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ANALYSIS OF TRANSPORT CONDITIONS FOR FROZEN FOOD ON THE WAY FROM THE SHOP TO HOME

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The transport of temperature sensitive products takes place under special conditions defined by specific agreements and international standards. The only exception to this rule is consumer transport. This transport is carried out by the consumer and takes place on the way home from the shop. The study examined consumers' awareness of the consumer transport of frozen food and analysed this type of transport in terms of the continuity of the cold chain. Such situation affects the deterioration of frozen food quality especially in case of its later storage in the home freezer. It was found that the average distance that customers cover from shop to home was 4.98 km. They usually used a car and covered this distance in an average of 12.85 minutes. During the summer months, this time is sufficient to partially thaw a package of frozen vegetables. Only 33% of the respondents used insulated bags to protect frozen food on the way home. When analysing the transport of frozen raw material carried out by consumers in real conditions, the use of insulated bags was found to be justified. These bags are able to keep the temperature of the packed raw material below -5°C. It was found that the legal imposition of the necessity to use such bags or the introduction by the manufacturer of frozen food of appropriate packaging protecting the food against transport at inappropriate temperatures in the summer months is necessary.

Keywords: frozen food quality; consumer transport; cold chain; insulating bags

1. Introduction

The frozen food market has been growing for several years (Martindale and Schiebel, 2017). As refrigerated production increases, so does the importance of refrigerated transport. To ensure adequate product safety, the temperature of the food must be kept at a consistently low-level during transport (Jackson *et al.*, 2018). The quality of frozen products can change rapidly due to fluctuations in temperature and relative humidity during transport and storage. Keeping frozen food products in the positive temperature range, even for a short time, results in a number of physical changes, most notably changes in texture and mass (caused e.g. by leakage after thawing) (Ali *et al.*, 2015). During temperature fluctuations, there is a change in the state of the food from one transition zone to another (e.g., between the glassy state and the gummy state). As the mobility of water in the food changes, more water loss may occur. The migration of moisture from the food to the surrounding environment lowers the freezing point of the liquid in the food. This makes it more difficult to keep the food solid under initial frozen storage conditions. Temperature fluctuation also affects the recrystallization of ice. Ice recrystallization is characterized by instability of ice crystals and changes in their number, shape, and size during frozen storage and transport. If the temperature increases the ice crystals melt, increasing the amount of unfrozen water and causing deterioration. Recrystallization is caused by the minimization of internal energy, which causes the rearrangement of the crystals. The quality of frozen food is more affected by temperature than by storage time. When a product is subjected to freezing for an extended period of time, water is able to migrate from the inner region of the cell to the compact intercellular region. This causes the cells to dry out, burst, lose turgor and crush the cells due to the large mass of intercellular ice (Góral & Kluza, 2009; Kumar *et al.*, 2020; Vicent, *et al.*, 2020).

The refrigerated road transport system is very diverse. Its components range from 12-meter refrigerated trailers to insulated vans transporting food to local retail outlets or directly to consumers. The "ATP - Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for such Carriage" (2015) regulates the requirements for the transport of perishable or deep-frozen products. These requirements relate to thermal conditions of transport, vehicle equipment and regular inspections of refrigeration equipment and means of transport (Degirmenci *et al.*, 2017). The term "cold chain" is related to the ATP convention and should be understood as a special logistics chain required for the transport of temperature-sensitive products. This is the totality of activities aimed at ensuring the safety and quality of the product from the moment of its freezing until its final use (Han *et al.*, 2021). The effectiveness of the cold chain in maintaining the shelf life and quality of frozen food is based on managing

the temperature of the product at every stage from producer to consumer. The safety and quality of chilled and frozen food largely depends on the transport time and product temperature history (AFGC, 2017). According to Ndraha *et al.* (2018), all links in the cold chain are equally important. At each stage, refrigerated transport is an element connecting the links of the cold chain (Salin and Nayga, 2003).

According to the ATP agreement, the temperature during transport of deep-frozen food should not be higher than -18°C. It is allowed to increase the temperature by 3°C during loading or unloading. However, to maintain this temperature also in retail outlets, frozen products must be at least -25°C when they leave the distribution centre or other storage location. A study by Ruiz-Garcia and Lunadei (2010) revealed that temperature during transport is higher than required in 19% of cases when products are transported from the supplier to the distribution centre and in 36% cases when transport is realized from the distribution centre to the store. The only exception to the ATP agreement is consumer transportation. This transport is carried out by the consumer and takes place on the way home from the shop. Increasingly, consumers are considered the weakest link in the cold chain in terms of food quality and safety due to the dynamics of the process and the inadequacy of means of transport for this purpose (Terpstra *et al.*, 2005).

A very important aspect of food safety is its contamination by pathogenic microorganisms. In the case of frozen food, strains of Listeria and Escherichia coli occurring in frozen fruit and vegetables are particularly dangerous. Willis *et al.* (2020) reported that Listeria monocytogenes was detected in 10% of samples of frozen vegetables obtained mostly from retail. Listeria cells have the ability to multiply in a wide range of pH (4.4-9.6) and temperature (0-45°C) (Adamczewski *et al.*, 2016), which means that transport in conditions provided by consumers may be favourable for development of this pathogen.

The aim of the study was to investigate consumer awareness of the use of thermal bags during consumer transport of frozen food and the impact of not using such bags on the continuity of the cold chain.

2. Materials and methods

2.1. Strategy and rationale for the choice of research methods

Investigations into the consumer transport of frozen products require a broad view of the problem and a lot of analysis in order to draw correct conclusions. Firstly, it was necessary to find out what type of products are most often transported, at what time and by what means of transport. To this end, surveys were carried out covering a number of aspects of consumer transport and consumer knowledge of awareness of the risks associated with breaking the cold chain. A triangulation of methods was used to reduce the error burden of the survey results. The responses given by respondents on the most frequently purchased frozen product range were compared with an analysis on sales in large-format shops. The next step in this research was to determine the temperature conditions of consumer transport. This was done by analysing meteorological data and the conditions in the varied vehicles. Knowledge of these conditions made it possible to study the impact of consumer transport on the quality and safety of frozen food. The thawing kinetics of the products under simulated conditions were performed and, on this basis, changes in product texture were assessed. Finally, it was investigated whether the use of commercial insulating bags could affect the safety of the transported product against quality changes.

2.2. Selection of frozen products

The selection of products was made on the basis of an analysis of the local market in Poland. Sales of frozen products in the summer season in 5 selected large-area stores were analysed. The data is based on daily sales reports (counted by unit). The results were averaged and the most frequently purchased products were selected taking into account the differentiation in terms of shape, texture, density and dry matter content. Conversely, ready-made vegetable mixes, soups and ready meals were rejected due to the presence of food additives affecting the shelf life of the product and thus making their analysis difficult. Especially the addition of sauces containing salt or sugar significantly affects the cryoscopic temperature of the food. Vegetables with different functional characteristics were selected: root plants (carrots), plants with edible tubers (potatoes), leafy vegetables (spinach) and vegetables with a developed surface (broccoli), and frequently purchased (green beans). Statistical evaluation of the significance of differences was carried out using R programme version 3.1.2 (Free Software Foundation's GNU General Public License).

2.3. Assessment of the thawing kinetics of packaged frozen vegetables

The research material consisted of previously selected raw vegetables without visible mechanical and biological damage. Prior to analysis, the vegetables were washed and peeled as needed. Carrots and potatoes were cut into cubes and bars of the dimensions of ready-made frozen products, respectively. The spinach was formed into

a 1 cm thick block. Broccoli was divided into florets with a diameter of 5 cm and a stem 2 cm long. The raw material was blanched according to industrial conditions and 0.3 to 1 kg was put into a plastic bag. Characteristics of temperature were obtained using the computer-aided measuring kit MPI-L (Metronic System, Poland) equipped with T-type thermocouples (measurement accuracy ± 0,5°C). Temperature measurement frequency was 1 per second. Additionally, LB - 515 P type 23 (EL – label, Poland) miniature temperature data logger that measures from -40°C to 85°C (with an accuracy of ±0.5°C and measuring frequency - 1 per minute) were inserted into the packaging. The mass of the samples was determined using a laboratory balance WPE 2000 (Sartorius, Germany). T-type thermocouples were placed in the thermal centre and on the surface of the raw material. The thermocouple measuring the broccoli temperature was placed centrally in the stem and on its surface. The thawing tests for each raw material were carried out with the use of 3 thermocouples placed in the centre and on the surface of the raw material. Then the samples were placed in a chest freezer (Whirpool AFG 6452, Poland). Raw materials were frozen at -30°C and then kept under these conditions for 10 days. After this time, all packages with frozen raw materials were placed in a tray and thawed under free convection in the temperature range of 20 - 25°C. Temperature during freezing and thawing was recorded every 1 minute. Experiments were performed in triplicate. The measurement results were exported to an MS Excel spreadsheet and temperature vs. time graphs were created.

The temperature field profile on the sample surface during the thawing process was evaluated with TESTO 882 infrared camera (Testo, UK). The assessment of temperature distribution was made using the TestoIRSoft software ver. 3.4 assisting the thermal imaging camera.

2.4. Effect of re-freezing on sample texture change

A penetration test was conducted to investigate the effect of re-freezing on the hardness of frozen vegetables. Potato French fries were chosen as the test material because of their repeatable size and regular shape. This test was performed on a LFRA TA 4500 machine (Brookfield, USA). A single cycle puncture test was carried out using a 2 mm probe with a test speed of 1 mm/s and penetration depth of 90% at room temperature (Al-Khusaibi, *et al.*, 2015). The values obtained in the measurements were entered into the program cooperating with the textrometer. The test was carried out on 9 samples.

2.5. Characteristics of the conditions of consumer transport

Trunks of three cars were tested: Honda HRV, year of production 2019 (body colour: red, black trunk upholstery), Volkswagen Passat station wagon, year of production 1995 (body colour green, beige trunk upholstery) and Honda Civic 4D, year of production 2013 (body colour black, black trunk upholstery). These cars were selected due to the different body colour, maximum and minimum solar radiation absorption, and a neutral colour. Similarly, the choice of the above types of cars was influenced by the colour of the trunk upholstery and the way it was separated from the passenger compartment. Honda Civic was sedan in which the luggage compartment was permanently separated from the passenger compartment. In the Volkswagen Passat station wagon, the passenger compartment was separated from the trunk only by a shutter and Honda HRV where the passenger compartment was separated from the trunk by rear deck. Temperature measurements in the luggage compartment of cars and in the front passenger seat were made in August in Poland under a cloudless sky. The cars stood in an unprotected parking lot for 30 minutes before inserting the data logger into the trunk. After this time, a mini data logger (Kimo KT 20, Germany) was inserted into the trunks. The cars then went through a half-hour city drive cycle simulating the journey from the shop to the consumer's home. The temperature during the cycle was recorded every 1 minute. The measurement results were then exported to an MS Excel spreadsheet.

2.6. Analysis of meteorological data

In order to analyse the meteorological data of the warmest months of the year, a modified HSY methodology - Hottest Summer Year (Narowski, 2006) was used. From the five-year observations taken from the meteoblue website (meteoblue 2020), one actual year of measurement data was selected based on the calculated monthly average dry bulb temperatures. The monthly mean temperatures in July and August were compared, then the year was selected with the extreme values of the monthly mean temperatures for these months. The mean temperature of the hottest month of the meteorological year determined in this way formed the basis for further analyses.

2.7. Consumer survey

The purpose of the consumer survey was to determine the method of transport and the time that elapses from the purchase of a frozen product to consumption or placing in the freezer for storage. The survey also examined consumer preferences and awareness of health risks caused by improper way of transporting products. The research material was collected directly and by means of a proprietary electronic survey in 2019-2020. The survey was anonymous and voluntary. The questionnaire contained questions about the respondent's gender, age, place of

residence, education and employment status. The remaining questions determined preferences in the selection of the assortment, store and the way of dealing with the purchased product. The survey questionnaire consisted of 14 questions. The group of respondents consisted of 104 people. The respondents were selected by the quota method. The share of people in the sample was determined in such a way that it is proportional to their actual share in the entire surveyed population. Data regarding the whole population was compiled on the basis of publicly available data from the Polish Statistical Office. The quota selection took into account gender, age and place of residence of the respondents. More than 58% of the respondents were women. Most of the respondents lived in large cities (38.2%) and were in the 18-25 age group (44.1%). Working people accounted for over 50%. The detailed characteristics of the respondents are presented in the table (Tab. 1).

Table 1. Socio-demographic characteristics of respondents

Characteristics	**n**	**%**
Gender		
Women	60	58.8
Men	44	41.2
Age		
18-25	45	44.1
26-40	26	25.5
41-60	24	23.5
>60	9	8.8
Place of residence		
Village	37	35.6
City < 100,000 inhabitants	19	18.3
City 100-500,000 inhabitants	39	37.5
City > 500,000 inhabitants	9	8.65
Education		
Primary, primary not completed	3	2.9
Vocational	14	13.5
Secondary vocational	19	18.3
General secondary	42	40.4
Higher	26	25.0
Employment status		
School pupil	3	2.88
Student	35	33.7
Employed	56	53.8
Unemployed	2	1,9
Retired/not able to work	8	7.69

Statistical analyses involving verification and evaluation of the survey results were carried out using Statistica version 10.0 (StatSoft Inc.). The chi-square test and the Mann-Whitney U test were used in statistical analyses. Cumulative analyses were performed. The product of frequency and the middle of the range was used to calculate the arithmetic mean of the interval distributive series (for example, the distance of consumer travels from store to home).

2.8. Consumer transport in real conditions

Investigations of temperature changes of frozen products during transport in real conditions and with the use of commercial packaging insulating bags were carried out using the following set-up: multichannel digital temperature meter equipped with T-type thermocouples. Frozen broccoli, carrots and green beans weighing 0.5 kg were placed in the trunk of a car immediately after purchase. Half of the frozen food was placed in commercial heat insulated bags that are sold in supermarket frozen food sections. Then, thermocouples were placed in all of the frozen food packages by puncturing the packaging film. The car was parked for 30 minutes in an uncovered parking lot in full sunlight. The recorded temperature in the trunk was 40oC. The next step was to move the car in traffic for 20 minutes. The recorded temperature kinetics are presented in graphical form.

3. Results and Discussion

3.1. Customer purchasing preferences

Meal planning, meal preparation and eating habits have changed significantly over the past decade. Consumers appreciate quick and easy methods of preparing meals. They willingly choose convenient, frozen products. These are widely available in. outlet stores, retail supermarkets, and convenience stores (Kumar *et al.*, 2020).

Based on the market analysis (subsection 2.1), it was found that vegetables sold in various forms are the most frequently chosen frozen products (Figire 1).

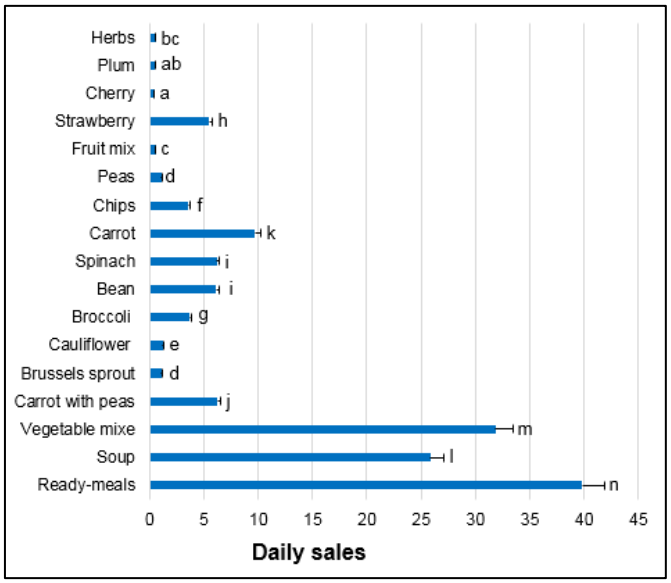


Figure 1. Average daily sales of frozen products on the local market. Means with the same latter are not highly significantly different (P < 0.05; n = 17)

Purchasing preferences in Poland do not differ significantly from global trends. Soups and ready-meals sold in Poland are generally mixtures of frozen vegetables with noodles and appropriate spices. According to Fortune Business Insights (2021), frozen vegetables and fruits are the largest segment of the global frozen food market. In 2019, this share was 22.66% of the total global market.

3.2. Kinetics of vegetable thawing

It is well known that fruit and vegetables are a valuable source of nutrients, including vitamins, minerals, and antioxidants (Augustin *et al.*, 2020). However, as perishable products, they are often chilled or frozen immediately after harvest (Zhu *et al.*, 2019). The temperature conditions in the distribution chain of frozen food determine the shelf life and final quality of frozen vegetables (Giannakourou and Taoukis, 2003).

Based on the thawing kinetics of selected deep-frozen vegetables, the rate of temperature changes in the surface and the thermal centre of the raw material were determined. It was found that the surface of the frozen carrot cube reached the temperature of 0°C after 350 seconds (5.83 min, SD ±0.18). The carrot thawing rate was 0.43 mm min-1. In the case of spinach, a surface temperature of 0°C was recorded after 300 seconds. Therefore, it was found that its surface was thawed after 5 min. In the spinach thermal centre, this temperature was recorded after 400 seconds (6.67 min, SD ±0.28). Trials for thawing potato fries were carried out under the same conditions. The surface of the fries was found to reach 0°C after 800 seconds (13.33 min) in air at 24.2°C. However, in the thermal centre, the thawed state was detected after 1000 s (16.17 min, ±0.79). Due to their specific structure, broccoli and cauliflower are frozen in the form of small florets up to 5 cm in diameter and up to 2 cm in length. As a result, this raw material has a different thickness depending on the place of measurement (the broccoli stem has a diameter of 1 cm and the flowers at the end of the floret - a few millimetres). Therefore, the edges of the broccoli inflorescence thaw much faster than the stems of these raw materials (Figure 2a). When analysing the histogram of the temperature distribution on the broccoli surface (Figure 2b) it was noticed that the temperature ranged from -15.2 to 2.2ºC.

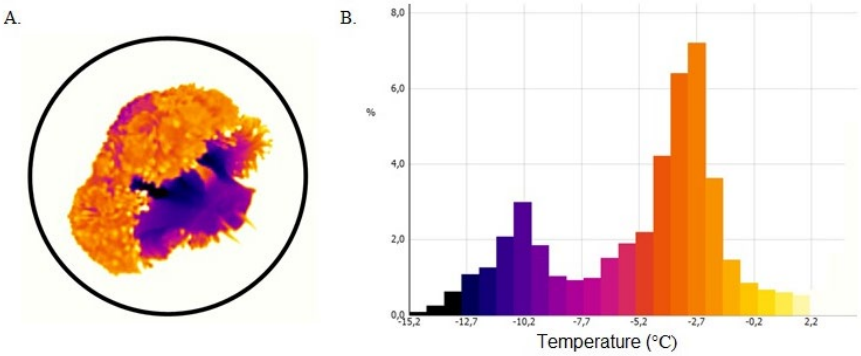


Figure 2. Thawing kinetics of broccoli florets: a) Image from a thermal imaging camera b) Histogram of temperature distribution on a sample surface

This proves that the speed of thawing in particular parts of the raw material varies greatly. When the surface temperature of the stem was still much below zero, the florets were already thawed. Cevoli *et al.* (2018), who conducted thawing kinetics analyses (at an ambient temperature of 5°C) of packed vegetables, obtained the following times: 14.8 ± 1.9 minutes for peas, 19.8 ± 1.8 minutes for diced spinach and 4.8 ± 0.5 minutes for grilled eggplants. The thawing start temperature was respectively -6.1°C for peas, -5.4°C for spinach cubes and -7.1°C for grilled aubergines. These studies confirm that the particles of the product that are in the centre of the package are still frozen, and that the outer layers in the package are thawing very quickly.

3.3. Effect of re-freezing on sample texture change

Maintaining the cold chain is extremely important in the distribution of frozen products. Improper management of this process can lead to serious physical and chemical changes of the frozen products. Temperature fluctuations cause repeated defrosting and freezing of products leading to deterioration of food quality (Kumar *et al.*, 2020).

The effect of re-freezing on the hardness of frozen vegetables was investigated by conducting a puncture test. The force-time dependence graph is characterized by two peaks. The first peak indicates the surface penetration force and the second peak indicates the hardness of the sample. Analysing the results of the thawed fries penetration test, it was found that the average hardness was 1.63 N, with a standard deviation of 0.21 N. The highest hardness measured was 2.07 N, while the lowest was 1.37 N (Figure 3).

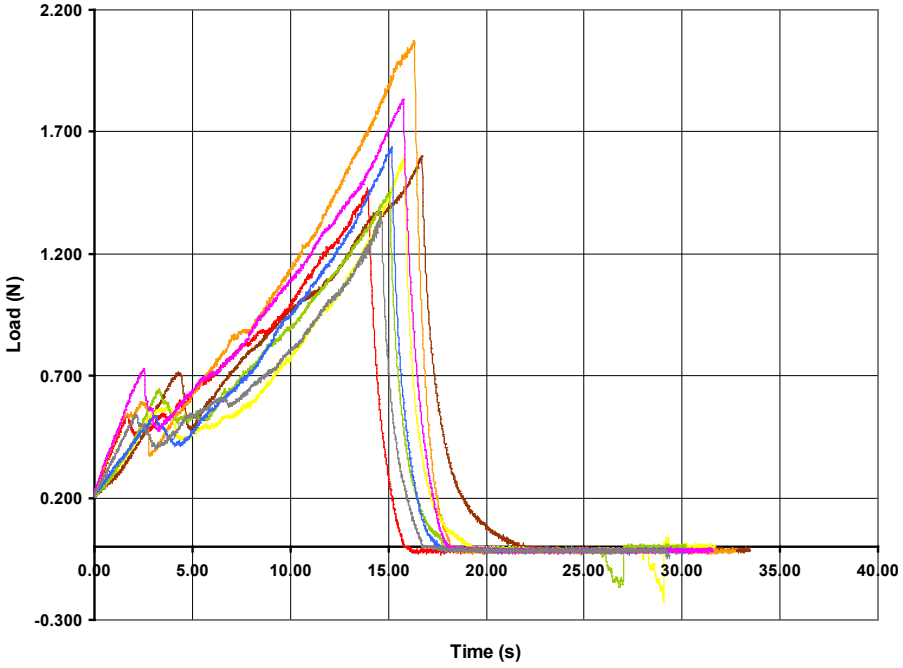


Figure 3. Dependence of puncture force on time measured for thawed French fries

Testing the re-frozen and thawed French fries, the following results were obtained: the mean hardness was 0.78 N, the standard deviation was 0.15 N, the highest hardness was 1.03 N and the lowest was 0.54 N (Figure 4).

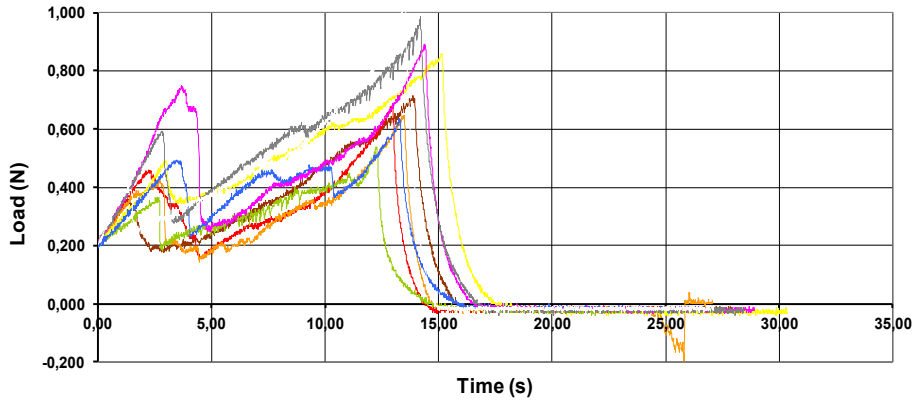


Figure 4. Dependence of puncture force on time for re-frozen and thawed French fries

Comparing the results of the penetration test, it was found, as expected, that re-freezing the previously thawed French fries compared to the once-thawed French fries resulted in a decrease in hardness. The average hardness values decreased from 1.63 N to 0.78 N. Since the P-value for the t-test is less than 0.05, there is a statistically significant difference between the means at the 5% significance level. This indicates a definite deterioration in the firmness of the tissue structure as a result of ice damage to cell membranes and associated leakage after thawing. Similar results were obtained by Boonsumrej *et al.* (2007). These authors investigated the effect of freezing and thawing cycles of tiger shrimp (Panaeus monodon) caused by temperature fluctuations. They observed that as the number of cycles increased the cutting force, an indication of toughening, caused cell membrane damage and increased drip loss. In addition, Kumar *et al.* (2019) investigated that temperature fluctuations reduced hardness in frozen thawed potatoes. They concluded, among other things, that the results could contribute to improved storage and transportation strategies to minimize quality changes in frozen potatoes. Khan and Afroz (2014) report that temperature fluctuations occurring during the storage of frozen fruits and vegetables cause changes in the physical structure of the food. These changes are the result of re-crystallization and sublimation phenomena associated with the stability of ice crystals inside and on the surface of the products. Temperature fluctuations during freezing are primarily responsible for re-crystallization and surface drying, although the importance of these physical changes decreases at lower storage temperatures.

3.4. Consumer survey

In many countries, the consumption of frozen vegetables and fruits reaches millions of tons per year (Herath, 2019; Alabi *et al.*, 2020). According to data from Nielsen, only in the last year the frozen food market has grown by 5.8% in terms of volume and by 7.4% in terms of value. Importantly, this positive trend applies to all types of frozen food, from stir-fry vegetables and vegetable mixes to the niche of frozen fruit (Anonymous, 2021). The development of the frozen products market in Poland is conditioned by the change in the lifestyle of consumers, as well as the ever wider market offer, especially ready-made frozen meals (Nosecka, 2012). Similar results were obtained by Kozirok *et al.* (2011) who examined the preferences of female consumers in the Tri-City (Gdańsk, Sopot, Gdynia).

Based on the findings, it was possible to learn about the consumers' behaviour and preferences related to the purchase and method of transport of frozen products, as well as their awareness of possible health risks resulting from the cold chain failures. The purpose of the first question asked to the respondents was verifying the correct selection of respondents. It was found that the fraction of respondents that buy frozen products is 96%. This proves that respondents are able to answer subsequent survey questions and the great popularity of frozen products among the surveyed consumers. Another question in the survey concerned the most frequently purchased frozen products. Based on the responses, it was found that frozen vegetables, potato fries and fish fillets are the most popular. Ready meals, fruit, soups, salads and other products (including seafood) were less popular among consumers (Figure 5).

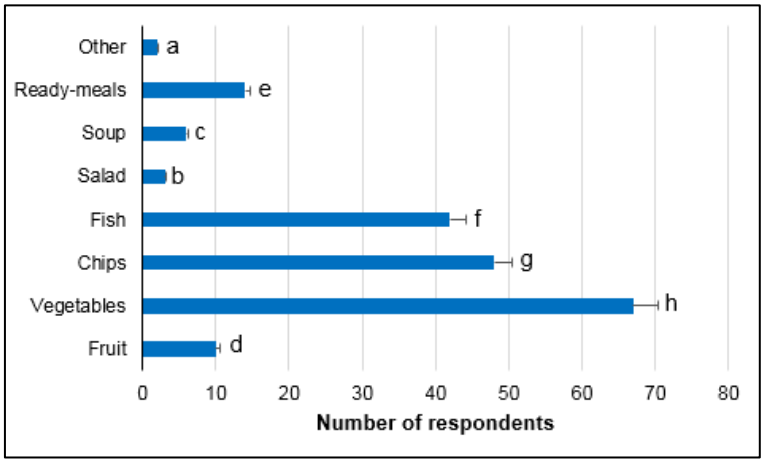


Figure 5. Types of frozen products purchased. Means with the same latter are not highly significantly different ($P < 0.05$; $n = 8$)

This is confirmed by the analysis of the local market (section 3.1). According to the analysis of the Polish market, in 2019 the share of frozen vegetables in the production of processed vegetables was approx. 50% (Anonymous, 2021).

The survey shows that frozen products are most often purchased in large-format stores. Supermarket and hypermarket were mentioned by 61 and 38 people, respectively, as the place of purchase of frozen food. In the next part of the survey, respondents were asked questions about the transport of frozen products from the shop to the house. When asked about the distance they cover from the shop to the house, the respondents most often declared

up to 5 km. The average distance was 4.98 km. In response to a question about the time of transporting deep-frozen products from the shop to their home, 54% of respondents indicated that it took them more than 10 minutes. On the basis of these results, it was found that only for a few consumers it took over 20 minutes to transport frozen products from the shop to their home. The average time of transporting frozen food home, as declared by the respondents, was 12.85 minutes. 50% of people declared shopping in large-format stores and at the same time indicated the transport time over 10 minutes. In the statistical analysis, using the Student's t-test for independent samples, the p value was = 0.311907 with a confidence level of 0.05, while the choice of the type of shop was significantly related to the distance between the shop and the house ($p = 0.0000162$, $\alpha = 0.005$). This apparent contradiction in terms of distance and time of transport seems to be due to the mode of transport used. When the distance from the store is large, the respondents use a private car or public transport, and at a short distance, they cover the road on foot. Hence, the transport time is not directly related to the type of shop or its distance from the respondent's home. Detailed results of the survey regarding the time, distance and means of transport of frozen products are presented in Table 2.

Table 2. Results of surveys on the time, distance and means of transport of frozen products

	Distance on the home-shop way (km)			
Distance	> 0.5	0.5- 5	5-10	10-25
n	28	57	9	11
%	27.45	55.88	8.82	10.78
	Transport time on the home-shop way (min)			
Time	5-10	10-20	20-30	>30
n	46	42	10	2
%	45.10	41.18	9.80	1.96
	Means of transport on the home-shop way			
Means of transport	On foot	By car	By bus	By other means of transport
n	39	59	18	0
%	38.24	57.84	17.65	0

The studies of DiSantis *et al.* (2016) found that for 57% of project participants, the most visited shop was within 1 mile (1.61 km) of their home. The average distance to the shop was 1.8 miles (2.90 km) and more than 50% of the participants in the project used a car to cover this distance. Kerr *et al.* (2012) obtained different results regarding the distance covered. The average distance from the grocery store was 4.35 miles (7 km). They showed that only 7% of people covered the distance to gastronomic points on foot. In surveys by Balzan *et al.* (2014) and Worsfold and Griffith (1997), respondents reported that the journey home from the shop took a maximum of 30 minutes, and most of the respondents travelled by car. These results are comparable with the results obtained by the authors of this publication.

The next series of questions concerned consumer awareness. Their aim was to find out whether respondents pay attention to the temperature of transport and storage and whether the expiry date is an important criterion for product selection. It was found that when buying, consumers are guided by the expiry date and price (69% and 67% respectively). Storage temperature was of marginal importance for buyers, because only 2% of respondents declared that they pay attention to this aspect. This low consumer awareness has been confirmed by research carried out in Slovenia. The respondents stated that the most important factor in ensuring the cold chain is the time of transport, and not maintaining the right temperature (Jevšnik *et al.*, 2008). Consumers were not aware that the main ingredient in fruit and vegetables is water, which accounts for 80-90% of their weight (Khan *et al.*, 2017). This high water content promotes microbial activity and enzymatic reactions in cells, causing chemical degradation and loss of product quality (Alabi *et al.*, 2020). It was noted that the respondents considered the type of product the most reliable information on the transport temperature (33%), and for 12% the appropriate temperature for the transport of frozen products is 0° C. On the other hand, 98.6% of respondents say that once thawed food cannot be re-frozen, 89% of respondents believe that re-thawed food is unsafe. In the studies of Balzan *et al.* (2014) all respondents admitted that short transport times are important for the safety and quality of food products. On the basis of these responses, it is difficult to state unequivocally whether there is no consumer awareness of the need to maintain the cold chain. On the one hand, the respondents do not know under what conditions frozen products should be transported, and on the other hand, almost all respondents are aware of the possible harmfulness of consuming re-frozen products. The low level of consumer awareness is also evidenced by studies conducted by Ovca and Jevšnik, (2009) and Balzan *et al.* (2014) to gather views on the cold chain. Most of the respondents (54.2%) knew the term "cold chain" but did not know its meaning, 25% of consumers knew the term but associated it with several other meanings (e.g. freezer, refrigerator, frozen food), while 20.8% of the respondents did not knew the term.

During the freezing, packaging and storage of products, significant physical, chemical and biochemical changes may occur as a result of changes in the thermal environment (Góral *et al.*, 2016; Cevoli *et al.*, 2018). When

asked about thermal packaging, only 33% of respondents answered that they use it. In a Slovenian study, the results showed that more than half (51.7%) of the respondents had never thought about using a insulated bag, and 33% believed that a insulated bag was not necessary. Of all Slovenian respondents, only 15.5% have ever taken a insulated bag with them when purchasing perishable food items (Jevšnik *et al.*, 2008). According to Worsfold and Griffith (1997), only 29% of those surveyed who transported food during the summer months of June, July, August and September used an insulated cooler bag. In contrast, studies by Balzan *et al.* (2014) found that 62.5% of respondents used a insulated bag, 20.8% felt it was not necessary because they had a short time to transport products from store to home, and 16.7% of respondents admitted they forgot their bag. However, older people participated in these studies, which may indicate their higher awareness of food safety. Losasso *et al.* (2012) noted that 14% and 25% of respondents respectively used insulated bags to transport chilled and frozen products.

3.5. Analysis of meteorological data and conditions of consumer transport

Research on the conditions of consumer transport was carried out in 2020. After analysing the temperature course during the five-year observation, it was found that the monthly average temperatures in June, July and August were the highest in 2020. In 2020, August was the hottest month (Figure 6).

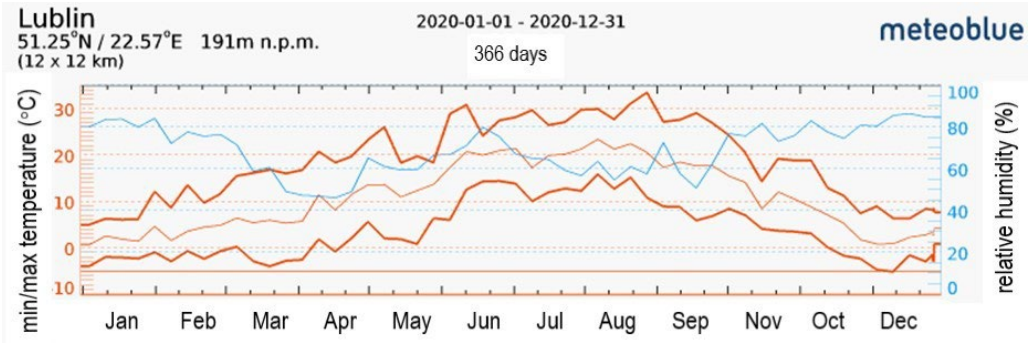


Figure 6. An example of the annual course of air temperature in Lublin in 2020

The average temperature of the individual days in August was over 25°C, and the highest temperatures of the day exceeded 35°C. In the analysed period of 2015-2020, this month had the highest average daily temperature and the number of days with a temperature exceeding 30°C. Therefore, the analysis of the conditions of consumer transport was carried out in August.

3.6. Consumer transport

The air temperature in the parking lot at the level of the trunk of the car was 30ºC. It was found that the temperature in the trunks of cars exceeded the outside temperature by about 10° C (Fig.7).

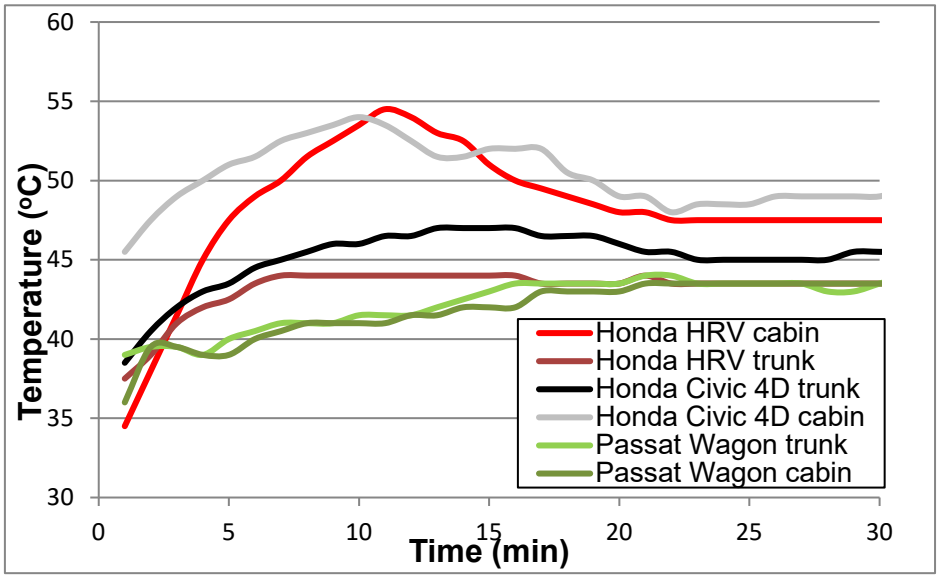


Figure 7. Temperature changes inside the trunks and cabins of the tested cars during the measurement

The highest increase in temperature was recorded in the front passenger seat, where the temperature reached 55°C. The temperature in the Honda cabin was measured directly on the seat. It was statistically significantly higher than the temperature in the trunk of a Honda, as well as in the trunk and cabin of the Passat. Such high values were influenced by solar radiation. This radiation penetrated the interior of the car through the windows and heated the surfaces of the seats similar to Kim *et al.* (2013) study. The cabin air supply caused the car's interior to slowly cool down. The trunks of the tested cars were sheltered and the solar radiation did not affect the heating. Godwin and Coppings (2005) found that 51% of consumers who use a passenger car transport purchased food in the trunk. Only 28% of the respondents transported their purchases in a different part of the car. The brand and colour of the car were not affected by the temperature inside the trunk. In the initial 15 minutes, the station wagon had a lower temperature of luggage compartment than the other cars. It is related to the way the trunk is not separated from the car's cabin.

3.7. Consumer transport in real conditions

Transport between the retail store and the consumer's home is quite short compared to other links in the cold chain. Nevertheless, its impact on product quality and safety should not be considered negligible (Ovca *et al.*, 2013). Consumer transport of frozen food without insulated bags, in real conditions in summer, will obviously result in partial or complete thawing of the goods. This was confirmed by assessing the thawing kinetics of vegetables. Therefore, an analysis of the raw material transport in real conditions with the use of insulated bags was carried out. Figure 8 shows the temperature inside a package of frozen vegetables during consumer transport in the trunk of a car. When pairwise comparisons were made between frozen food packed in and without an insulating bag, the P-value (0.0) for the t-test (6.16) was found to be less than 0.05. This means that there is a statistically significant difference between the mean temperatures at the 5% significance level.

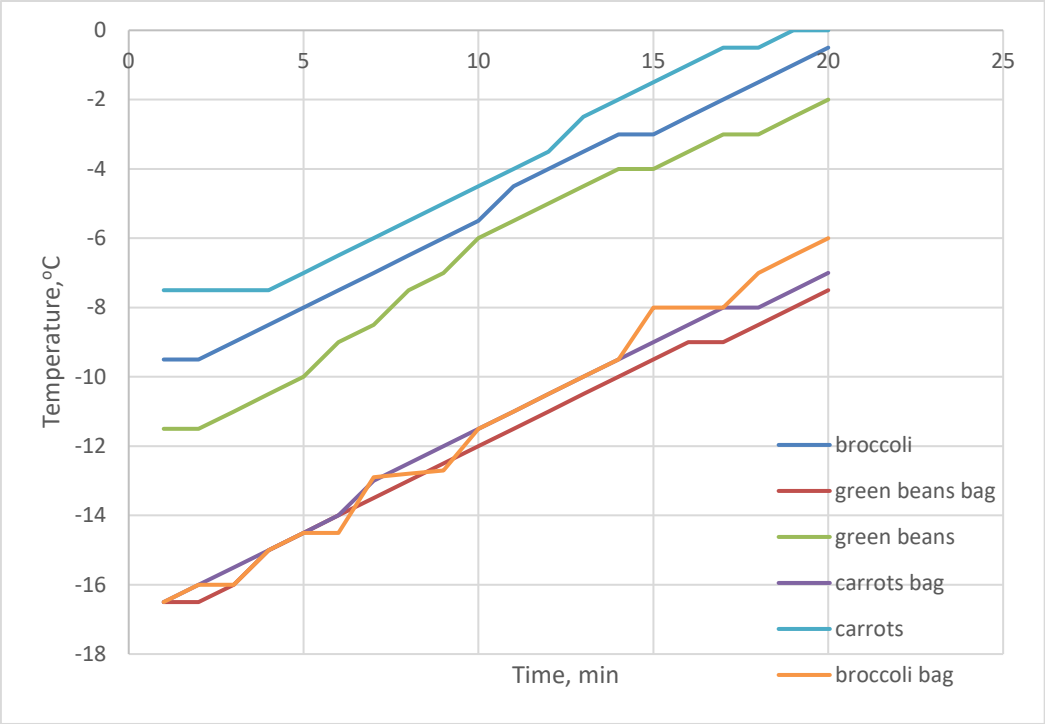


Figure 8. Intra-pack temperature of frozen vegetables during consumer transport with and without use of an insulating bag.

The discrepancy in initial temperatures was caused by the time required to travel from the store checkout to the car. As can be seen from Figure 8, when insulated bags were used, the -5°C temperature inside the package was never exceeded. After 20 minutes of driving, the temperature inside the frozen food transported without the insulated bag approached 0oC, and after unpacking the package walls were moist. This indicates that the use of insulated bags can significantly protect the product from thawing.

4. Conclusions

Frozen products are very popular among customers. Vegetables are the most frequently chosen frozen foods. Research on consumer purchasing preferences has shown that frozen products are most often

purchased in large-format stores. The most frequently chosen means of transport was a car, which is confirmed by numerous literature data. The average distance that customers cover from the shop to their home was 4.98 km. It was covered on average in 12.85 minutes. The results concerning the thawing kinetics of vegetables showed that the temperature of 0°C was achieved in the shortest time on the spinach surface (5 min), while the broccoli was thawed the longest (the temperature of 0°C was reached in the thermal centre of broccoli after 16.17 min). Thus, the transport time was sufficient to begin the thawing process of the packaged frozen vegetables. Thawing and refreezing affects product texture. Therefore, consumer transport of frozen products has been found to cause deterioration in product quality. The surveyed consumers were aware of the possible consequences of breaking the cold chain. On the other hand, there was a lack of consumer awareness of the transport conditions of frozen food. Only 33% of the respondents used insulated bags to secure appropriate transport conditions on the shop-home way, and few of these consumers emphasized the importance of maintaining the cold chain throughout the entire transport of frozen products. The survey was carried out as a reference point for researching the actual transport conditions. August, the warmest month of the year, was selected to carry out the research on the conditions of consumer transport on the basis of the analysis of the temperature courses. The brand and colour of the car did not affect the temperature inside the trunk. The highest temperature increase was recorded in the front passenger seat. When analysing the consumer transport of frozen raw material in real conditions, the use of thermal bags was found to be justified. These bags are able to keep the temperature of the packed raw material below -5°C. The survey shows that consumers are reluctant to use thermal bags. Therefore, it seems necessary to legally impose the necessity to use such bags or introduce appropriate packaging by the manufacturer of frozen food, protecting the food against transport in inappropriate temperatures during the summer months.

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