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A CONCEPTUAL FRAMEWORK FOR THE LONG-TERM STORAGE OF UNUSED FOOD FOR THE PURPOSE OF CREATING FOOD RESERVES AND PREVENTING FOOD WASTE IN POLAND

Key words: food losses, food waste, food security, food reserves, buffer stocks

ABSTRACT. The goal of this study is to create a theoretical model for the assessment of the least resource-intensive storage methods for the buffer stocks. The subject of the study was the available literature on food waste and food preservation methods. Food waste is often mentioned in the context of food security. Meanwhile, research on food waste mainly focuses on *ex-post* management of food waste rather than reducing food waste in the future. Thus, research on food waste tends towards energy security rather than food security. The bibliometric analysis shows that most of the research conducted focuses on the proper functioning of the supply chain and secondarily on economic food security. Therefore, the paper chooses to link the relevant elements of the analysis of food stock research to possible ways of processing food for long-term storage, based on the literature review. This is a preliminary analysis carried out using the expert method. This may allow some food to be processed into long-term food reserves, whose role is to stabilize food prices and make efficient use of resources in the value chain. To make proper use of such food, its processing and storage must be economically viable. According to this preliminary study, vacuum sealing may be the most efficient of the studied long-term storage methods, although it is not as durable as other methods.

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THE COMPLEXITY OF CAUSES, EFFECTS AND RESPONSES TO WASTE

Food waste can occur both before and after the consumer purchases it. Pre-purchase may result from errors or inefficiencies at the level of transport, storage, staff errors, marketing strategies, or legal errors, e.g. non-compliance with the labeling, exceeding the expiration date, etc. [Gruber et al. 2016]. These inefficiencies also influence subsequent consumer decisions [Lu et al. 2021], e.g. in the event of delivery delays, the possible period of adequate use of food is shortened. On the consumer side, waste results primarily from behavioral factors such as perception or attitude [Huang and Tseng 2020, Zhang et al. 2020], which influence, for example, planning purchases, paying attention to certification or expiration dates, but also food preparation and storage [Knežević et al. 2019], or reluctance to consume imperfect food products [Norman et al. 2019]. Thus, the decisions and actions of food sellers and consumers have a key impact on the level of food waste [Łaba et al. 2020, Li and Pan 2021]. Sylwia Łaba et al. [2020] cites two possible definitions of food waste which are: (1) "food produced for consumption that has not been consumed by humans", and (2) "raw materials and food products produced for food purposes that have not been consumed by humans, and therefore have not been used for their original purpose".

THE EFFECTS OF FOOD WASTE

The effects of waste have many dimensions. In addition to economic losses, they also lead to environmental and social losses [Aramyan et al. 2020], and the complexity of the issue indicates that this problem should be solved holistically [Horton et al. 2019], and waste should be prevented in many areas: economic, regulatory, but also technological [Diaz-Ruiz et al. 2018]. Research indicates the impact of food waste on the environment due to greenhouse gas emissions [Ghosh et al. 2017, Łaba et al. 2022] or losses of raw materials such as water, fuels, fertilizers and pesticides, and land [Bermudez et al. 2016]. Moreover, from a financial point of view, food losses and waste in 2021 have been estimated at over USD 160 billion [Brenes-Peralta et al. 2021]. Thus, reducing waste is beneficial both economically and environmentally, ensuring food security [Thorsen et al. 2022].

POSSIBILITIES OF MANAGING WASTED FOOD

The authors point to various aspects of food management that support food security. Silvia Saravia-Matus et al. [2012] discuss technological or institutional aspects, such as price instability or food waste. Alison Misselhorn et al. [2012] talk about cross-sector cooperation, science, and technology. The technological aspect appears in many publications. Wasted food can be used in several ways, such as being turned into animal feed, into bioenergy, or enzymes. Although only a small portion of wasted food is used as animal feed [Salemdeeb et al. 2017], it reduces waste and provides an alternative source of protein for animals [Nath et al. 2023]. Some nutrients can be recovered, e.g. by co-fermentation of wastewater with wasted food [Nghiem et al. 2017], also for bioenergy production [Pfaltzgraff et al. 2013], influencing water management [Ridoutt et al. 2009, Capone et al. 2014]. Wasted food can be used to produce high-quality products [Lin et al. 2013], such as enzymes [Javed et al. 2023], i.e. crude enzyme extract produced by the fermentation of bakery waste [Han et al. 2015]. However, these are not solutions that completely optimize losses, so to increase food security, it is important to reduce the number of losses by processing food in the long term.

CREATING FOOD RESERVES TO ENSURE FOOD SECURITY

The food security system functioning at the beginning of the 21st century is based on global food trade and price standardization through universal competition. However, the resulting opportunities to speculate on these markets led to the decline in food reserves, what indicates the importance of the issue of self-sufficiency [Mikuła 2012]. Mariola Kwasek [2012] emphasizes the role of reserves in maintaining national food security, in addition to the appropriate volume of domestic production for self-consumption and trade, and the effective functioning of processing and distribution systems. Fadillah Amin et al. [2021] believe that this is the role of both the government and society, but as Halima Yahya and Zhang Xiaohui [2014] point out, creating processing facilities and warehouses to protect household food security is the role of the state. Similarly, Micheal O'Flynn [2009, p. 40] wrote that "… (a)ny serious explanation of the problem of food insecurity requires attention to how subsistence food production is organized, by whom, for what purposes, and how it is distributed". Jörg Friedrichs [2019] believes that, first of all, historically, social stratification forced states to create public goods – e.g. irrigation, and food distribution in times of famine – from surpluses, ensuring the survival of their subjects and protecting themselves from their potential wrath (which he calls "depredation of subalterns"); secondly, those in power were able to offer their subjects the resources of enemy tribes/states (what he calls

"depredation of outsiders"). Although, as Carlos Madariaga [2022] points out, nowadays "depredation of outsiders" may take place rather in an economic context, the creation of reserves may also become a defense tool against such plunder, which may, for example, take the form of a cheap purchase of food in the event of a speculative attack.

Currently, many countries have or are planning strategic reserve programs to ensure food security in the event of supply shocks, especially cereals [Adeyeye 2017]. Such programs exist, for instance, in the Middle East and North African countries [Wright and Cafiero 2011] or in Zambia, where the Food Reserve Agency stabilizes corn prices [Mason and Myers 2013]. The role of such reserves is emphasized in the context of global trade, which may be sensitive to systemic shocks [Puma et al. 2015]. Thus, trade dependence may increase susceptibility to shocks, and reserves may reduce the risk level [Marchand et al. 2016].

POSSIBILITIES OF TRANSFORMING WASTED FOOD INTO RESERVES

To effectively counteract the waste of raw materials, new cognitive tools and terms categorizing wasted food are needed. Some of this food is not suitable for consumption and can be used as feed, fertilizer, or a source of bioenergy. However, some of it can be processed for the human consumption. Mattias Eriksson et al. [2020] discuss the need for legal changes to address food waste, distinguishing between "avoidable" and "unavoidable" food waste. This distinction is used, for example, in the 2019 EU project REFRESH. The effectiveness of introducing such solutions depends on the processing capabilities in all these sectors. Hossam Gabbar [2021] discusses a network of infrastructures, including food systems, to strengthen resilience to food crises, with particular attention to food waste management for disaster response. Christian Madu and Chu-Hua Kuei [2014] point out that in the event of a disaster, it is crucial to assess relief needs and mobilize relief items such as food and water.

Transforming food waste into reserves is important from the perspective of a sustainable food economy, especially in the context of ensuring food security during crises. It can buffer domestic food price shocks, trade disruptions, and shortages caused by disasters and crises [Lassa et al. 2018]. Consumers' willingness to pay for food reserves, especially fresh food, is influenced by factors such as income, education level, and gender, indicating the potential for consumer participation in supporting food reserve initiatives [Wang et al. 2020].

FOOD WASTE IN POLAND

Poland is the fifth largest producer of food waste in Europe, after the United Kingdom, Germany, France, and the Netherlands [Przezbórska-Skobiej and Wiza 2021]. The scale of food losses and waste in Poland is significant, which emphasizes the need for effective management and use of food resources [Florkowski et al. 2018]. In Poland, almost 5 million tons of food are wasted annually. Most, as much as 60% of discarded food comes from households, primary production (agriculture) and processing also have a significant share – 15% each [Łaba et al. 2020]. Furthermore, consumer behavior and opinions regarding the causes of food waste in households were assessed, highlighting the need to understand consumer perceptions and behavior in addressing this issue [Ankiel-Homa and Samotyja 2021, Tomaszewska et al. 2021]. Legal regulations regarding food waste in Poland were analyzed by EU directives, emphasizing the importance of the legal framework in solving the problem of food waste and its impact on sustainable development [Łaba et al. 2019, Zębek and Žilinskienė 2021]. Moreover, the role of labels and perceived health risks in avoidable food waste was examined, revealing consumer uncertainty about the freshness and suitability of food for consumption in Poland [Ankiel-Homa and Samotyja 2020].

In addition to the Common Agricultural Policy, Polish food security is supported by maintaining food stocks and grain reserves [Fraser et al. 2015, Sowa and Bajan 2019]. Legislation in Poland is constantly adapted to changes in EU directives to reduce the amount of waste and increase the level of recovery of secondary raw materials [Zarębska et al. 2018]. These strategic measures are essential to create resilient food systems and ensure the sustainability of national food production and supplies [Fraser et al. 2015]. The issue of food waste in rural households in Poland has also been studied in the context of supporting local biogas production, especially in the Lublin Voivodeship [Florkowski et al. 2018]. Moreover, the most common agri-food residues are used as substrates for biogas plants in Poland are corn silage, slurry, and distillery waste [Koryś et al. 2019].

MATERIAL AND METHODS

The goal of this study is to create a theoretical model for the assessment of the least resource-intensive storage methods for the buffer stocks. The subject of the study was the available literature on food waste and food preservation methods. There were two methods used to develop the conceptual model. First, a bibliometric analysis was performed to identify main themes in the broad literature on buffer stocks. Second, an expert method (based on the literature review) was used to assess potential expenses (in different forms)

of different stocking methods (except for the information in Table 3, which was supplemented based on the literature, as an example). The experts were academics and research staff from two research units with experience in both the processing and storage industries. The whole study was conducted using streamlined search strategy for the literature review, due to its iterative process and new research avenues appearing.

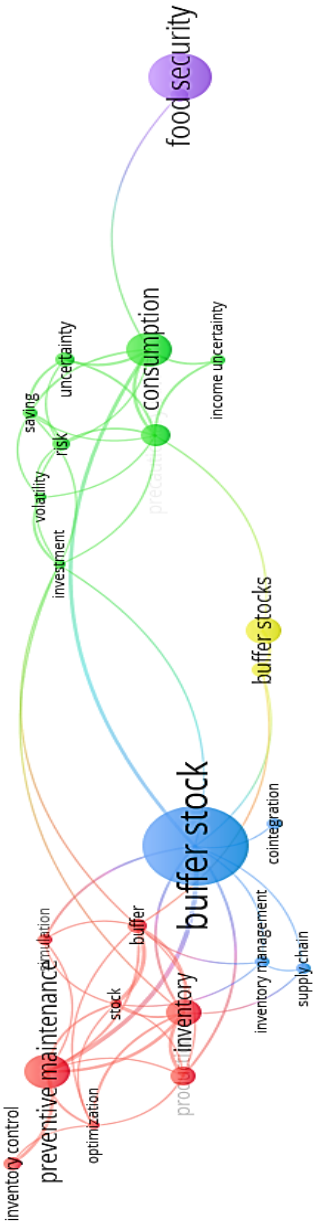

Figure 1. Neural map of key words appearing in the literature on food reserves
Source: own research, performed in the VOSviewer program

BIBLIOMETRIC ANALYSIS

In order to analyze the contexts of the literature on food reserves, the Scopus and Web Of Science (WOS) databases were searched. In addition to the term "food security", six synonyms or expressions similar to food reserves were also used. The following code was then created:

(TITLE-ABS-KEY ("Food Stockpile*") OR TITLE-ABS-KEY ("Strategic Grain Reserve*") OR TITLE-ABS-KEY ("National Food Reserve*") OR TITLE-ABS-KEY ("Emergency Food Reserve*") OR TITLE-ABS-KEY ("Buffer Stock*") OR TITLE-ABS-KEY ("Food Security Reserve*") AND TITLE-ABS-KEY ("Food security"))

The Scopus database search yielded 66 results and 536 in the WoS database. Both databases were combined and deduplicated in the RStudio program using the "bibliometrix"library [Aria and Cuccurullo 201], obtaining a total of 568 publications (34 duplicate documents were removed).

VOSviewer software was used for bibliometric analysis. It identified 1,202 total key words in the article database, 27 of which appeared at least 5 times. The names of continents and countries (India, Africa, Ghana) that indicated repeated case studies were manually excluded. The key words are presented in Figure 1.

The Figure 1 shows a neural map divided into thematic clusters. The clusters have been arranged in Table 1, and common key words have been assigned to the appropriate clusters.

The bibliometric analysis shows that most research focuses on the proper functioning of the supply chain and, secondarily, on ensuring economic food security. Therefore, in the next part of the study, it was decided to relate important elements of the analysis of research on food reserves with possible methods of food processing for long-term storage. Seven methods were selected, and six categories were assigned to them, according to which they were assessed:

Table 1. Key words within the identified clusters

	Cluster				
	1 (red)	2 (green)	3 (blue)	4 (yellow)	5 (purple)
Words	buffer, inventory, inventory control, optimization, preventive maintenance, production, simulation, stock	consumption, income uncertainty, investment, precautionary saving, risk, saving, uncertainty, volatility	buffer stock, cointegration, inventory management, supply chain	buffer stocks, price stabilization	food security, poverty
Common feature	efficient production and supply chain management	financial security and stability	effective supply chain and inventory management	price stability	food security

Source: own research based on the results of bibliometric analysis

work input, energy required for preparation, energy used for storage, space required, cost of food to be processed, and cost of food storage materials. Most of the estimated preservation methods were selected based on the methods collected by Sangeeta Dwivedi et al. [2017] (with the exclusion of jellying, freezing and water bath), supplementing it with freeze-drying [Nowak and Jakubczyk 2020], and mylar/plastic storage [Kandel et al. 2021].

The categories were assessed using the expert method (except storage capacity, see Table 4) for the scale of an industrial plant as follows:

1. Low: methods with low labor intensity, low energy requirements, low space requirements, and low material costs were rated as “low”.
2. Moderate: methods with moderate characteristics fall into this category, indicating moderate levels of labor, energy requirements, etc.
3. High: if a method involves high labor intensity, high energy requirements, significant space requirements, and high material costs, it is rated “high”.

These assessments are made with the understanding that industrial-scale operations often involve larger volumes, specialized equipment, and potentially more streamlined processes compared to household-scale operations. As the idea is to develop this concept for Poland, these thresholds were assumed for an industrialized country. The estimated thresholds for the rating of economic viability of different processing for long-term storage is presented in Table 2.

Table 2. Thresholds for different rating categories

Threshold for:	Low	Moderate	High
Labor intensity [hour per batch/unit]	1-2	3-5	6-10
Energy expenditure (preparation/storage) [kWh]	1-2	3-5	6-10
Space requirement [m^3/t]	1-2	2-4	4 >
Material costs (food products) [USD/kg]	5-10	15-30	30 >
Material costs (storage) [USD per batch or unit]	10-20	20-50	50 >

Source: own elaboration

Table 3. Storage capacity of processed foods, according to the processing method

Method	Storage capacity [m^3/tonne]	Rating	Source	Additional notes
Canned	1.5	low	Food Security Nutrition Network (n/a)	may depend on a can type
Dehydrated	2.4	moderate	Food Security Nutrition Network (n/a)	dried skimmed milk in 25 kg bags
Freeze-Dried	11.9	high	Aqua-Calc (n/a)	strawberries example
Vacuum-Sealed	1.6-4.0	low to moderate	Coldmax [2020]	depends on a food type
Ready-to-Eat	2.9 or 3.2	moderate	Defense Logistics Agency (n/a)	by cases or pallets
Pickled/ Fermented	1.5	low	Food Security Nutrition Network (n/a)	assumes “canned” capacity
Mylar/Plastic	1.5	low	Food Security Nutrition Network (n/a)	grains in 50 kg mylar bags

Note: These calculations do not account for the caloric value
Source: own elaboration, based on professional online sources

It must be noted that these methods differ also in the costs of maintenance. For instance, vacuum sealed products cannot be stored for such a long time as the other storage methods and require refrigeration which consumes energy. Yet, it can be used as a temporal method of storage before product can be transported and processed otherwise.

The data from Table 3 is the first step in a more rigid classification of the costs associated with long-term food processing and storage, presented in Table 4. The rest of the categories were rated by the expert method.

Table 4. Long-term food storage methods and their rating

Method	Labor intensity	Energy for preparation	Energy for storage	Need for space	Material costs for food products	Material costs for storage
Canned Foods	low	moderate	low	low	low to moderate	low to moderate
Dehydrated Foods	moderate	low to moderate	low	moderate	low	low to moderate
Freeze-Dried Foods	moderate	high	high	high	moderate to high	moderate to high
Vacuum-Sealed Foods	low	low	high	low to moderate	low to moderate	low to moderate
MREs (Meals Ready-to-Eat)	low	low to moderate	low	moderate	moderate to high	moderate to high
Pickled or Fermented Foods	moderate	low to moderate	low	low	low to moderate	low to moderate
Mylar/Plastic	low	low to moderate	low	low	low	low to moderate

Source: own research

From the above analysis, it can be concluded that vacuum storage of food is the most effective (low level of resources), while canned, dehydrated, fermented foods, and grains in mylar/plastics require low to medium resources, MRE requires medium resources, and freeze-dried foods requires medium to high commitment of resources.

SUMMARY

Much of global food is wasted. Some of the wasted food is used to produce bioenergy, fertilizers, or animal feed, but loses some of its energy potential. An example of such solutions is, among others: Poland, but also other EU countries where food waste is common. The distinction between "avoidable" and "unavoidable" may allow some food to be processed into long-term food reserves, the role of which is to stabilize food prices and effectively use resources in the value chain. To properly use such food, its processing, and storage must be economically justified. In our opinion, such methods are primarily vacuum storage, followed by canning, dehydrating, or fermenting food, and storing grain in mylar/plastic containers. Such a process would be the most effective from the point of view of budget constraints, but also the state's responsibility in the context of ensuring food security. It has to be yet noted, that vacuum storage can be stored for a shorter timespan as compared to other methods. Moreover, to properly determine the possible reduction of food waste, it is necessary to determine its quantity and categories. Moreover, our analysis was conducted via an expert method. The future iteration of this study shall be based on the broader approximation of the data on resources, which are required to turn "avoidable food waste" into food reserves.

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RAMY KONCEPCYJNE DŁUGOTERMINOWEGO PRZECHOWYWANIA NIEWYKORZYSTANEJ ŻYWNOŚCI W CELU TWORZENIA REZERW ŻYWNOŚCIOWYCH I ZAPOBIEGANIA MARNOTRAWIENIU ŻYWNOŚCI W POLSCE

Słowa kluczowe: straty żywności, marnotrawstwo żywności, bezpieczeństwo żywnościowe, rezerwy żywnościowe, zapasy buforowe

ABSTRAKT. Celem opracowania jest stworzenie teoretycznego modelu oceny najmniej zasobochłonnych metod przechowywania zapasów buforowych. Przedmiotem badań była dostępna literatura dotycząca marnowania żywności i metod jej utrwalania. Marnowanie żywności jest często wymieniane w kontekście bezpieczeństwa żywnościowego. Tymczasem badania nad marnotrawstwem żywności koncentrują się głównie na zarządzaniu *ex-post* zmarnowaną żywnością, a nie na ograniczaniu marnotrawstwa żywności w przyszłości. W związku z tym badania nad marnotrawstwem żywności zmierzają raczej w kierunku bezpieczeństwa energetycznego niż bezpieczeństwa żywnościowego. Analiza bibliometryczna pokazuje, że większość przeprowadzonych badań koncentruje się na prawidłowym funkcjonowaniu łańcucha dostaw, a w drugiej kolejności na ekonomicznym bezpieczeństwie żywnościowym. W związku z tym, na podstawie dostępnej literatury powiązano istotne elementy analizy badań nad zapasami żywności z możliwymi sposobami przetwarzania żywności w celu jej długoterminowego przechowywania. Jest to wstępna analiza przeprowadzona metodą ekspercką. Może to pozwolić na przetworzenie części żywności w długoterminowe rezerwy żywności, których rolą jest stabilizacja cen żywności i efektywne wykorzystanie zasobów w łańcuchu wartości. W celu właściwego wykorzystania takiej żywności, jej przetwarzanie i przechowywanie musi być ekonomicznie opłacalne. Według wstępnego badania, pakowanie próżniowe może być najbardziej wydajną z badanych metod długoterminowego przechowywania, chociaż nie jest tak trwałe, jak inne metody.

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