Food Control 29 (2013) 66–70

Contents lists available at SciVerse ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Short communication

Temperature increase of foods in car trunk and the potential hazard for microbial growth

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ARTICLE INFO

Article history:
Received 10 January 2012
Received in revised form
19 May 2012
Accepted 26 May 2012

Keywords:
Foods temperature
Temperature increase
Car trunk
Weather conditions

ABSTRACT

This study assessed the potential microbial hazard posed by temperature increases on refrigerated and frozen food stored in car trunk exposed to sunlight. The internal temperatures in the trunk and of food items (egg, milk, tofu, fresh meat, and frozen meat) stored in it during summer were measured at 10 min intervals for up to 3 h (12:00 PM to 15:00 PM). Trunk temperature steadily increased from 32.3 °C up to 41.5 °C, with longer exposure times. Food temperature also increased substantially during this period, reaching 33.5 °C (frozen meat), 35.3 °C (milk), 35.6 °C (tofu), 37.0 °C (egg), and 38.4 °C (fresh meat). Cloud cover and solar radiation affected car and food temperature, with lower cover and higher radiation associated with higher food temperatures (7.1 °C higher in the car trunk when compared to a situation of extensive cloud cover and low radiation, and 6.9 °C higher for eggs, 5.9 °C for milk, 5.0 °C for tofu, and 7.4 °C and 5.5 °C for fresh and frozen meat, respectively). The temperature of refrigerated foods (egg, milk, and fresh meat) reached 20 °C within 40 min (tofu: 60 min) and 30 °C within 90–110 min (tofu: 130 min). The temperature of frozen meat reached to danger zone (5–60 °C), which is associated with bacterial growth, after 90 min. Consumers should therefore realize the importance of time–temperature control, particularly in warm and sunny weather. Purchased foods should be transferred to a refrigerated environment as fast as possible, and the car trunk should be avoided. The present results can be used for consumer education, contributing to the recognition of the importance of food safety.

1. Introduction

Food safety is a growing concern of consumers and is of crucial importance to the industry and economy (Jevšnik, Hlebec, & Raspor, 2008; Kwak, Kim, & Rhee, 2011; Röhr, Lüddecke, Drusch, Müller, & Alvensleben, 2005; Scheule & Sneed, 2001). Proper food handling is important at all stages, including production, processing, storage, distribution, and preparation, both to ensure stability in the biochemical and physical properties of food and microbiological safety for consumption.

Although consumers tend to associate foodborne disease with eating outside home, many foodborne diseases are caused by food prepared at home (Griffith, Mathias, & Price, 1994; Redmond & Griffith, 2003). Proper handling and preparation practices at home have been identified as critical in this regard (Altekruse, Street, Fein, & Levy, 1996; Unusan, 2007). When interviewed, approximately 50% of consumers in the USA indicate that they use the car trunk to transport food from the grocery to their homes (Geuens, Brengman, & S'Jegers, 2003; Godwin & Coppings, 2005). In Korea, 50.3% of consumers also indicated that they use the car trunk to transport food items purchased at large discount and department stores (Kim, Jung, et al., 2011). However, as a consequence of the prolonged exposure of the car to direct sunlight, this behavior may cause the growth of microorganisms due to the increase in the internal temperature of food. Although the hazardous nature of this behavior is unquestionable, there is currently only limited information and quantification of its associated risk.

The objective of the present study is to assess the potential microbial hazard by increased temperature of food items that required time–temperature control to be safe for consumption (including egg, milk, tofu, fresh meat, and frozen meat) when placed in car trunk exposed to sunlight. Additionally, the effect of weather including cloud cover and solar radiation on car trunk and food temperature were also examined.

2. Materials and methods

The weight or size of egg, milk, tofu, fresh meat, and frozen meat samples were determined based on the most frequent sale unit. All

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doi:10.1016/j.foodcont.2012.05.064

Table 1
Outdoor temperature, cloud cover, and solar radiation at each trial.

Group	Trial	Average of outdoor temperature (°C)	Cloud cover[a]			Solar radiation[a] (MJ/m^2)
			12:00–13:00 PM	13:00–14:00 PM	14:00–15:00 PM	
Group A	1	32.6	5	5	6	17.9
	2, 3[b]	34.9	7	5	5	15.3
	6, 7	31.3	6	5	7	14.6
Group B	4, 5	33.2	0	1	3	22.3
	8, 9	34.4	0	0	0	21.1
	10, 11	35.5	1	1	1	21.1

[a] Data provided by the Korea Meteorological Administration for Jeung Reung (Seoul).
[b] Two trials performed on the same day using two cars.

samples were purchased from a local market in Seoul (Korea). A shell of a medium sized-egg (weight: 44–52 g) was broken with a pointed gimlet and a wire sensor of digital thermometer (TES 1300, TES Electrical Electronic Corp., Taipei, Taiwan) was placed into the center of egg and fixed with adhesive tape. In the case of milk and tofu, the thermometer was inserted into the center of a Tetra Pak milk box (200 mL) and in the center of a tofu (weight: 210 g, size: 9 × 6 × 3.5 cm). In the case of fresh and frozen meat,

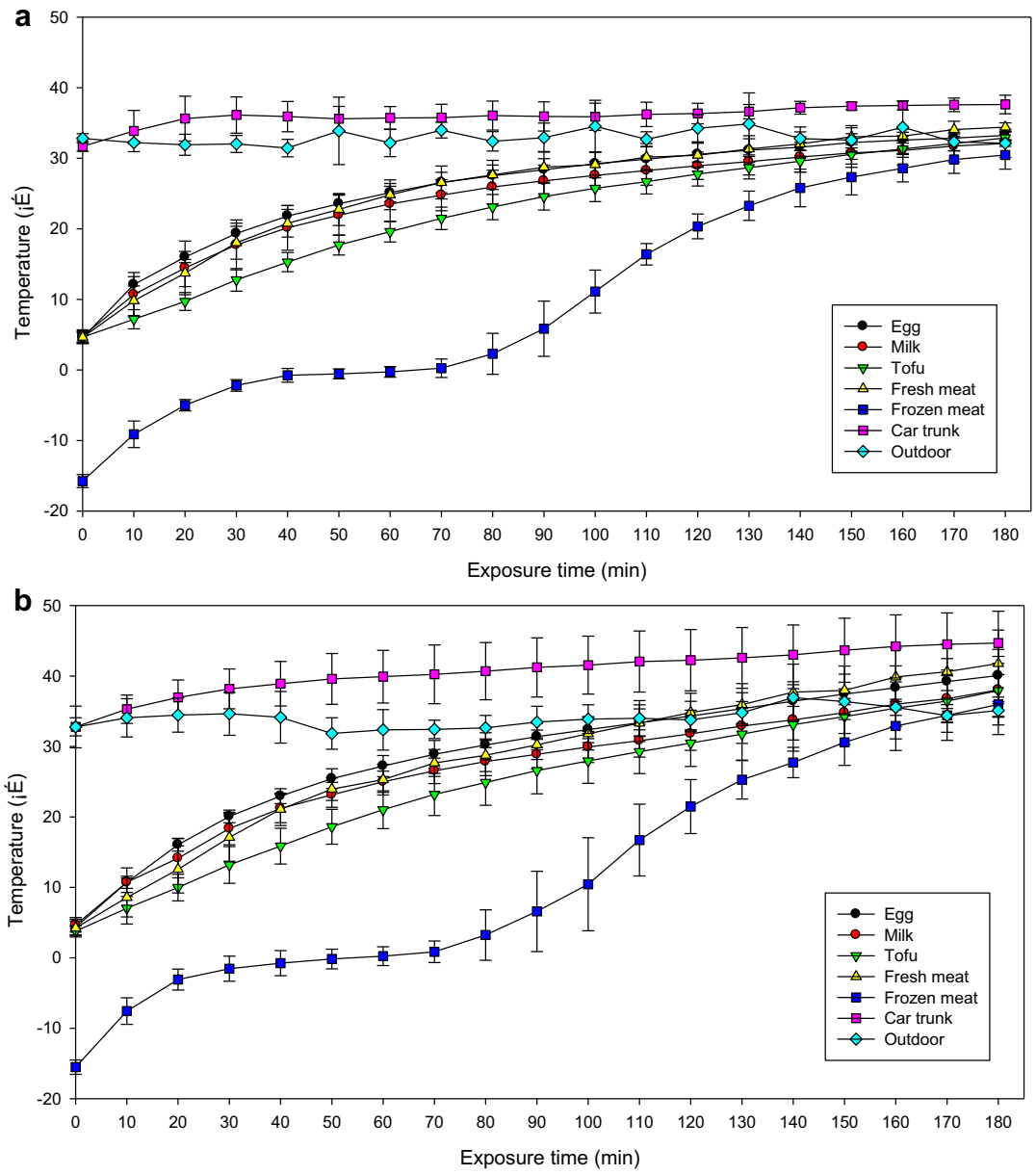

Fig. 1. The temperature outdoor, in the car trunk, and of food items (egg, milk, tofu, fresh meat, and frozen meat) stored in the car trunk under (a) a high cloud cover level and low level of solar radiation (Group A) and (b) a low level of cloud cover and high level of solar radiation (Group B).

a thermometer probe (TES 1300) was inserted from one of the roll sides toward its center (Pork chuck roll, 10 × 10 × 1.5 cm). The tofu and meat samples were re-packed with polyethylene bag and wrap, respectively, which are the traditional packaging method. Prepared samples were stored at 4 °C (for egg, milk, tofu, and fresh meat) or −18 °C (for frozen meat) to maintain their refrigeration and freezing temperatures before the experiments.

From August to September 2010, a total of 11 experiments were performed using two cars (Kia Porte and Chevrolet Cruze) of dark gray color. The cars were exposed to sunlight for 30 min before the experiments. All samples were transferred immediately from the refrigerator or freezer to the car using an ice box and then placed into the car trunk. A thermometer used to measure air temperature was also placed in the car trunk. The inner temperature of the food, internal temperature of the trunk, and outdoor temperature were recorded every 10 min for up to 3 h. Cloud cover and solar radiation measurements were provided by the Korea Meteorological Administration for the nearest observation post (Jeungreung-dong, Seoul, South Korea). Cloud cover is measured every 1 h on a scale from 0 (sunny) to 10 (cloudy). Solar radiation is a general term for the electromagnetic radiation emitted by the sun and is measured as the total quantity emitted in one day.

Average cloud cover and solar radiation were classified using cluster analysis with the FASTCLUS procedure from SAS software (SAS version 8.2, SAS Institute Inc., Cary, NC). Analysis of variance (ANOVA) was performed using the general linear models procedure (GLM) of the statistical analysis system. When the analyses of variance indicated significant differences, least-square means were separated by the probability option (PDIFF, a pairwise *t* test).

3. Results and discussion

3.1. Atmospheric conditions and cluster analysis

Outdoor temperature, cloud cover, and radiation at each trial are shown in Table 1. To examine the relationship between atmospheric conditions, foods and car temperature, measurements were clustered into two groups (Group A and B) based on cloud cover and solar radiation. Group A (trials 1, 2, 3, 6 and 7) was associated with a high cloud cover and low solar radiation (cover: 5.7, solar radiation: 15.9 MJ/m^2), whereas Group B (trials 4, 5, 8, 9, 10, and 11) was associated with a low cover (average = 0.8) and high solar radiation (average = 21.5 MJ/m^2).

3.2. Temperature increase of car trunk and stored foods

The average temperature of the food samples and in the car trunk during the experimental period is shown in Fig. 1. Overall (for total 11 trials), the initial temperature in the trunk (32.3 °C) was similar to the outdoor temperature (33.4 °C). The trunk temperature steadily increased reaching 41.5 °C after 3 h (7.9 °C higher than the outdoor temperature which was 33.6 °C). The temperature in the car trunk depended on the atmospheric conditions. Air temperature varied from 36.6 °C (trial 6) under the lowest solar radiation (14.6 MJ/m^2) and maximum cloud cover (average: 6) to 50.8 °C (trial 9) with no cloud cover and highest solar radiation (21.1 MJ/m^2). The temperature difference between the car trunk and outdoor on the 9th and 6th trial was 15.8 and 4.8 °C, respectively.

Food temperature dramatically increased immediately after storage in the trunk, but at a lower rate as exposure time increased. The tofu sample showed the lowest temperature change compared to other refrigerated foods, possibly because of its solid phase and largest weight (210 g) in the sample. In contrast, the egg was associated with the fastest change in temperature, possibly due to its liquid phase and lowest weight (approximately 65 g) among the food items examined. The temperature of the frozen meat sample rapidly increased to 0 °C, at which it was maintained for approximately 40 min (a period during which the latent heat was used for change from ice to water). After 180 min, the temperature reached 33.5 °C (frozen meat), 35.3 °C (milk), 35.6 °C (tofu), 37.0 °C (egg), and 38.4 °C (fresh meat).

The temperature of car trunk and food items from Group A and B are shown in Table 2. Overall, car trunk from Group B achieved a significantly higher ($P < 0.05$) final temperature (44.7 °C) than those in Group A (37.6 °C), although their initial temperatures

Table 2
The temperature of car trunk and food items (egg, milk, tofu, fresh meat, and frozen meat) stored in the car trunk under a high cloud cover level and low level of solar radiation (Group A) and a low level of cloud cover and high level of solar radiation (Group B).

		Temperature from Group A (°C)	Temperature from Group B (°C)
Car trunk	Initial temperature	31.7 ± 0.7	32.8 ± 1.3
	Average temperature	36.0 ± 0.9[a]	40.6 ± 3.5[b]
	Final temperature	37.6 ± 1.3[a]	44.7 ± 4.5[b]
Egg	Initial temperature	4.6 ± 0.9	4.3 ± 1.0
	Average temperature	25.7 ± 2.1[a]	28.6 ± 1.6[b]
	Final temperature	33.2 ± 2.0[a]	40.1 ± 3.8[b]
Milk	Initial temperature	4.8 ± 0.9	4.7 ± 0.8
	Average temperature	24.3 ± 1.3	26.6 ± 2.9
	Final temperature	32.1 ± 0.8[a]	38.0 ± 4.9[b]
Tofu	Initial temperature	4.6 ± 0.8	3.8 ± 1.2
	Average temperature	22.2 ± 1.0[a]	24.2 ± 1.6[b]
	Final temperature	32.9 ± 0.6[a]	37.9 ± 3.7[b]
Fresh meat	Initial temperature	4.6 ± 0.6	4.2 ± 1.0
	Average temperature	25.5 ± 1.6[a]	28.1 ± 1.6[b]
	Final temperature	34.4 ± 0.6[a]	41.8 ± 4.8[b]
Frozen meat	Initial temperature	−15.8 ± 0.9	−15.5 ± 1.0
	Average temperature	9.9 ± 0.9	11.5 ± 2.1
	Final temperature	30.5 ± 2.0[a]	36.0 ± 4.3[b]

[a–b]Mean values in the same row followed by different superscript letters represent statistically significant differences ($P < 0.05$).

(31.7 °C and 32.8 °C in Groups A and B, respectively) were similar ($P > 0.05$). As exposure time increased, so did temperature for the car trunk from Group B: the temperature increased by 2.5 and 1.7 °C after the initial 10 and 20 min, respectively, and then at an average of approximately 0.5 °C every 10 min. For Group A, in turn, there was an increase in the temperature of 2.2 and 1.8 °C after the initial 10 and 20 min, respectively, and then approximately 0.1 °C every 10 min. Since temperature in the car trunk was initially much higher than that of any of the food samples, the temperature increased at a similar rate during early exposure both in Group A and B. However, as the exposure time increases, food samples from Group B showed a significantly higher temperature ($P < 0.05$) than those in Group A. The temperature reached 40.1 °C (egg), 38.0 °C (milk), 37.9 °C (tofu), 41.8 °C (fresh meat), and 36.0 °C (frozen meat) in Group B, whereas in Group A, it reached 33.2 °C (egg), 32.1 °C (milk), 32.9 °C (tofu), 34.4 °C (fresh meat), and 30.5 °C (frozen meat). The temperature difference between foods from Group A and B was 6.9 °C for eggs, 5.9 °C for milk, 5.0 °C for tofu, 7.4 °C for fresh meat, and 5.5 °C for frozen meat, respectively. These results indicate that both cloud cover and solar radiation affect the temperature in the car trunk and of the food stored in it. Consumers should therefore check not only the outdoor temperature, but also cloud cover and solar radiation, when shopping for food, taking the necessary measures to prevent leaving food in the car during sunny and hot weather.

The range from 5 °C (41 °F) to 60 °C (140 °F) is regarded as the temperature danger zone, as foodborne bacteria can grow and survive within this temperature range (USDA, 2011b). The temperature of refrigerated foods, including egg, milk, tofu, and fresh meat, reached the danger zone in the first 10 min in the car, and frozen meat reached the danger zone temperature after approximately 90 min. In Korea, consumers that purchase foods from large discount and department stores take approximately 1 h and 40–50 min (79.1 and 82.6 min, respectively) to return home (Kim, Jung, et al., 2011). In Turkey, 31.5% and 3.4% of consumers were observed to take 1–2 h or more than 2 h, respectively, to get home after purchasing meat (Karabudak, Bas, & Kiziltan, 2008). Similarly, Badrie, Gobin, Dookeran, and Duncan (2006) reported that 20.5 and 4.0% of consumers in Trinidad (West Indies) took within 1–4 h and more than 4 h, respectively, to refrigerate purchased food items. In the present study, the temperature of refrigerated food items quickly reached 20 °C within 40 min (except tofu: 60 min). The temperature of foods steadily increased, reaching 30 °C after 90–130 min (egg: 90, fresh meat: 100, milk: 110, and tofu: 130 min), which is the optimum temperature for psychrotrophic pathogenic bacteria, such as *Listeria monocytogenes* and *Yersinia enterocolitica*. At this temperature, many mesophilic pathogenic bacteria, including pathogenic *Escherichia coli*, *Salmonella* spp., and *Bacillus cereus*, can also grow. In addition, spores can germinate in this temperature range and cause foodborne disease. The USDA Food safety and inspection service recommends the refrigeration of perishable foods within 2 h (the so-called 2 h rule), but when the outdoor temperature reaches 90 °F (32.2 °C), perishable foods should be refrigerated within 1 h (USDA, 2011a).

A number of studies reported the need of continued consumer education on proper food handling practices (Finch & Daniel, 2005; Li-Cohen & Bruhn, 2002; Mitakakis et al., 2004). This is especially important since there are no enforceable regulations for food handling at home (Karabudak et al., 2008) so consumers can easily ignore the importance of safe food handling practices. For example, one study showed that only 4.8% of respondents stored purchased raw meat in a cooler bag for transport (Karabudak et al., 2008). Another showed that only 15.5% used a freezing bag for transport after buying highly perishable food (Jevšnik et al., 2008). To encourage proper consumer habits, knowledge of food safety is essential. Consumer education is the most effective strategy to raise such knowledge and reduce the incidence of foodborne disease (Kim, Oh, et al., 2011). Therefore, governments should continuously educate the population about the potential hazards of improper food handling after purchase using a varied approach, including face-to-face education programs, media campaigns, and the distribution of written material.

Since the most important factor to ensure food safety during transfer and storage is time and the maintenance of safe temperature levels, the following practices are essential: (1) those preparing food at home need to be educated about the importance of time–temperature control; (2) special care must be taken to keep food out of the temperature danger zone; (3) perishable foods should be transported home and stored at a proper temperature as fast as possible, and no longer than 1 h; (4) in cases of a long transportation time, the use of a cooler or ice pack should be advised; (5) consumers should avoid storing food products in the car trunk; and (6) if placing food in the car trunk is unavoidable, consumers should avoid parking the car under direct sunlight.

The present study provides comprehensive information about the potential hazard of increasing the temperature of purchased food items by storing them in the car trunk for a long period of time. These results can be used for consumer education programs, as they can contribute toward the recognition of the importance of food safety practices and reduce the incidence of foodborne illness.

Acknowledgments

This study was supported by the Korea Food and Drug Administration. The authors also thank the Institute of Biomedical Science and Food Safety, Korea University Food Safety Hall for providing the equipment and facilities.

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