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TRANSPORT OF FROZEN PRODUCTS AS A SOURCE OF ENVIRONMENTAL AND CONSUMER RISKS

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Abstract: The article presents the problems related to changes in the quality of frozen food due to its transport, from the point of view of the burden on the environment and the risk for the consumer. The paper presents physical, chemical, and microbiological threats to the quality of frozen food, which are caused by conditions related to the logistics process. Transport of frozen products, which is an essential part of the logistics process, is described in the context of the ATP agreement, the concept of sustainable development, and the HACCP system. As a result of the discussion, it was found that the quality of frozen products during transport may change as a result of different processes and dynamics, which depend on the logistics process as a result of many variables. The logistics process should therefore be considered as a set of related operations from acquisition of raw materials, through production, storage, transport, and distribution, to consumption. The discussion made make it possible to conclude that the integrity of logistics processes determines the quality of frozen products, the final level of which should be considered in terms of the environmental burden and the threats to the safety of consumers. The socio-economic progress and the increasing globalisation in the trade of goods lead to an intensified use of transport processes, the implementation of which should be optimised to ensure high quality of transported goods, including frozen food, and to reduce environmental pollution.

Keywords: logistics, sustainability, frozen products, food, cold chain.

1. INTRODUCTION

The significant socio-economic development has forced the intensification of logistics processes. As a conglomerate of processes and activities, such as transport, storage, and warehousing, but also as a broadly defined logistics infrastructure, logistics takes part in the implementation of tasks aimed at trade in goods and is determined by the specific characteristics of the cargo to be traded. The primary logistics tasks result from the basic production process of raw materials and then finished products, which are collectively referred to as products. The scope of logistics tasks is expanded with the appearance of products in the market, which is accompanied by assignment of prices and transformation into goods that are subject to commercial transactions. By narrowing the notion of logistics to theoretical considerations, it can be concluded that it is a range of scientific activity that focuses on such topics as supply of objects and means of labor, distribution of raw materials and products, transport of cargo, operation of fixed and current assets, but also environmental protection and rational, comprehensive and economic management of logistics subsystems for existing resources and limitations in a specific place and time [Niziński and Kolator 2007; Chaberek 2011].

Food product transport logistics deals with transport of dry, fresh, frozen, liquid, loose, plant, and animal products alike. It is therefore clear that, due to their different characteristics, the transport conditions must be adapted accordingly. For all, manufacturer, the logistic specialist, and the consumer, it is essential that the products are transported in the shortest possible time, at the lowest cost and in an unchanged condition [Satora and Szkoda 2019].

The purpose of this paper is to identify risks to the quality of frozen products that result from their transport. Prevention of risks that determine the quality level of frozen products after the transport process is analysed from the standpoint of both the consumer and the environment. This is a clear opportunity to avoid losses of goods caused by inappropriate transport.

2. FROZEN CARGO TRANSPORT

The ATP Convention (A – agreement, T – transportation, P – perishable), drafted as early as on 1 September 1970 in Geneva, concerns the conditions of transport of perishable goods. The ATP international agreement regulates the requirements that apply to transport of frozen or deep-frozen food products in the first group or non-frozen food products in the second group. These requirements refer to thermal transport conditions, vehicle equipment, and regular inspection of refrigeration equipment and means of transport. The most commonly used modes of transport for frozen food are maritime, road, and rail transport. The provisions of the ATP Convention apply to:

- transport by road, rail, or combined transport carried out for third parties or for own benefit;
- maritime transport over a distance of less than 150 km, provided that the traded goods are delivered to their final destination by land transport or collected directly without reloading.

It should be emphasised that the provisions of the ATP do not apply to land transport of containers in the absence of reloading of goods when they were previously transported by sea [Stajniak, Konecka and Szopik-Depczyńska 2016].

According to the ATP agreement, refrigerated equipment or mechanically refrigerated equipment can be used to transport frozen goods. Refrigerated equipment is an insulated means of transport that uses a cooling source other than mechanical or absorption cooling to reduce the temperature inside an empty body.

The source of cold in refrigerated equipment can be natural ice with or without the addition of salt, eutectic plates, dry ice, or liquefied gases. Mechanically refrigerated equipment is also an insulated means of transport, but is fitted with a refrigerating appliance, e.g. an absorption device or a mechanical compressor unit. These devices may be individual or common for several means of transport, but their purpose is to cool the space inside an empty body and keep it at an appropriate level [ATP Agreement 1970].

Road transport has a number of advantages, but also numerous limitations. Its use is limited, but also delineated, by the area of a given continent, owing to a very extensive road infrain the first group

Owing structure. Road transport can be adapted to carry almost all types of cargo. Because of the high availability of means of transport and the ease of choosing the most economical route, transport time can be quite short. One of the important limitations of this mode of transport is the lack of even development of road networks in individual countries. The technical condition of the roads can also vary considerably. At the same time, when using low-capacity vehicles, the cost of transport of a unit of product may be prohibitive. It is particularly noteworthy that frozen cargo transported by wheeled means of transport is most often mechanically damaged. Common causes of such damage to cargo are traffic accidents, vehicle breakdowns, but also changes of driving direction and bumps on the road. The possible results of these situations include pierced product packaging, bruising, and crushing of goods, which lead to a decrease in product attractiveness or even shortening of its shelf life [Rymarz, Dmowski and Niewczas 2010; Leleń and Wasiak 2017].

The significant role of road transport is the reason for the pressure on vehicle manufacturers to minimize their negative environmental impact. In 2018, road transport in Poland made it possible to transport almost 2 billion tons of various types of cargo, which accounted for about 85.5% of total transport. Rail transport, on the other hand, accounted for about 11.4% of total Polish transport and shipping – for only 0.4%. In the study carried out by Statistics Poland in 2018, the volumes of goods transport according to the type of vehicle body were estimated, which indicated that out of the 1.39 billion tons of transported goods, only 0.86 billion tons were transported in refrigerated or mechanically refrigerated vehicles [Central Statistical Office 2018].

It should be emphasised that due to its prevalence, road transport is one of the main sources of air pollution. Vehicle exhaust gases are a source of many pollutants, including heavy metals, particles, hydrocarbons (including polycyclic aromatic hydrocarbons), and carbon and nitrogen oxides. Between 2000 and 2017, the quantity of carbon dioxide emitted in connection with logistical tasks using road transport increased from 27,000 tons to 61,000 tons. There was also an increase in nitrous oxide pollution by 100 %, in nitric oxides by 50%, particles by almost 100%, sulfur dioxide by 100%, and lead by 15%. At the same time, due to the development of the technology, it was possible to reduce the following pollutants emitted by road transport: methane by 50%, carbon monoxide by 50%, and non-methane volatile organic compounds by 50% [Central Statistical Office 2018]. This fact is all the more important because the emission of volatile pollutants significantly increases the incidence of respiratory and circulatory diseases, especially on a local scale. Emissions of volatile pollutants associated with road transport also affect organisms present near roads (grazing animals, crops) which, because they are an element of the trophic chain, are then taken up by humans with food. Heavy metals from exhaust fumes get into both food and groundwater and cause their contamination. It should be noted that heavy metals do not degrade as a result of storage or processing. Therefore, regardless of these factors, they are present in the finished product in the same quantity as in the ingredients. In addition, road transport generates noise, the long-term impact of which (e.g. in areas inhabited by people, especially in city centers) leads to a gradual shift of the hearing threshold.

Rail transport is characterised by the mass character of the goods transported by it. The use of rail transport, similarly to road transport, is limited and delimited by the area of a given continent. The main advantage of rail transport is its ability to transport larger cargo than in the case of road transport. The railroad networks in most countries are widely developed and, consequently, medium- and long-distance freight rates are relatively low per unit of cargo. Similarly, as in the case of road transport, rolling stock offers the possibility of diversifying the conditions of cargo transport by using different types of cars or containers. Cargo carried in a particular rolling stock may be varied, as each element of the train can be selected independently of the others.

This mode of transport is to some extent environmentally friendly and consumes relatively small amounts of non-renewable energy sources per unit of transported cargo. The limitation of the use of rail transport to transport of certain types of cargo only is mainly due to the long transport time and the need to involve other modes of transport to deliver cargo to the railway station and then to its destination. Taking into account the fact that rail transport in the European Union represents only 6.1% of the total volume of passenger transport and 10.7% of freight transport, it can be concluded that the risks associated with this mode of transport are incomparably lower than those associated with road transport. The main sources of environmental pollution caused by rail transport are noise, vibrations, and exhaust fumes. As for exhaust fumes, these are not large quantities, as the pollution from diesel locomotives is estimated to be in the order of 1–3% of the total amount of pollution from transport in the European Union. Inhabitants of areas bordering frequently-used transport corridors are particularly exposed to the risk resulting from noise and vibration [Badyda 2010].

Unlike the above-mentioned modes of transport, maritime transport is not limited by the road network, railway lines, and intercontinental spaces, but cannot operate in continental zones. The container ship transports huge amounts of cargo during each voyage. Depending on the size of the ship, it can transport from 200 TEU [TEU – a unit equivalent to the volume of a 20 ft container] in the case of delivery container ships to almost 20,000 TEU in the case of the largest container ships. As in the case of rail transport, the cargo transported in individual containers may vary in terms of its properties and resistance to transport conditions, which determines the selection of suitable containers. Cargo may also be transported loose in cargo holds, which is a method suitable especially for transport of loose goods. The volume of maritime transport, and therefore the beneficial effect of economies of scale, entails lower transport costs per cargo unit. The main disadvantage of maritime transport is the need to involve other modes of transport to transport cargo from the port to its destination. Unfortunately, despite many benefits, maritime transport is highly time-consuming due to the distances covered [Woźniak and Kukiełka 2011].

Maritime transport in the European Union accounts for 37.3% of total freight transport. Poland's share in EU maritime transport is only 1.3%. Carbon dioxide emitted by maritime transport represents 4.3% of total emissions, which translates into 15.3% of total transport emissions. The emission of gases and dust associated with maritime transport increases every year: from 1990 to 2007 a 50% increase in emissions was recorded. Ships generate pollution that has the greatest impact on the environment, up to 400 km from the coastline, which contributes to a deterioration of air quality through formation of ground-level ozone. Increased concentrations of sulfur and particulate matter are recorded in the vicinity of ports operated intensively. It should also be emphasised that it is much easier to eliminate negative effects of road and rail accidents than those of ships. Even if ships do not transport hazardous substances, the fuel escaping from tanks as a result of accidents poses a huge threat to the environment on a global scale [Badyda 2010].

Each of the modes of transport has many advantages, but each to a smaller or greater extent generates a burden on the environment and causes risks to the quality of transported goods.

3. SUSTAINABLE DEVELOPMENT AND LOGISTICS

Discussions on sustainable development started in the 1970s. The interest in this issue was caused by the acceleration of socio-economic development and the emergence of its negative effects, primarily on the environment. The concept of sustainable development was identified as a priority for further functioning and development of the global economy, individual countries, businesses, and consumers. As a result, the implementation of logistics processes should also take into account the premises of this concept.

In June 1990, the Earth Summit in Rio de Janeiro adopted two basic documents on which the concept of sustainable development is based. The first, called the Rio

Declaration, presents the general philosophy behind this concept. The second, called Agenda 21, presents the mechanisms and principles of this concept, and the ways to implement it. In general, the concept of sustainable development has three basic objectives, i.e.:

1. An environmental objective, the role of which is to stop the degradation of the environment and to eliminate environmental threats.
2. An economic objective, the role of which is to meet the material needs of the society using means that do not damage the environment.
3. A socio-humanitarian objective, the role of which is to ensure minimum social standards, healthcare services, spiritual development, security, and education.

To sum up, sustainable development is defined as a way of recognising and then solving contemporary economic, social, and environmental problems, and its essence is to permanently improve the quality of life of present and future generations. The above considerations clearly demonstrate that sustainable development has become an important premise in the implementation of logistics processes and should be taken into account at every planning stage [Sadowski 2008; Płaczek 2011]. The concept of sustainable development plays an extremely important role already at the stage of design of any means of transport.

Therefore, by giving preference to and then implementing pro-environmental design solutions, numerous risks associated with transport as an important part of the logistics process can be avoided or reduced. Thus, the burden on the environment resulting from its direct pollution during transport can be reduced. In addition, opportunities can be created to maintain the high quality of cargo, e.g. frozen food, thereby minimising food waste while reducing direct risks to the consumer of such food.

4. RISKS ASSOCIATED WITH TRANSPORT OF FROZEN CARGO

Frozen or deep-frozen food requires special treatment during transport because of the need to maintain a relatively stable (±3°C) set temperature. Elimination of temperature fluctuation makes it possible to maintaining the high quality of the goods and its safe condition for the consumer. Food safety should be analysed in terms of prevention of physical, chemical, and microbiological contamination, with protection against growth of undesirable microorganisms being an essential safety factor. Physical hazards include foreign bodies such as glass, metal, and wood, and organic contaminants such as insects, which may appear during the transport process. Chemical hazards include any residue associated with the condition of the transport equipment or the presence of other cargo, and natural toxic substances from the environment are also a serious risk.

It is therefore extremely important to comply with the provisions of the ATP agreement, which impose the following requirements: to remove remains of previous cargo from the means of transport; to use food-grade cleaning and disinfecting products; to carry out disinfection according to appropriate procedures; to check the proper functioning of refrigeration equipment or heat exchangers in refrigerated means of transport; and to check the temperature of the cargo compartment before loading. If these requirements are not met, the cargo may be subject to physical changes, e.g. if the previous cargo had a powerful odor, failure to follow the procedures may result in transfer of the odor to the next cargo. In theory, this will not affect product safety.

Consumers may even buy such goods, but in the end it will be unattractive in terms of sensory perception and will not be used in accordance with its original purpose. The sequence of such actions always leads to a burden on the environment and to losses for the consumer. It should be emphasised that before a specific product is wasted, the raw material for the product must be obtained, and the product must be made, sold, and transported. Despite the fact that these processes cause a burden on the environment, the product is ultimately not used effectively, but is handed over for disposal [Nieoczym et al. 2014].

Bacteria, molds, and fungi, and the toxins they produce, are mainly responsible for biological contamination of food. It should be noted that at 5–8°C there is a significant slowdown in the growth of many microorganisms. It should be emphasised that most of these microorganisms do not grow at and below storage temperatures of frozen food (-18°C). At the same time, such temperatures do not cause inactivation of microorganisms, let alone their toxins. After the food is thawed, they continue to multiply, often at a higher pace.

Temperature stability is not the only condition for ensuring the safety and the quality of frozen products expected by consumers. The important role of ambient humidity, its gaseous composition, exposure to electromagnetic radiation (especially in the visible range), and vibrations should be emphasised. In addition, the right packaging plays an important role. The starting factor is the condition of the product before and after freezing.

In the case of transport of frozen cargo, the risks potentially affecting its safety and quality can be systematised, taking into account the likelihood and consequences of such risks. In the case of transport of frozen food, the ambient humidity does not affect food safety and quality, as the humidity is temperature-dependent and cannot be freely regulated. Maintaining a low temperature keeps the steam content in the air at an insignificant level, which decreases with the temperature. Consequently, low temperature, low humidity, and low water activity determine food safety. Moreover, during transport, frozen food is usually stored in packages with a high barrier to steam, which protects it from sublimation which, in turn, leads to loss in weight by drying. Similarly, for the same reason (presence of packaging), the gas composition of the atmosphere has no significant impact on the quality of frozen food. Lack of packaging may promote oxidation, which leads to a deterioration of the sensory and nutritional quality of food as a result of oxidation mainly of lipid fractions.

In contrast, light does not pose a risk due to the fact that it is eliminated during storage. Vibrations to which the loads are subjected during transport can contribute to mechanical damage to frozen food. This is because freezing of food causes the water contained in it to turn into ice, which, being a crystalline body, is hard and, consequently, brittle. Therefore, vibrations, and particularly impacts, can cause disintegration which leads to poor food quality.

Consequently, maintaining the right and stable temperature is the most important factor that determines the quality and safety of frozen food during logistics processes, especially its transport. Controlling the ability to maintain the right temperature in the freezer is also an important aspect of transport of frozen food. When loading frozen goods onto a ship, a truck, or rolling stock, special attention should be paid to the condition and quality of the refrigerating equipment and the cleanliness of the spaces intended to be used for transport.

However, the most important thing in the case of frozen cargo is to check that the transport chamber has been cooled to the right temperature before the cargo is loaded. At the same time, special care must be taken to ensure that the loading/unloading area is not excessively exposed to sunlight. These measures help avoid the risk of partial thawing of the cargo and, consequently, a reduction in its quality or an emergence of risks associated with deterioration of food safety.

According to the ATP agreement, five temperature groups are specified for transport of frozen and deep-frozen food:

- -20°C – ice cream, cream, fruit juices and juice concentrates;
- -18°C – fish, mollusks, crustaceans, and other products sensitive to thawing damage not included in any other category;
- -14°C – fats (except for butter);
- -12°C – other products less sensitive to partial thawing damage not included in any other category;
- -10°C – butter [Stajniak, Konecka and Szopik-Depczyńska 2016].

It should be noted that the above framework is not strictly defined and, therefore, leaves a lot of room for interpretation. Classification of products according to their susceptibility to damage can be very different, as it depends on the decisions made by logistics specialists based on their knowledge of products and cargo management. Due to the high energy consumption associated with the process of cooling down freezer chambers to -18ºC, there may be a temptation to classify products as less sensitive to damage, which will require a less energy-intensive process as of cooling the chambers down to -12ºC. Clarification of the rules of such classification would reduce possible cases of dishonest transport management.

When analysing sources of risks to food safety, the greatest attention is paid to biological factors. In the transport of frozen and chilled products, psychrophilic and psychrotrophic microorganisms should be considered in particular. Psychrotrophic microorganisms are aerobes or anaerobes capable of growth at cooling temperatures (0–7°C). Psychrotrophy is a characteristic of strains, not of species. Psychrotrophs include G(+) bacteria, such as: micrococcus, some lactic fermentation bacteria, *Bacillus* sp., molds, and yeasts. On the other hand, G(-) psychrotrophs are baccilli coming from water and production surfaces, e.g. *Pseudomonas* sp., *Acinetobacter* sp., *Alcaligenes* sp., and *Aeromonas* sp. These microorganisms grow most intensively in products with low acidity and the most frequent defect that they cause is a tainted, usually bitter and rotten taste (a result of proteolysis) or rancid, soapy, or fishy taste (a result of lyoplysis). Psychrophillic microorganisms are sometimes called cryophyllic. Their minimum growth temperature ranges from -23 to 0°C, while the optimum temperature for rapid growth ranges from 0 to 15°C. However, it should be emphasised that these microorganisms are able to grow in temperatures up to 20°C. They include: *Pseudomonas* sp., *Alcaligenes* sp., *Flavobacterium* sp., yeasts of the *Candida* sp. and *Rhodotorula* sp. genera, and some molds [Piotrowska and Nowak 2005].

Ensuring the right temperature during transport of frozen products does not completely eliminate the risks associated with physical and chemical factors, but it does have a significant impact on a reduction or even elimination of biological risks. By limiting temperature fluctuations during the logistics process and thus preventing the products from thawing and re-freezing, it is possible to eliminate the risk of having to dispose of the products after their purchase by the consumer due to their reduced or disqualifying quality.

However, the transport process is not the only component of the logistics process associated with trade in goods that may pose risks to the quality and safety of frozen food due to the existence of potential biological risks. Therefore, in order to minimize the risks to the safety and quality of frozen food associated with contamination and microbial growth throughout the entire logistics process, from production through transport and storage to distribution, the cold chain has been designed.

The cold chain is an important tool allowing the maintenance of food safety at the right level. The essence of the cold chain is to ensure unchanged conditions during food transport and storage. The chain starts when raw materials are obtained and its subsequent links are production, storage, transport, and distribution up to consumption by the consumer. At each of these stages, the product, which constitutes a commodity and sometimes also a cargo, should be stored at the right temperature. Efficient operation of a cold chain is closely linked to its integrity. Breaking any of the links is tantamount to a drop in the quality or definite spoilage of the product [Grabowska 2014].

Another important aspect of storage and transport is the analysis of microbiological factors. It includes three closely related elements: risk assessment, risk management, and risk communication. It is important to efficiently provide information on the existing microbiological risks and the actions taken [Wojdat and Kwiatek 2004].

Risk management in logistics processes includes risk identification, which makes it possible to determine the causes and their possible consequences; analysis – specifying the probability of risk occurrence; planning – developing and documenting a risk management strategy; organization – implementation of the adopted strategies; monitoring – observation; and controlling to improve the system [Szymonik 2014].

An analysis of microbiological risks associated with the transport of frozen products should be conducted in terms of the following several criteria. If the ingredients from which the food was produced were contaminated, there is a likelihood of microbial growth and development during improper storage.

It is therefore necessary to heat treat the food before it is consumed. The adoption of such criteria is necessary because the presence, growth, survival, and death of microorganisms that cause spoilage of food is influenced by many factors, i.e.: production process, packaging method, and storage method, but also factors directly related to the properties of food (pH, water activity, accompanying microflora) [Wojdat and Kwiatek 2004].

Supplying frozen food products that are safe for health, of high quality, and with unchanged taste to consumers is a very difficult task. Ensuring short transport times and the use of modern equipment at each stage of trade may not be sufficient to ensure the safety and appropriate quality of food.

Therefore, the importance of the initial quality of the product, as expressed in its condition before and after freezing, is also emphasised. Therefore, it is necessary to implement appropriate quality management systems allowing to obtain products manufactured with the highest hygiene and production standards.

The most common system used to control food safety and quality is the HACCP (Hazard Analysis and Critical Control Points System). The HACCP concept has been developed for the purpose of provision of food for astronauts and the military, and consists of detailed identification of the risks associated with the production and marketing of foods which have the potential to be dangerous for the health and life of consumers. This system makes it possible to minimize all types of hazards, physical, chemical, and biological alike. It also protects the consumer against harmful effects of products whose quality has deteriorated during their entire life cycle. The safety of the consumer in this respect is related to the traceability of the goods in the course of trade [Satora and Szkoda 2019].

At the same time, it should be emphasised that deterioration of the quality of frozen food during the logistics process, e.g. during transport, poses a risk not only to the consumer but also to the environment, as an unfit product should be safely disposed of and, at the same time, the environmental burden associated with its production and storage, e.g. in freezing conditions, and its transport, should be borne in mind. Each of these stages generates a carbon footprint. Allowing food spoilage is not only a manifestation of food wastage, but also a clear environmental burden and possible exposure to consumers.

6. SUMMARY AND CONCLUSIONS

On the basis of the above discussion, it is possible to formulate conclusions on the impact of frozen food on the environment and consumers. For almost 50 years there has been a struggle for the quality of the environment and a fight against its pollution and progressive degradation. One important indicator of the quality of environment is the carbon footprint, which should be link to both production and global trade of food and, therefore, to its transport. The current advanced technologies do not enable complete elimination of factors that pose a threat to the environment and which are related to the logistics process, including transport.

However, as a result of an analysis of the progress in the development of the transport industry and the economic effects of implementation of modern solutions, it can be expected that environmental risks associated with transport can be minimized. To this end, logistics processes should be planned in accordance with the concept of sustainable development. The final effect of implementation of the concept of sustainable development will be not only an improvement of the state of the environment but also an improvement in consumer safety.

The analysis of the factors that directly influence the safety of frozen food shows that the complex logistics process should be interpreted in a holistic way, starting from obtaining raw materials through to the production of the product and to its consumption. Integrity of the cold chain is an important feature that ensures supply of safe food to consumers. However, it should be emphasised that food safety and quality also depend on other types of risks that are not related to such an important factor as temperature, which may occur in the logistics process.

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