang Xinqi Microwave Industry Co., Ltd, Guiyang, China), moisture analyzer (HX204, Mettler Toledo Co., Ltd, Switzerland), muffle furnace (KSL-1200X, Hefei Kejing Material Technology Co., Ltd), Kjeldahl nitrogen analyzer (ATN-300, Shanghai Hongji Instrument Equipment Co., Ltd, China), fat analyzer (SZF-06, Shanghai Xinjia Electronics Co., Ltd, China).

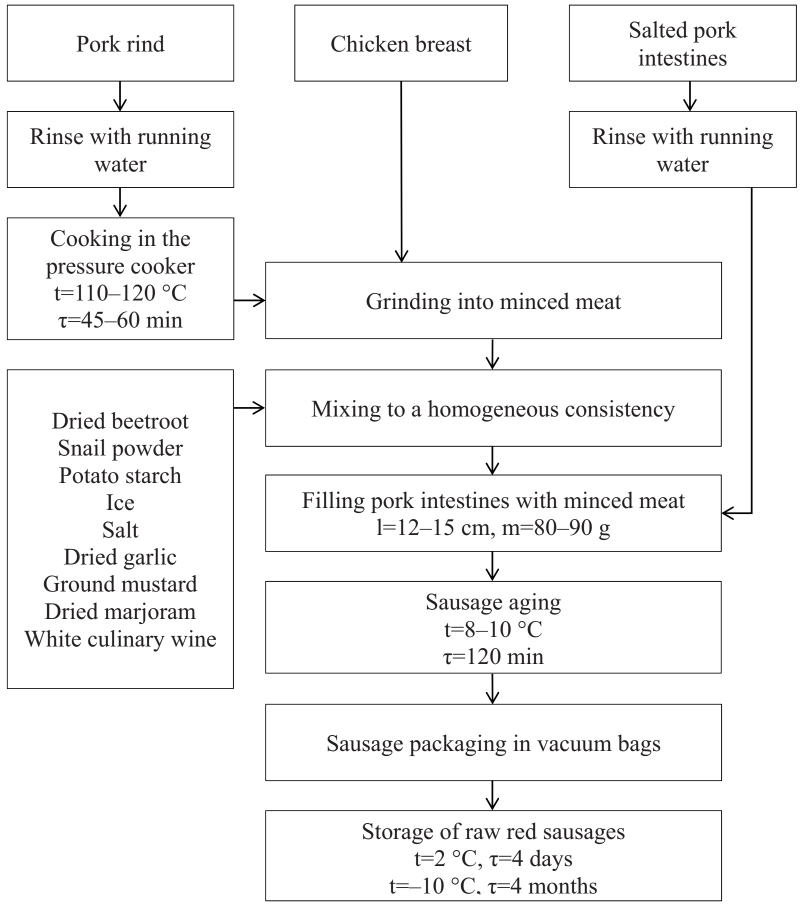

Fig. 1. Technological scheme of semi-finished red sausages

4. 4. Preparation of snail powder

Fresh snail meat is salted in tuzluq for an hour, washed with water, and dried in the sun, on nets in one layer, to a moisture content of 20 %. Dry snail meat is ground to a powdery consistency and passed through a 200-micron sieve. Snail powder is packed in vacuum bags and stored for further use.

4. 5. Freeze-thaw pretreatment

Before experiments, fresh beetroots were washed with tap water to remove surface impurities, peeled and then sliced crosswise into slices with 7.5 cm in diameter and 4 mm in thickness using a stainless steel slicer. Fresh beetroot slices were put into a polyethylene bag, then put them in the refrigerator (-20 °C) to freeze for 12 h, and then thawed in the refrigerator (4 °C) for 12 h.

4. 6. Preparation of beetroot powder

Freeze-thawed pretreated beetroot slices (300.0±2.0 g) were evenly placed on a tray (61×43×5 cm), and the tray was placed in a microwave vacuum oven. The degree of vacuum was set to –90 kPa. The microwave vacuum drying was first performed at microwave power of 700 W. After drying for 45 min, the microwave power was switched to 400 W to continue drying. The microwave vacuum drying process was stopped, as the final moisture content of beetroot slices was lower than 7.0 %. Dried beetroot slices were subjected to a grind, and then passed through 60-mesh sieve. Beetroot powder was packed in a polyethylene bag and stored at 25° C for further use.

4. 7. Processing of red sausages

The production technology of sausages is shown in Fig. 1.

The production of traditional European white sausages, Biała kiełbasa and Weißwurst, is taken as the basis for the technology of red sausages. This technology was refined according to the requirements of food sustainability. Recipe ingredients for the control sample, which differ from the tested samples with beetroot and snail powder, are added to the minced meat at the stage of mixing it to a homogeneous consistency.

4. 8. Sensory evaluation of red sausages

Group of 20-trained specialists from the School of Food and Bioengineering, Hezhou University, China, conducted a sensory evaluation. Before participating in the sensory evaluation, the specialists were trained on the sensory descriptors of the different sausages. A ten-point hedonic scale was used to test the color, odor, flavor, texture and overall acceptability of sausage samples. The hedonic scale consisted of ten points: 1 – terrible; 2 – don't like it very much; 3 – dislike moderately; 4 – don't like it a bit; 5 – neither likes nor dislikes; 6 – like it slightly; 7 – moderately liked; 8 – really like it; 9 – like it very much; 10 – excellent.

4. 9. Determination of moisture content and pH of red sausages

The moisture content of the sausages was determined using a moisture analyzer (HX204, Mettler Toledo Co. Ltd., Switzerland) at 105 °C until constant weight was reached. The pH value of the samples was determined using a pH meter. Having taken 10 g of meat emulsion, and then cut them with scissors, added 100 ml of distilled water, mixed, and left for 10 minutes. The supernatant was collected, and the pH value was measured six times.

4. 10. Color determination of red sausages

The L^*, a^*, and b^* values of the sausages were measured with a colorimeter (CR-400, Konica Minolta Sensing, Inc., Tokyo, Japan) operated with a D65 light source, a viewing angle of 10°, and a CIELAB system. L^*, a^*, and b^* values were determined as indicators of lightness, redness, and yellowness, respectively. Eight measurements were taken for each group sample and the mean value was calculated.

4. 11. Texture characteristics analysis of red sausages

Texture profile analysis (TPA) of sausages was performed according to the double compression method using a texture analyzer (TA.XT PLUS, Stable Micro Systems Ltd., London, UK) equipped with a cylindrical probe (P50) [53]. The sample was compressed twice, with a delay of 5 s between the dips, a preliminary speed of 5 mm/s; test speed and post speed 1 mm/s; compression ratio 50 %; descent force 5.0 g. The following parameters of the texture profile were quantified: hardness, springiness, cohesiveness, resilience, and chewiness. Results are averages of at least eight replicate runs for each treatment per batch.

4. 12. Determination of thiobarbituric acid reactive substances and peroxide value of red sausages

The index of thiobarbituric acid reactive substances (TBARS) was determined according to the method of Bruna et al. [54]. The peroxide value was determined according to the procedure described in "National standard for food safety –Determination of peroxide value in foods" [55]. All measurements were performed 6 times.

4. 13. Determination of protein, fat, and ash content of red sausages

Protein content was analyzed using an automatic Kjeldahl nitrogen analyzer [56]. The fat content was determined by the Soxhlet extraction method according to AOAC (2006) [56]. The ash content of the samples was measured according to AOAC (2000) [57]. All measurements were performed 6 times.

4. 14. Statistical analysis

Results were expressed as mean±standard deviation (SD). Statistical analysis was performed using SPSS Statistics Version 20 (IBM Corporation, Chicago, IL, USA). Differences in mean values were compared according to one-way analysis of variance (ANOVA) and Tukey's multiple range test. A value of $p<0.05$ was considered significant.

5. Results of research of sausage technology for food sustainability

5. 1. Development of sausage technology for food sustainability

To determine the compliance of food products with the principles of sustainable development, it is necessary to analyze their technology for compliance with the main criteria of food sustainability. The main criteria of food sustainability used in this study are food culture and traditions, dietary, local, seasonal, and economically available raw materials. The criteria of food culture and traditions are ensured by production technology, culinary processing, and serving of sausages. The development of sausage technology included the use of dietary, local, seasonal and economically available semi-finished products with a long shelf life, which is a component of food sustainability, public health, and zero hunger. The criteria of dietary, local, seasonal and economically available raw materials were ensured by changing the ingredients of the recipe. Non-traditional ingredients were added in the form of powder in a small amount to preserve the traditional organoleptic of sausages.

The recipe of red sausages (Table 1), cooking and serving (Fig. 2), is based on the traditional recipe for making white boiled sausages in Poland (Biała kiełbasa) and Germany (Weißwurst). In Poland, white sausages are usually made from pork, and in Germany with the addition of pork in the recipe [58, 59]. To ensure the traditional texture of minced meat in sausages, it is necessary to add pork fat in a significant amount, so traditional white sausages do not meet the requirements of dietary nutrition.

Ukraine is a habitat for snails, which are easy to grow under Heliciculture conditions and as mini-livestock on households, satisfying the criteria of food sustainability. Snails are seasonal raw materials, so they must be preserved for storage. To increase the shelf life and use during the year, the snails were dried in the sun and ground into powder for further use in the recipe. Snails can be stored in pieces and chopped just before use. For dietary nutrition, the fat content of the developed sausage has been reduced by replacing part of the pork rind with snail powder in the recipe. Snail powder will additionally fortify the sausages with complete protein since the main part of pork rind proteins are connective tissue. Snail powder is a source of poly- and monounsaturated fatty acids, which are beneficial for human health. Snails can be easily farmed as mini-livestock that do not require a special ration to meet food sustainability needs.

The most common first hot dish in Ukraine is borsch and white sausages are great as a side meal to first dishes served as a main course. However, white sausages for Ukraine should be in shades of red to complement harmoniously the dishes of Ukrainian cuisine. Dried beetroot, pretreated by freeze-thaw method was chosen as a red food coloring. Beetroot powder was obtained using microwave vacuum drying. Beetroot has been grown on the territory of Ukraine for centuries, which ensures its high yield and undemanding storage conditions, which meet the criteria of food sustainability.

5. 1. 1. Sustainable recipe of red sausages

Dried beets were added to the recipe in the amount of 0 % (B0), 0.5 % (B1), 1.0 % (B2), 1.5 % (B3), 2.0 % (B4), and 2.5 % (B5) from the weight of the chicken fillet. Pork rind is replaced in the recipe with snail powder in different ratios of 0 % (B0), 15 % (B1), 30 % (B2), 45 % (B3), 60 % (B4), and 75 % (B5). The ingredients used for the cooking of red sausages are listed in Table 1.

Each recipe ingredient was checked for compliance with food sustainability criteria (dietary, local, seasonal and economically available food raw materials) and replaced, if necessary, with sustainable for Ukraine. Recipes of white sausages traditional for Europe, Biała kiełbasa [58] and Weißwurst [59], have recipe ingredients that do not meet the criteria of food sustainability in Ukraine, Poland, and Germany (Table 1). Despite the fact that these recipe ingredients have been used for many years, they are mostly non-dietary (pork, pork rind), imported from other countries (spices), or do not meet the criteria of economic availability (veal, pork). The control sample is an industrial version of the sausages with the addition of raw materials, which are traditional for white sausages but do not meet the criteria of food sustainability, and also contain stabilizers and antioxidants. Culinary wine is used to improve organoleptic indicators, texture, and increase the shelf life of sausages during industrial production. If the community does not have access to cooking wine, it is advisable to replace it with ice. Access to ice at different times of the year can also significantly reduce economic availability, so it is advisable to use cold water during such periods.

Snail powder is used in the recipe as a source of complete protein, minerals, and unsaturated fatty acids. Dried beetroot, pretreated by freeze-thaw method is used in the recipe as a food coloring, a source of nitrites, and a source of nutrients. Innovative recipe ingredients meet the criteria of food sustainability in Ukraine (dietary, local, seasonal and economically available food raw materials).

White sausages in Poland (Biała kiełbasa) and Germany (Weißwurst) are traditionally served as an independent dish with sauces or as a side meal to the first hot dishes [57, 58]. This serving is close to the culture and traditions in Ukraine, as meat products are also served with sauces and can be served as a side meal. Red sausages are served as an independent dish with horseradish sauce, mustard sauce, and fish sauce, and flour products, 2 pieces per serving, or as a side meal to the first hot dishes, such as borsch. This technology of culinary processing and serving is most satisfying to the culture and traditions of Ukrainian cuisine. Fermented alcohol improves organoleptic parameters. The peculiarities of fermented alcohol effect on the process of cooking sausages should be further investigated. Fermented alcohol is not necessarily used in cooking as its use reduces the economic availability of red sausages. Steam cooking is a technologically simple and dietetic technique of heat treatment that meets the criteria of food sustainability (dietary and economically available food).

Table 1

Sausage recipes with dried beetroot and snail powder

Traditional ingredients of white sausages in Poland, Biała kiełbasa [58]	Traditional ingredients of white sausages in Germany, Weißwurst [59]	Sustainable ingredients, g/kg	Control	Red sausage samples				
			B0	B1	B2	B3	B4	B5
Pork	Veal	Chicken breast	600	600	600	600	600	600
Beef	Pork							
–	–	Dried beetroot	–	3	6	9	12	15
–	–	Snail powder	–	15	30	45	60	75
Pork rind	Pork rind	Pork rind	100	85	70	55	40	25
–	–	Potato starch	100	97	94	91	88	85
Ice	Ice	Ice	140	140	140	140	140	140
Salt	Salt	Salt	10	10	10	10	10	10
Garlic	Onion	Dried garlic	–	4	4	4	4	4
–	Fresh parsley	Ground mustard	–	2	2	2	2	2
Marjoram	Lemon powder	Dried marjoram	–	2	2	2	2	2
–	Nutmeg	Nutmeg	6	–	–	–	–	–
–	Pepper	White pepper	2	–	–	–	–	–
–	–	White culinary wine	40	42	42	42	42	42
–	–	Tripolyphosphate	1.5	–	–	–	–	–
–	–	Sodium isoascorbate	0.5	–	–	–	–	–

5. 1. 2. Sustainable cooking technology of red sausages

Red sausages are made according to the technological scheme shown in Fig. 2. Steam cooking with the addition of fermented alcohol at a temperature of 100–104 °C was chosen as the heat treatment method.

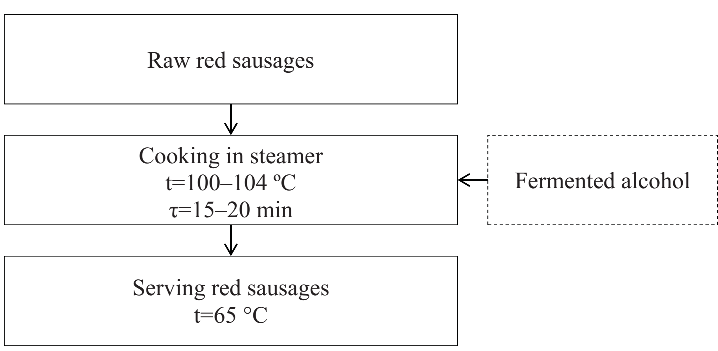

Fig. 2. Cooking red sausages

5. 2. Red sausage color parameters

Color characteristics of red sausages, which are affected by the addition of beetroot powder, are shown in Fig. 3. Color parameters demonstrated a significant effect of adding beetroot powder to red sausages. From Fig. 3, it can be seen that compared to the control sample (B0), with the increase of beet powder, the L^* values of red sausages decreased significantly ($p<0.05$), indicating that the red sausages became darker. The addition of beetroot powder led to an increase in a^* values for red sausages and was the largest for sample B5. The results showed that the beetroot powder was very effective in increasing the redness and maintaining the desired red color of the red sausages, which is related to the content of betalains in the beetroot powder. The use of beetroot powder in the recipe of red sausages caused an increase in yellowness indicators b^* ($p<0.05$), which began to decrease with the addition of a larger amount of beetroot powder.

Beetroot powder showed efficacy as a food coloring, while snail powder did not significantly affect the color of red sausages. The presence of natural nitrates in the composition of beetroot powder and the formation of nitrites during the production of minced meat and sausages contributed to the preservation of their color.

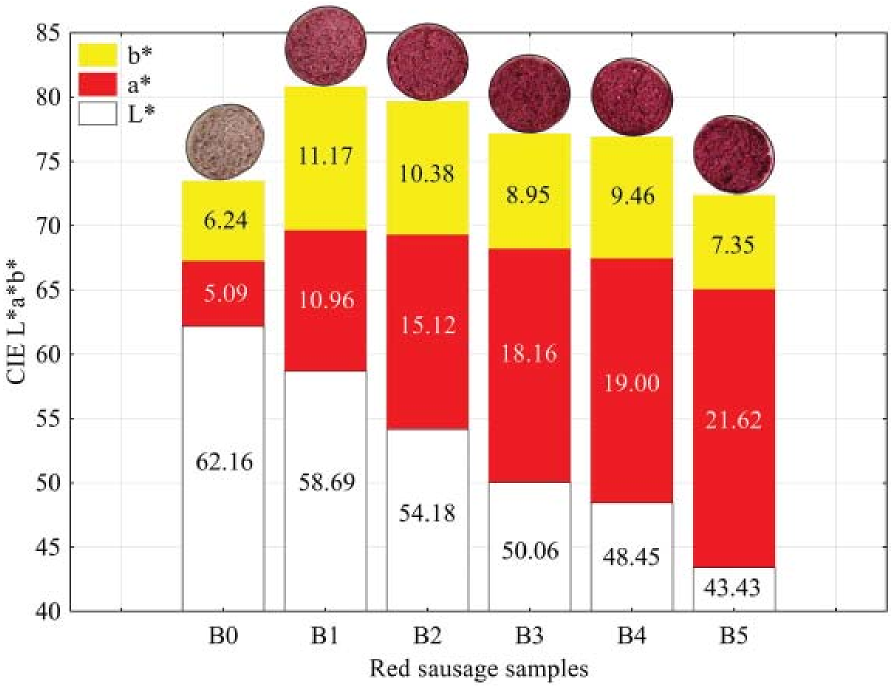

Fig. 3. Ratio of colors and photo of minced red sausages *n*=8

beetroot and snail powder significantly affected the pH value of red sausages. The addition of dried beetroot and snail powder significantly reduced the pH value of red sausages (p<0.05). The lowest pH value was 5.81 for sample B3. Lipid oxidation is one of the main factors affecting the quality characteristics of meat products as it can lead to the development of rancidity and affect the nutritional value, color, and flavor of the products. Peroxide value is the first intermediate product after lipid oxidation. It is extremely unstable and can decompose into small molecular substances such as acids, aldehydes, and ketones. Therefore, the peroxide value can determine the degree of lipid oxidation. Due to the addition of dried beetroot and snail powder, the peroxide value of red sausages decreased significantly (p<0.05) compared to the control sample (B0). This demonstrates that dried beetroot and snail powder can reduce lipid oxidation in sausage products. The TBARS value reflects the result of the reaction between a secondary substance formed as a result of the oxidation and decomposition of unsaturated fatty acids in the oil and malondialdehyde, which can indicate the degree of secondary oxidation of the fat. The addition of dried beetroot and snail powder resulted in a significant decrease in TBARS values for red sausages (p<0.05) compared to the control sample (B0). The smallest value of TBARS was 0.667 mg/100 g for sample B3. This may be due to beetroot powder, which has antioxidant properties and tends to reduce lipid oxidation in red sausages. The antioxidant properties of snail powder have not been studied to date.

5. 3. Quality characteristics of red sausages

5. 3. 1. Organoleptic evaluation of red sausages

As shown in Table 2, the addition of beetroot powder had different effects on the color, odor, flavor, texture, and overall acceptability of red sausages. Beetroot powder significantly influenced the color (Fig. 3) and flavor of the developed sausage (p<0.05). Snail powder significantly affected the texture and flavor of red sausage (p<0.05).

Table 2

Organoleptic evaluation of red sausages

Sample	Color	Odor	Flavor	Texture	Overall acceptability
B0	7.02±0.11*e*	8.01±0.14*a*	8.41±0.15*ab*	8.33±0.07*b*	7.96 0.16±*b*
B1	7.74±0.11*d*	7.24±0.11*bc*	7.93±0.12*c*	8.02±0.08*c*	7.75±0.11*bc*
B2	8.30±0.16*c*	7.44±0.11*b*	8.19±0.09*b*	8.21±0.07*b*	8.00±0.10*b*
B3	9.75±0.11*a*	7.88±0.19*a*	8.33±0.12*ab*	8.64±0.11*a*	8.67±0.08*a*
B4	9.38±0.10*bc*	7.98±0.12*a*	8.52±0.10*a*	8.67±0.12*a*	8.72±0.13*a*
B5	9.51±0.08*b*	7.80±0.16*a*	8.40±0.16*ab*	8.62±0.13*a*	8.69±0.07*a*

Note: results are expressed as mean±SD (n=8). Values with different letters in the same column indicate a significant difference (p<0.05)

Sensory evaluation of red sausages containing dried beetroot and snail powder was better than control sample (B0). In addition, due to the influence of color and texture on other sensory perceptions, red sausages had higher overall acceptability scores.

5. 3. 2. Lipid oxidation and pH of red sausages

In order to increase the shelf life and ensure food sustainability criteria, it is important to determine the oxidation of lipids and the pH of red sausages, which are given in Table 3.

The pH value is one of the commonly used physicochemical parameters for evaluating the quality of meat products, which can indirectly reflect the microbial characteristics and sensory quality of meat products. The addition of dried

Table 3

Lipid oxidation and pH of red sausages

Sample	pH	Peroxide value, g/100 g	TBARS, mg/100 g
B0	6.04±0.01a	0.326±0.006a	0.973±0.036a
B1	5.94±0.01b	0.301±0.005b	0.781±0.014b
B2	5.84±0.01cd	0.270±0.007c	0.720±0.022bc
B3	5.81±0.03d	0.248±0.005d	0.667±0.038c
B4	5.86±0.03c	0.249±0.008d	0.671±0.030c
B5	5.91±0.03b	0.253±0.009d	0.673±0.027c

Note: results are expressed as mean±SD (n=6). Values with different letters in the same column indicate a significant difference (p<0.05)

5. 3. 3. Nutritional value of red sausages

The nutritional value of red sausages enriched with dried beetroot and snail powder is given in Table 4.

With increasing addition of powders, moisture gradually increases significantly (p<0.05). For samples B3 and B5, the average moisture content increased by 13.0 % compared to the control sample B0. Such changes are caused by significant absorption of moisture during the recovery of powders in minced meat. The presence of a significant amount of dietary fiber in the beets also contributed to the preservation of moisture in the red sausages. The higher moisture content of the red sausages improved the texture and overall acceptability of the sausages (Table 3), especially for sample B3, and the texture scores were close to the control sample B0 (Table 2).

The ash content in red sausages significantly increased with the addition of dried beetroot and snail powder ($p<0.05$). On average, the increase was 8.93 % compared to the control sample B0. With increasing addition of dried beetroot and snail powder to the recipe of red sausages, a slight decrease in fat content was observed ($p>0.05$). The addition of beetroot and snail powders to the red sausage recipe increased the protein content, but significant changes were observed only for sample B1, which had 5.71 % more protein than the control sample B0. In other samples of red sausages, the protein content did not increase significantly ($p>0.05$). Despite the fact that beetroot and snail powders contain a significant amount of protein, the recipe itself is based on chicken fillet, and its quality composition has the greatest impact on the protein content of the final food product.

Table 5

Texture profile analysis of red sausages

Sample	Hardness, g	Springiness, %	Cohesiveness, %	Resilience, %	Chewiness
B0	3138.1±175.3*c*	0.364±0.047*ab*	0.272±0.047*a*	0.070±0.009*a*	319.6±54.5*ab*
B1	2472.5±112.5*d*	0.377±0.044*a*	0.251±0.025*a*	0.075±0.010*a*	240.9±30.5*bc*
B2	3052.0±143.3*c*	0.316±0.027*b*	0.260±0.020*a*	0.071±0.007*a*	251.6±47.2*bcd*
B3	3640.7±131.3*b*	0.328±0.017*ab*	0.264±0.027*a*	0.070±0.009*a*	306.6±46.2*abc*
B4	2871.2±179.4*c*	0.304±0.022*b*	0.235±0.016*a*	0.064±0.005*a*	205.2±21.0*d*
B5	4391.3±138.4*a*	0.335±0.020*ab*	0.249±0.021*a*	0.067±0.007*a*	347.6±36.4*a*

Note: results are expressed as mean±SD (n=20). Values with different letters in the same column indicate a significant difference (p<0.05)

Table 4

Nutritional value of red sausages

Sample	Nutrient content, %			
	Moisture content	Protein	Ash	Fat
B0	51.14±0.31*c*	15.23±0.15*b*	3.09±0.01*b*	3.55±0.05*a*
B1	52.64±0.38*b*	16.10±0.20*a*	3.36±0.02*a*	3.45±0.05*a*
B2	53.31±0.45*b*	15.69±0.18*ab*	3.35±0.03*a*	3.43±0.09*a*
B3	57.81±0.41*a*	15.72±0.11*a*	3.36±0.01*a*	3.40±0.06*a*
B4	57.07±0.53*a*	15.68±0.17*ab*	3.37±0.02*a*	3.38±0.06*a*
B5	58.00 ±0.47*a*	15.80±0.10*a*	3.39±0.02*a*	3.39±0.09*a*

Note: Results are expressed as mean ± standard deviation (n=6). Values with different letters in the same column indicate a significant difference (p<0.05)

5. 4. Texture profile analysis of red sausages

In meat products, texture analysis can not only accurately reflect the sensory needs of consumers, but also reflect the structural integrity of the protein matrix and the state of connection with other components. Texture profile analysis of red sausages is given in Table 5. The chewiness had different values when added different amounts of dried beetroot and snail powder. For samples B3 and B5, chewiness was not significantly different from the control sample B0 ($p>0.05$), but it was significantly different for other samples ($p<0.05$). The chewiness was most affected by the hardness of red sausages, which was the highest for samples B3 and B5. The hardness of sample B3 was 16.0 % higher and the hardness of sample B5 was 39.9 % higher than the control sample B0.

Other parameters of the texture profile (springiness, cohesiveness, resilience) of the studied samples did not differ significantly from the control sample B0 ($p>0.05$).

6. Discussion of research results of sausage technology for food sustainability

The ingredients of red sausages confirm the effectiveness of their use to increase food sustainability (Table 1). Beets and snails are cultivated in households and farms and are common in the wild. Recipe components can be obtained not only by growing but also by collecting. In general, beets and snails are dietary, local, seasonal, and economically available food raw materials for the Ukrainian population. Red sausages meet the criteria of food sustainability, since the recipe and production technology are part of the concept of sustainable development [60]. The study of the quality composition of red sausages confirmed the effectiveness of their fortification with dried beetroot and snail powder and the replacement of other ingredients with stable ones. The color (Fig. 3), texture (Table 5), and general acceptability (Table 2) of red sausages improved compared to the control sample B0. The pH and degree of lipid oxidation of red sausages decreased (Table 3), which increases their shelf life. The extent to which the shelf life has increased should be determined in further research. The nutritional value of red sausages increased, which is confirmed by the increase in protein and ash content (Table 4). Despite the reduction in fat, its quality composition has improved with snail powder, but the exact content of beneficial mono- and polyunsaturated fatty acids remains to be investigated.

The features of our research are the creation of a food product that meets the criteria of food sustainability. New criteria, different from the generally accepted ones, were used to create new sustainable food systems [1–4]. The recipe of red sausages is supplemented with innovative food ingredients, dried beetroot, pretreated by freeze-thaw method, and snail powder, which were not used in sausage technology for food sustainability. Other recipe ingredients were also changed according to the criteria of food sustainability (Table 1), as well as cooking, which is a cost-effective and dietary way of food processing (Fig. 2). The research should be continued with the application of the principles of the circular economy for sustainable development, which is an effective method of its improvement [5, 6].

The main research limitations are the analysis of food sustainability for the needs of Ukrainian communities. Methods for evaluating food sustainability criteria are adapted to Ukrainian consumers and may not have significant practical value in countries with climatic and cultural differences. However, the general principles of food sustainability can be used to create food sustainability criteria in any corner of our planet [60].

Among the shortcomings, it should be noted that only one type of sausage products is used, which does not provide a variety of food products. In further studies, several different types of sausages should be compared. However, under the conditions of an urgent need for food, which ensures food sustainability of communities, red sausages create a basis for further research.

The given research methodology allows using red sausages as a model for creating food recipes to ensure food sustainability [60]. Beetroot and snail powders is suitable not only for meat products, but also for confectionery and bakery production. The lack of complete protein, pigments, unsaturated fatty acids, and dietary fiber is an unsolved problem for the adaptation of these industries to food sustainability and resistance to world hunger. Our technology of red sausages, meeting the sustainability criteria, could be effective for confectionery, bakery, meat industries, and restaurant industries, including fairs and festivals.

When conducting further research, special attention should be paid to raw materials, production technology, and culinary processing of food products that must meet the criteria of food sustainability. Their incorrect selection can create obstacles for the correct conduct of research and reduce the practical value of research results. It is necessary to investigate in more detail the conditions and periods of storage that have a significant impact on food sustainability.

7. Conclusions

1. A sustainable recipe and a sustainable technology for the culinary processing of sausages have been created to ensure the criteria of food sustainability. The addition of innovative and sustainable ingredients to the recipe (beets, pretreated by freeze-thaw and dried by microwave vacuum drying; snails, dried by solar drying, and ground into powder) significantly improved the food sustainability and quality of red sausages. Dried beetroot were added to the recipe in the amount of 0 % (B0), 0.5 % (B1), 1.0 % (B2), 1.5 % (B3), 2.0 % (B4), and 2.5 % (B5) from the weight of the chicken fillet (Table 1). Pork rind is replaced in the recipe with snail powder (Table 1) in different ratios of 0 % (B0), 15 % (B1), 30 % (B2), 45 % (B3), 60 % (B4), and 75 % (B5). Other recipe components, which are traditional for the recipe of sausages, but do not meet the criteria of food sustainability (pork, pork rind, veal, spices), have been replaced with sustainable for Ukraine. The technology of cooking includes steaming with the addition of fermented alcohol, which is a technologically simple and dietetic method of heat processing, to ensure the criteria of food sustainability.

2. The addition of beetroot powder significantly affected the color of the sausages. Since red sausages were made for Ukrainian cuisine, the red color was important in determining the organoleptic evaluation. The tasting group of experts highly rated the color indicators of red sausages. As the amount of dried beetroot in the sausages increased, their color became darker. Natural nitrates, containing a significant amount in dried beetroot, improved the color of red sausages. During the ripening of sausages, part of the nitrates turned into nitrites, which helped stabilize the color at all stages of the red sausages technology. Snail powder showed no effect on color as it was close to the color of chicken breast, which is the main ingredient in the red sausage recipe.

3. The organoleptic properties, physicochemical parameters, and nutritional value of red sausages improved with the addition of beetroot and snail powders. These indicators were the best for sample B3. The overall acceptability of B3 was higher than B0 by 8.92 % and was 8.67. Physicochemical parameters for B3, such as pH 5.81, peroxide value 0.248 g/100 g, and thiobarbituric acid reactive substances 0.667 mg/100 g, were better than B0. For B3, the moisture content was 57.81 %, protein 15.72 %, ash 3.36 %, and fat 3.40 %. This is explained by the technological properties of dried beetroot and snail powder and their nutrient composition.

4. Texture profile analysis of the red sausages showed an increase in chewiness for sample B5, which had the highest amount of beetroot and snail powders in the recipe. Sample B3 had chewiness similar to B0, which was marked by improved texture and a higher organoleptic evaluation for red sausages.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The work is supported by the State Topic "Development of technical documentation for semi-finished products from vegetable raw materials with increased biological value for dual purposes" (0122U201635); State Topic "Development of technical documentation for dual purpose protein raw materials" (0122U201388); and State Topic "Development of technical documentation for a semi-finished product from vegetable raw materials for dual-use minced meat products" (0122U202024).

Data availability

All data are available in the main text of the manuscript.

Acknowledgments

The authors would like to thank Sumy National Agrarian University and Guangxi Key Laboratory of Health Care Food Science and Technology for providing laboratory equipment and technical support in this research work.

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