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The efficiency of thermal insulating bags during domestic transport of chilled food items

Andrej **OVCA**[1*], Telma **NOVO**[2], Silvia **SÊCO**[2], Mojca **JEVŠNIK**[1]

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[1] University of Ljubljana
Faculty of Health Sciences
Department of Sanitary Engineering
Zdravstvena pot 5, SI-1000 Ljubljana
Slovenia

[2] IPC, ESTeSC, Coimbra Health School, Rua 5 de Outubro, Apartado 7006, São Martinho do Bispo, 3046-854 Coimbra, Portugal

[*] *Corresponding author*
Andrej Ovca
University of Ljubljana
Faculty of Health Sciences
Department of Sanitary Engineering
Zdravstvena pot 5
SI-1000 Ljubljana, Slovenia
Phone: +386 1 300 11 82
Fax: +386 1 300 11 19
E-mail: andrej.ovca@zf.uni-lj.si

ABSTRACT

It has been demonstrated that temperature control is critical in the last three steps in the cold chain including transport between retail and the consumer's home. The aim of this study is therefore to evaluate the efficiency of thermal insulating bags meant to transport frozen foods from stores to consumers' homes also in case of transporting chilled foods. The efficiency of three insulating and one typical PVC bag as a control is evaluated. Evaluation is done at different internal (related to the load of the bag) and external (related to the outside temperature) conditions, also taking their price into consideration. During evaluation, measurements of test objects' internal temperature were executed at five-minute intervals with a Testo 177-T4 data logger. The measurements reveal variations of the test objects' internal temperature in accordance with air temperature outside the bag and the degree of load in the bag. The evaluated insulating bags are not efficient enough to preserve appropriate temperature environments for chilled food items under experimental conditions. There was also no confirmation of any significant impact of insulating bag purchase price.

Key words: Food safety, food transport, cold chain, insulating bags

Considering the potential microbiological risk presented by perishable food items, maintaining the cold chain should continue up to and within a consumer's home.

In addition to a high resistance to the transfer of heat, a good insulating material must have various characteristics (depending upon the application); low cost, low moisture susceptibility, ease transportation, consumer appeal, and mechanical strength are the most relevant ones.

INTRODUCTION

Refrigeration is one of the most widely practiced methods of preserving the quality and safety of foodstuffs. Maintaining a cold chain is an important preventive step for ensuring food safety, and temperature is one of key parameters effecting growth of microorganisms and their survival in food. Therefore, in order to provide safe food at high quality, attention must be paid to every aspect of the cold chain from production to consumption. It is important that the process of maintaining the cold chain does not end with the retailer. Considering the potential microbiological risk presented by perishable food items, maintaining the cold chain should continue up to and within a consumer's home.

Transfer points are well known problem areas for temperature mishandling and refer to points in the cold chain where products are transferred from one cold area to another. In a survey conducted in France [1], in which refrigerated products were monitored throughout the cold chain, it was revealed that maintaining appropriate temperature is especially critical in the last three steps in the cold chain (the display cabinet in store, domestic transport and the household refrigerator). Furthermore, several studies reveal consumers' insufficient knowledge about the importance of maintaining the cold chain and carelessness in handling perishable foodstuffs [2,3,4].

Lack of time is the reason consumers frequently and regularly buy chilled and frozen food that either has a short preparation time or does not even require any further heat treatment. Jackson et al. [5] report that chilled and frozen foods including products that can be consumed without further heat treatment represent more than 60 % of the typical shopping basket of an average European consumer. To reduce the risk of temperature mishandling in case of perishable food items, transport in an insulating bag or box is generally recommended. In addition to a high resistance to the transfer of heat, a good insulating material must have various characteristics (depending upon the application); low cost, low moisture susceptibility, ease transportation, consumer appeal, and mechanical strength are the most relevant ones [6]. Furthermore, a clean insulating bag interior is essential to avoid contamination or cross-contamination of food and to prevent changes in sensory properties, especially the adsorption of foreign smells.

Evans [7] investigated the effect of the time period, and the manner of transport on a food temperature purchased from a large retail store and placed in a pre-cooled insulating box or left in the boot of a car unprotected. In some products, temperatures in the boot rose up to 40°C during a one-hour car journey during which most of the samples placed in the insulating box did not change their temperature during the transport. Those transported in a boot of a car then required approximately five hours after being placed in a domestic refrigerator before the temperature was again reduced below 7 °C.

A study among Slovenian population revealed that the average time a consumer needs to travel from store to home is 25 min [4], which is less than reported by Derens [1] for French consumers, where the duration of the domestic transport between retail and the consumer's home is typically an hour. Others report up to or even more than 90 min for 7 % of consumers investigated [8]. The study of Jevšnik et al. [4] also revealed that 51.7 % of the respondents never even thought of using an insulating bag, while additional 33 % believed that an insulating bag is not necessary. Among all respondents (N = 985), only 15.5 % had ever taken an insulating bag to the store when buying perishable foodstuffs, while this percentage was significantly higher among respondents who also believed that the consumer is also responsible for food safety.

In spite of the issue addressed above, there is little evidence regarding the efficiency of insulating boxes; such research is extremely rare and mostly in the context of material testing [6,9]. The aim of the current research is therefore to evaluate the efficiency of insulating bags meant for maintaining the cold chain by consumers during the transport of perishable food items from the store to the their home. The efficiency of insulating bags will be evaluated at different internal and external conditions, also considering their price, with different insulating bags at different prices are available to the consumer.

METHODS

Apparatus and materials

The efficiency of insulating bags available at different purchase prices and one typical bag was tested. All three insulating bags are made of metallized low-density polyethylene (LDPE) with snap-in type closures (polyethylene terephthalate (PET)) and same outside dimensions (approx. 50 cm × 50 cm). A typical bag is made of Polyvinyl chloride (PVC). For further presentation of the data, they were numbered as follows:

- Bag 1: typical PVC bag
- Bag 2: low price insulating bag (€0.79)
- Bag 3: middle price insulating bag (€1.49)
- Bag 4: high price insulating bag (€2.24)

The internal temperature was measured with an artificial "test object" with weight of 246 g. The material used for its preparation is tylose gel (77 % water, 23 % methylcellulose powder). Tylose gel is often used for studying heat transfer during freezing and thawing operations, while its thermal properties are similar to lean beef; it has been previously validated [10]; it is homogeneous and can be reused for several repetitions.

During the measurements of internal temperature, a probe was placed in the interior of the test object. For the collection of data during temperature measurements, a Testo 177-T4 data logger with a -200 °C to +400 °C measurement range, 0.1 °C resolution and ± 0.3 °C accuracy was used. The internal temperature was monitored in five-minute intervals. Measurements were done at two different external air temperatures (15 °C and 30 °C) simulating different outside temperatures. Internal conditions were related to the load of insulating bag during the experiment. Three different situations were tested with *i)* one test object only, *ii)* three

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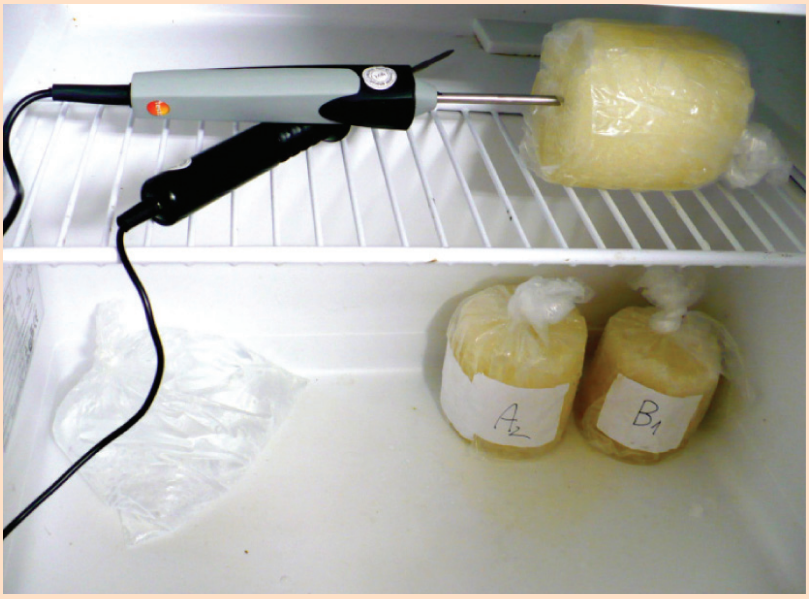

Picture 1: Test product together with the thermometer probe in the insulating bag

Picture 2: Test product together with the data logger and thermometer probe in the insulating bag

Picture 3: Insulating bag with content in the incubator

test objects and *iii)* three test objects plus 1.5 L of water in PET bottle. In all cases, a thermometer probe was inserted in only one test object to monitor internal temperatures. For controlled experimental conditions, a Kambič I-45 CK air temperature incubator (with a volume of 44 L, forced air circulation, 0.1 °C resolution of temperature setting) and a Zanussi ZRG309W refrigerator (with volume of 91 L) were used. The average air temperature in the refrigerator during the measurements was 4.8 °C (SD = 1.0). The average air temperature in the incubator during the measurements was 15.4 (SD = 0.5) and 29.7 (SD = 0.6) respectively.

Experimental procedure

Initially, the test object (together with the thermometer probe) was placed in the refrigerator for 24h to adapt (Picture 1). During each measurement, the internal temperature of the test object was monitored after the first 15 minutes while still in the refrigerator. After 15 minutes, the test object, together with thermometer probe and data logger, was placed into the selected bag (Picture 2). The closed bag was transferred into the incubator for 60 minutes (Picture 3). Afterwards, the test object is again placed in the refrigerator, where the internal temperature was still monitored for additional 300 minutes. The next measurement was executed at least after 15 hours rest of the test object (together with the thermometer probe) in a refrigerator.

RESULTS AND DISCUSSION

The results presented in Table 1 clearly show that insulating bags are not effective in preserving appropriate temperature environment for one hour in the described experimental conditions to which test object was exposed. An evaluation of results in Tab. 1 demonstrates the impact of bag external conditions (temperature outside the bag) as well as bag internal conditions (degree of load) on the test object's internal temperature. Although 30 °C was chosen as an experimental condition, it must be mentioned that in real situations when food is transported in cars, air temperature varies in accordance with solar radiation and cloud cover. Kim et al. [11] report that the temperature difference between the car trunk and outdoor can be up to 15.8 °C with no cloud cover and the highest solar radiation (21.1 MJ/m^2) or just 4.8 °C under the low solar radiation (14.6 MJ/m^2) and maximum cloud cover.

The difference between initial internal temperature of the test object and the intermediate temperature after 60 minutes of exposure to described bag internal and external conditions is expressed as ΔT. An average ΔT comparing only insulating bags (Bags 2–4) was 2.4 °C and 6.2 °C at outside temperatures 15 °C and 30 °C, respectively. An average ΔT of a typical PVC bag (Bag 1) was 2.6 °C and 8.2 °C at outside temperatures of 15 °C and 30 °C respectively. Closer examination shows that ΔT is decreasing in relation to the higher bag number and higher degree of load. Differences between values of ΔT (when comparing different bags) are becoming smaller when the degree of load is increased. Bag 1, used as a control bag, proved to be at least efficient to preserve the initial

Table 1: Internal temperatures of test object at different internal and external bag conditions

EC	IC	Bag nr.	Initial T (°C)	Intermediate T (°C)	Maximum T (°C)	Final T (°C)	ΔT (°C)	Case number
15°C	1	1	4.8	7.9	8.8	5.8	3.1	1
		2	4.8	7.8	8.4	5.4	3.0	2
		3	4.7	7.5	8.1	5.5	2.8	3
		4	5.1	7.4	7.9	5.4	2.3	4
	3	1	4.7	7.1	7.8	5.3	2.4	5
		2	4.5	6.9	7.3	5.1	2.4	6
		3	4.6	6.9	7.3	5.2	2.3	7
		4	4.8	7.1	7.5	5.2	2.3	8
	3+	1	4.9	7.2	7.8	5.5	2.3	9
		2	4.9	7.1	7.4	4.8	2.2	10
		3	4.4	6.4	6.4	5.4	2.0	11
		4	4.8	6.8	7.3	5.5	2.0	12
30°C	1	1	4.8	13.5	15.1	6.7	8.7	13
		2	4.9	12.2	13.6	6.4	7.3	14
		3	5.0	12.3	13.5	5.8	7.3	15
		4	4.7	11.9	13.3	6.4	7.2	16
	3	1	4.6	12.5	13.4	6.1	7.9	17
		2	4.8	11.5	13.0	6.1	6.7	18
		3	4.4	10.8	12.2	5.8	6.4	19
		4	4.7	10.8	12.2	5.9	6.1	20
	3+	1	4.9	12.8	13.2	6.5	7.9	21
		2	4.9	10.5	11.3	6.3	5.6	22
		3	5.1	9.9	11.2	5.3	4.8	23
		4	5.2	9.9	10.6	5.5	4.7	24

Legend: *EC* – Bag external conditions; *IC* – Bag internal conditions; *Initial T* – Initial internal temperature of test object in the refrigerator; *Intermediate T* – Intermediate internal temperature of test object after 1h in selected bag exposed to experimental conditions; *Maximum T* – Maximum internal temperature of test object measured; *Final T* – Final internal temperature of test object after taken out of the selected bag and stored in refrigerator for 5 h; *ΔT* – Internal temperature difference of the test object during one hour exposure to experimental conditions; *1* – one test object; *3* – three test objects; *3+* – three test objects with 1.5L of water in PET bottle.

temperature of the test object. In contrast, the most expensive insulating bag (Bag 4) was the most efficient in comparison to the other bags. Consequently, the smallest Δ*T* is observed for case number 12 and the highest for case number 13 (Tab. 1). Comparing the typical plastic bag with insulating bags also demonstrates that differences of Δ*T* are more obvious at higher outside temperatures (30 °C) and higher degrees of load. Further comparing Δ*T* only between insulating bags (Bags 2–4) reveals that the differences are minimal with no significant impact of their purchase prices.

Closer examination of the maximum internal temperature reached also reveals that when the outside temperature is 30 °C the test object's internal temperature reaches 13.6 °C if stored in insulating bag. Although some previous studies [7] report that during a one-hour car journey most of the samples placed in the pre-cooled insulating box did not change their temperature during the transport, this was not confirmed with our measurements. This could be due to the fact that insulating bags were not pre-cooled, and the relatively small test object (246 g)

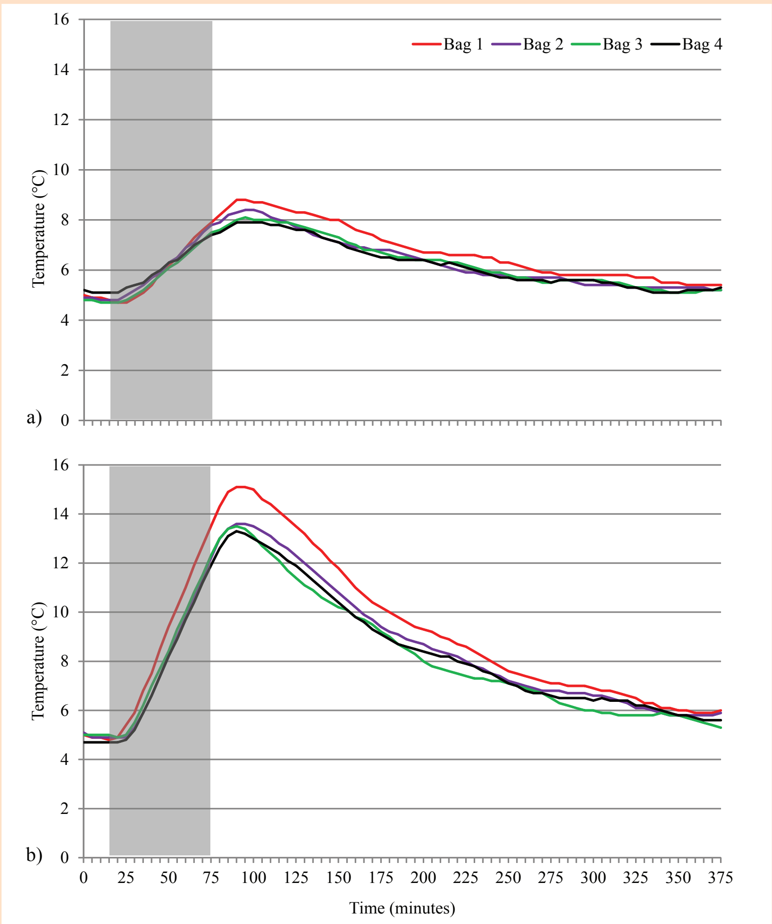

Figure 1:
Comparison of internal temperatures movement of test object placed in different bags at a) 15 °C and b) 30 °C external temperature. The grey area indicates the time period (60 minutes) when the insulated bag and its content were exposed to controlled outside temperature.

used. In our study, bigger test objects were not evaluated. As reported by Kim et al. [11], among the food items examined the temperature dramatically increased immediately after storage in the trunk by food items with the lowest weight.

The maximum internal temperatures (Tab. 1) measured already present a rather favourable temperature environment for the progress of psychotropic microorganisms which grow well at 7 °C and have their optimum at 10–15 °C, depending on nutrient content, pH and the availability of liquid water [12]. However, the higher surface temperature of the test object (not measured) and time of exposure to these temperatures should not be neglected.

Closer examination of the test object's internal temperature rise if placed in different bags at different external temperatures (Fig. 1) reveals that internal temperatures also rise after the test object is placed back into the refrigerator. The maximum internal temperatures of the test object were reached 15 to 20 minutes after placement in the refrigerator, and retained at a maximum level for an additional 10 minutes, exceptionally 15 minutes in cases 6 and 11 (Tab. 1), before they began to drop. Closer examination (Fig. 1) of the test objects' internal temperature inclines between initial and maximum value, calculating the slope, additionally reveals that at both (15 °C and 30 °C) outside temperatures, the internal temperature of the test objects placed in Bag 1 increases faster (higher slope) compared to the insulating bags after exposure to experimental

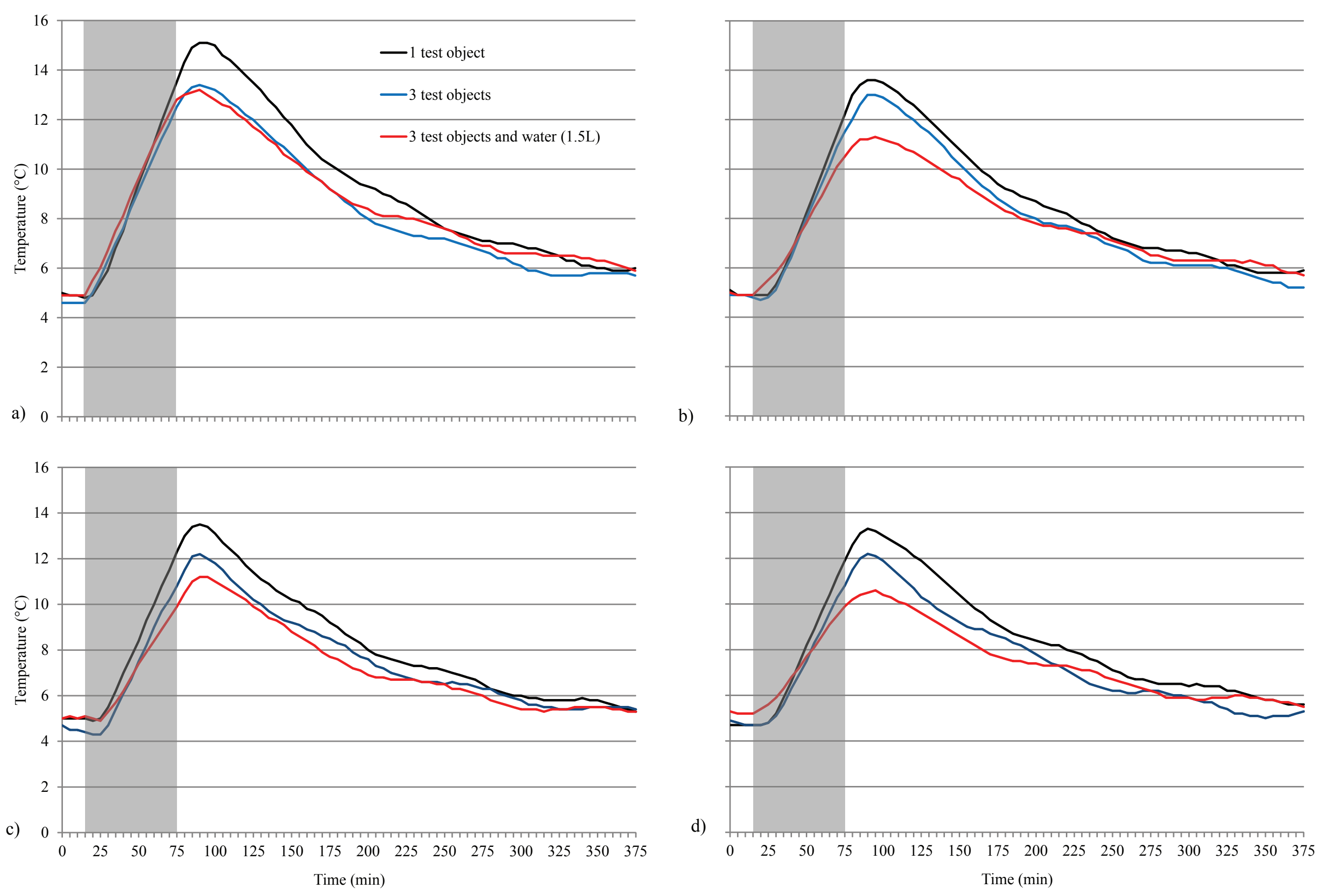

Figure 2:
Comparison of internal temperature movement of test object at 30°C external temperature and different internal conditions in a) bag 1, b) bag 2, c) bag 3 and d) bag 4. The grey area indicates the time period (60 minutes) when the insulated bag and its content were exposed to controlled outside temperature.

conditions. Furthermore, a slope comparison between insulating bags reveals that the value decreases in correlation with the bag's price (Fig. 2). However, this is true only if one test object is present in the bag.

A comparison of the test objects' internal temperature at 30 °C external temperature and different internal conditions demonstrates that increases of internal temperatures of the test object is diminished when the degree of load is increased in all bags examined (Fig. 2a–d). The highest internal temperatures of test objects' are achieved with one test object only. A closer examination of temperature rises in correlation to time also reveals that approximately five hours are necessary after test object is placed in a refrigerator, for the internal temperature to be again reduced below 6 °C.

In this context, consumer behaviour should be taken into account. Godwin & Coppings [13] report that consumers using insulating bags consequently extend the time of transport to their home, which also otherwise differs between different countries [1, 3, 4, 7, 14]. If insulating bags are not as efficient as consumers would expect or believe, irrespective of the outside temperature and degree of load in the bag, the risk for infection or spoilage is increased. Additionally it must be considered that consumers often do not pay any particular attention to the temperatures in domestic refrigerator. As reported by James and others [15], it is clear that many refrigerators throughout the world are already running at higher temperatures than recommended.

From the total cold chain point of view based on the measurement done by Darens et al [1], a refrigerated product spends two thirds of its life in an environment managed by professionals and the rest managed by the consumer. However, professionals in food stores do not always maintain appropriate temperatures. As reported by others [16,17], the temperatures measured differed from the required ones by for up to 10 °C.

Guidelines of good hygienic practices and the principles of the HACCP system in stores [18] recommend to consumers that food items requiring maintaining of the cold chain should be stored in insulating bags during the transport. A commercial insulating bag is a type of shipping container in the form of a bag made of materials with thermal insulation properties used to maintain the temperature of its contents. Most insulating materials utilize low thermal conductivity as a means of restricting the transfer of heat, although radiation and convection are also significant means. Resistance to heat transfer depends on various characteristics that determine the insulating ability of a container [6,19]. The wall thickness affects heat transfer via conduction, the number of surfaces via convection and the number of reflective surfaces (such as aluminium foil) via radiation. According to the manufacturer, the insulating bags used in this study should be effective up to one hour, and are intended for repeated use. However, it has to be stressed that, according to the manufacturers' statement written on the exterior of the insulating bag, they are effective up to one hour for deeply frozen food items.

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CONCLUSIONS

The results revealed in this study indicate that insulating bags whose primary purpose is to preserve appropriate temperature environment for deeply frozen food items are not sufficiently effective to preserve appropriate temperature environment for chilled food items. Although insulating bags proved to be more efficient in comparison to the typical PVC bag, the difference was not as significant as expected. Furthermore, the differences between insulating bags are not correlated with their purchase price. The measurements revealed that the internal temperature of the test object varies in accordance with air temperature outside the bag and the degree of load in the bag.

The measurements suggest that insulating bags are not sufficiently effective to preserve chilled foods, especially when not filled with many food products. This suggests a need to modify the insulating bags regarding their effectiveness for chilled foods and highlights the importance of short transport times from the store to home.

Transport between retail and the consumer's home is quite short in comparison to other links in the cold chain, sometimes leading to the idea that the impact of this link on food safety should be less important. Nevertheless, its impact on the quality and safety of the product should not be considered negligible. To obtain exact prove of food safety, microbiological predictive models or microbiological analysis should be performed in the future, establishing an integrated approach of the evaluation of chilled product's safety.

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