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Temperature control efficacy of retail refrigeration equipment

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ABSTRACT

Temperature control of food products in retail food stores (food stores) is essential for food safety. The food business operator (FBO) must ensure that the product temperatures comply with food regulations. This study investigated the temperatures of products in 32 food stores and the relationship between the product temperature with the temperature of the refrigeration equipment (open front) and the temperature settings. The FBOs awareness of the equipment and product temperatures and the equipment temperature settings (temperature setpoint, alarm setpoint, timing for alarm to go off) were also investigated. The food stores represented four nationwide chain-store groups in Finland. The study included four categories of food products namely: fresh fish, minced meat, vacuum packed ready-to-eat processed fish and other ready-to-eat products, all of which are easily perishable products. Vacuum packed fish products and other ready-to-eat products are also sensitive to *Listeria monocytogenes* contamination. The temperatures of the products ($n = 84$) and refrigeration equipment ($n = 86$) were measured by a temperature data logger by the health inspector for 24 h.

Temperature violations were observed in 50% of the products and 17.9% of the products exceeded the temperature limit by over 3 °C for more than 30 min. Products that were most often in noncompliance were fresh fish and vacuum packed processed fish products. Temperature violations were observed in food stores in all four chain-store groups and no significant difference between the chain-store groups was observed. The temperature of the equipment as measured by the refrigeration equipment's fixed thermometers differed significantly from the temperatures of the products. Moreover, no significant correlation was found between the equipment temperatures (fixed thermometer) and the products with the exception of minced meat. These results highlight, that the product temperature could not be reliably determined by the equipment's fixed thermometer.

There was a lack of awareness of temperature settings in all chain-store groups. Only three stores (9.4%) were aware of all the settings of the inspected equipment. The results show that the FBOs own-check of equipment and product temperatures is not functioning correctly in food stores. This can have serious consequences for food safety. FBOs, equipment manufacturers, monitoring system providers and official food control authorities should take active measures to improve the situation.

1. Introduction

The actions taken in retail food stores have important effects on food safety, specially food stores selling products that need cold holding must have the appropriate refrigeration equipment and a functioning own-check system (self-regulation system) (Anonymous, 2011). However, studies indicate that the temperature of refrigeration equipment may not always be adequate in food stores (González, Vitas, Díes-Leturia, & García-Jalón, 2013; Likar & Jevšnik, 2006; Lundén, 2013; Lundén, Vanhanen, Kotilainen, & Hemminki, 2014; Morelli, Noel, Rosset, & Poumeyrol, 2012) despite having their own-check system (Lundén et al., 2014).

It is important that the temperature of the refrigeration equipment is adequate, but it is even more important to make sure that the food product is at the correct temperature. However, it is not obligatory to measure the actual temperature of the food products in the own-check according to Finnish legislation (Anonymous, 2011), it is only the equipment temperature that the food business operators (FBO) are obliged to monitor. The temperatures of the refrigeration equipment and the product they contain are not necessarily the same (González et al., 2013; Lundén et al., 2014), which should be considered by the FBO and the official food control authority.

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Previous studies have shown that the required temperatures of products may be violated for some time (Likar & Jevšnik, 2006; Lundén et al., 2014; Morelli et al., 2012). The magnitude of possible temperature violations of products in food stores is not well known, because FBOs or official control normally only make a spot-check observation of the product temperature (Anonymous, 2014). The magnitude and duration of possible temperature violations is essential for product safety and should be investigated on the retail level.

The temperature of the equipment is especially important when storing products that are easily perishable and products that may cause a serious food poisoning. Examples of especially sensitive products include vacuum packed processed fish products that are commonly contaminated with *Listeria monocytogenes* (Kramarenko et al., 2013; Thisted-Lambertz et al., 2012). Vacuum packed processed fish products are suspected to have a major role in human listerosis cases in Finland (Anonymous, 2013). Such products usually have long shelf-lives and may be stored at retail food stores' open front equipment for considerable periods of time. Therefore the cold holding of such products should also be strictly monitored at retail level.

The FBOs should have the appropriate means to make sure that the temperature of the equipment is correct. This necessitates the accurate measurement of equipment and an adequate frequency of measurements. The FBO should be aware of the equipment temperature settings and also alarm settings in order to react when needed. However, the FBO's awareness of the equipment settings and product temperatures has not been investigated.

The aim of this study was to investigate the extent and magnitude of noncompliance in the temperature of food products in retail food stores and to elucidate the relationship between the temperatures of the refrigeration equipment and of the products. The FBO's knowledge of the temperature settings of the equipment was also investigated.

2. Material and methods

2.1. Retail food stores

Thirty two retail food stores (grocery shops) located in a local food control unit (Food and Environmental Health Unit, Region of Espoo, Finland) were included in the study. Four different chain-store groups (grocery multiple retailers) were represented in the study (16, 12, 3 and 1 stores, respectively) of which two are the biggest chain-store groups in Finland. The stores were categorized into two groups according to size: 20 small stores and 12 large stores (supermarkets) for further analysis.

2.2. Inspections

Inspectors inspected the food stores during January–March of 2012. The inspectors used temperature data loggers (Temperature logger iButton DS1922L, Maxim Dallas Semiconductor) to measure the temperatures of the refrigeration equipment (air temperature) and also of the products. The temperatures of two-to-three self-service refrigeration equipment (open front) in every food store were determined. The temperature of one product within every refrigeration equipment was measured. In total, the temperatures of 86 refrigeration equipment and 84 food products (Table 1) were measured (two products were misplaced during the measurements). The products included in the study were fresh fish, minced meat, vacuum packed processed fish (gravad or cold smoked fish) and other ready-to-eat-foods. These are products that are easily perishable, and require low storage temperatures (fresh fish max 2 °C, vacuum packed processed fish max 3 °C, minced meat max 4 °C and ready-to-eat products max 6 °C) according to Finnish regulations (Anonymous, 2011, 2014). Vacuum packed processed fish, in particular but also other ready-to-eat products are considered to cause a *L. monocytogenes* risk. The results of the temperature violations are presented as temperatures that exceed the temperature limit by over 1 °C and by over 3 °C for at least 30 min. The Finnish regulations stipulate that the temperature of the product can exceed the product temperature limit by a maximum of 3 °C for only a short period of time (Anonymous, 2011). The short period of time is defined in the instructions of National Food Safety Authority (Evira) to be 24 h (Anonymous, 2014). In this study 30 min was chosen as a time limit because experience from official control has shown that temperature violations of this magnitude can influence the product temperature and it has been used as time limit in an earlier study (Lundén et al., 2014).

The temperature data logger was placed within the product package and pushed into the product. The product located in the middle of the equipment close to the back wall. Another logger, that measured the temperature of the equipment's air, was placed next to the product between the product and the back wall of the equipment. The loggers were located close to the back wall of the equipment so that the loggers would not be misplaced by customers. The temperatures were measured for 24 h with 15 min intervals. The temperature indicated by the equipment's own thermometer (fixed thermometer, digital display on the equipment) was documented once during the inspection.

The food stores were asked to show (or to tell the inspector) the temperature settings of the refrigeration equipment including the temperature of the equipment at the time of inspection, the temperature setpoint, alarm setpoint and the time from reaching the alarm setpoint to the triggering of the alarm.

2.3. Statistical analysis

The statistical significance of differences between the temperature that was indicated by the fixed thermometer, the mean temperatures of the equipment as indicated by the logger and the mean temperatures of the product was analysed by the Mann–

Table 1
Temperature violations of food products in food stores ($n = 32$) during a 24 h (1440 min) measurement.

Food type (number of food products)	Proportion of products exceeding temperature limit by >1 °C %	Duration of time (min) when products exceeded temperature limit by >1 °C Mean (min–max)	Proportion of time when products exceeded temperature limit by >1 °C % of 24 h	Proportion of products exceeding the temperature limit by >3 °C for >30 min %
Fresh fish (19)	89.5	781 (15–1440)	54.2	52.6
Processed fish (8)[a]	50.0	641 (45–1395)	44.5	25.0
Minced meat (30)	40.0	249 (15–1425)	17.3	10.0
Ready-to-eat (27)[b]	33.3	308 (15–1395)	21.4	0
Total (84)	50.0	–	–	17.9

[a] Vacuum packed processed fish (ready-to-eat).
[b] Ready-to-eat product other than vacuum packed processed fish.

Table 2
Temperatures (°C) of refrigeration equipment and products in food stores ($n = 32$).

Product type	Product temperature limit	Temperature of refrigeration equipment (fixed thermometer)[a]	Temperature mean over 24 h measured by logger[b] (min–max)	
			Temperature of refrigeration equipment	Temperature of product
Fresh fish ($n = 18$)	2	1.5A[c]	2.2 (−0.8 to 4.7)B	3.5 (0.3 to 8.6)A
Processed fish ($n = 8$)	3	1.0A	2.4 (0.8 to 4.6)B	2.7 (1.2 to 5.1)A
Minced meat ($n = 28$)	4	1.3A	2.4 (−2.7 to 6.0)B	3.1 (0.1 to 6.9)A
Ready-to-eat ($n = 27$)	6	3.4AB	4.5 (−0.5 to 8.1)B	4.8 (0.0 to 8.1)A

[a] The temperature observed at time of inspection was documented.
[b] Temperature data logger positioned next to the product.
[c] Similar capital letters within rows indicate significant difference between temperatures (Mann–Whitney U test, $p < 0.05$).

Whitney U test. The Kruskall–Wallis test was used to analyse the significance of the differences between the equipment and the product temperatures between the chain-store groups. The Chi-square test was used to analyse whether the measurement of the product temperature performed by the FBO had any significant relationship to the occurrence of temperature compliance of products. The correlation between the temperature of the fixed thermometer with equipment temperature (logger), product temperature and temperature setpoint of the equipment was analysed using the Spearman's rank correlation (2-tailed). The significance of possible differences between the temperature of the equipment or the temperature of the products according to the size of the stores was analysed with Mann–Whitney U test. The influence of the store size to the awareness of the temperature settings was analysed by Chi square test. Statistical significance was accepted when p-value was <0.05.

3. Results

Temperature violations were observed in 50% of the products (Table 1). Those products that were most often in noncompliance were fresh fish and vacuum packed processed fish products. The fresh fish and vacuum packed processed fish were more than 1 °C over the temperature limit for 54.2% and 44.5% of the 24 h time in average. The temperatures of several products exceeded their respective temperature limit of over 3 °C for more than 30 min (Table 1). Only ready-to-eat products were not observed to exceed the temperature limit by more than 3 °C for more than 30 min. Temperature violations were observed in food stores in all chain-store groups. No significant differences between chain-store groups were observed. Furthermore, no significant difference was observed between the temperatures of the equipment or between the temperatures of the products according to the size of the stores.

The temperature of the products differed significantly from the temperatures of the equipment as indicated by the fixed thermometers (Table 2). The mean differences between product temperatures and the temperatures indicated by the fixed thermometers at time of inspection ranged between 1.4 and 2.0 °C. The biggest difference between the mean temperature of the product and the equipment's temperature observed at the inspection was 6 °C. There was also a significant difference between the ready-to-eat product equipment (fixed thermometer) temperatures and the temperatures of the equipment that were obtained by loggers (Table 2).

The temperature indicated by the equipment's fixed thermometers did not show any significant correlation with the temperatures recorded by the equipment logger with the exception of the fresh fish equipment (Table 3). Moreover, the temperatures of the fixed thermometers did not have any significant correlation with temperatures of the product logger with the exception of the minced meat. The temperatures of the equipment indicated by the fixed thermometer and temperature setpoint were not significantly correlated (Table 3).

The temperature setpoint of the equipment was below or equal to the product temperature limit in all cases (data not shown). The temperature alarm setpoints for the equipment were over the temperature limit of the products in the majority of cases (Fig. 1). The differences between the median of the alarm setpoint and the temperature limit for the products were between 3 and 6 °C. The highest gaps in temperature between the alarm setpoint and the product temperature limits were observed in fresh fish and also ready-to-eat product equipment (10 °C) (Fig. 1). The time intervals for the alarm to go off after the temperatures reached the alarm setpoint, were between 15 and 60 min. The alarm of one vacuum packed processed fish equipment was set to go off when the equipment temperature had risen by 12 °C or higher for 60 min (data not shown).

The food stores were usually aware of the temperatures of the equipment (86.0%) during the inspection (Table 4). The awareness about the temperature setpoints of the equipment was much less. The temperature setpoints were known for only 44.2% of the equipment at the time of inspection. The alarm setpoint and the time for the alarm to go off after the temperature reached the alarm setpoint was known for 52.3% and 54.7% of the equipment, respectively. The highest awareness of temperature settings were for the fresh fish equipment and the lowest awareness were for the

Table 3
Correlation between the temperatures indicated by the refrigeration equipment's fixed thermometers with the temperature setpoints of the equipment and with the product and equipment temperature measured by temperature data loggers.

Product type	Spearman's rank correlation with temperature of fixed thermometer		
	Correlation coefficient		
	Temperature of product (logger)	Temperature of equipment (logger)	Temperature setpoint of equipment
Fresh fish	0.350	0.530*[a]	0.111
Processed fish	0.571	0.238	–[b]
Minced meat	0.422*	0.234	0.264
Ready-to-eat	0.003	−0.091	−0.372

[a] The asterisk indicates that the correlation with the temperature of the fixed thermometer was significant ($p<0.05$).
[b] Correlation analysis was not done due to low number of data.

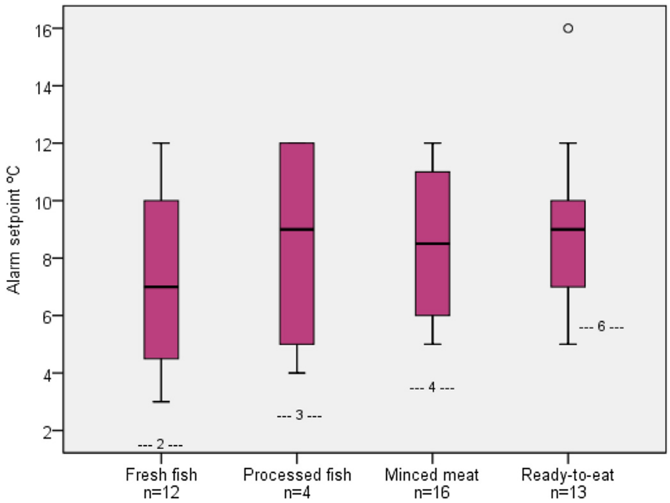

Fig. 1. Alarm setpoint of refrigeration equipment according to food type. The dashed line with a number indicates the maximum storage temperature allowed by national legislation for the food product type. Alarm setpoints were not available for all refrigeration equipment.

vacuum packed processed fish equipment (Table 4.). There was a lack of awareness of temperature settings in all the chain-store groups. Only three stores (9.4%) were aware of all the settings of the inspected equipment (temperature of the equipment, temperature setpoint, alarm setpoint and time before alarm goes off). No significant differences were observed between the awareness of the small or large stores concerning any temperature setting.

The refrigeration equipment was connected to automatic temperature follow-up and alarm system in 94% of the stores. Two FBOs' refrigeration equipment was monitored only manually. Most of the FBOs (62%) informed the inspector that they checked the temperatures of the products occasionally, whereas 38% stated that they did not measure temperature of products at all. The measurement of product temperatures carried out by the FBO was not observed to be related to increased compliance of food product's temperatures.

4. Discussion

Product temperature violations were observed for 50% of the products and 17.9% of all the products exceeded the temperature limit by more than 3 °C for over 30 min. The results strongly indicate that problems in own-check of product temperatures are common in food stores. The biggest problem for compliance was seen in products with the lowest temperature limits i.e. fresh fish and vacuum packed processed fish. Temperature violations in fresh fish increase the spoilage rate, accelerate organoleptic changes and may have an adverse effect on safety by the production of biogenic amines in certain fish (Visciano, Schirone, Tofalo, & Suzzi, 2012). A major food safety concern is the possible effects of the temperature violations on vacuum packed processed fish such as gravad and cold smoked fish. These products are often contaminated by *L. monocytogenes* that can multiply during a long shelflife even under low temperature conditions (Kramarenko et al., 2013; Thisted-Lambertz et al., 2012). These products may even pose a possible *Clostridium botulinum* risk (Lindström et al., 2006).

The time that the temperature of the products was in noncompliance could not be regarded as momentary in many of the cases. The vacuum packed processed fish products that were stored over the product temperature limit exceeded the temperature limits for a mean of 44.5% of the 24 h time period. Consequently the products that had the highest risk of *L. monocytogenes* were temperature abused for several hours during the one-day follow-up period. There is no evidence to suggest that the 24 h follow-up period would be any different from other days, which leads one to the conclusion that the product temperatures can be in noncompliance for substantial time during a number of days depending on the shelf-life and the turnover of the products. Such sustained temperature abuse has substantial effects on the growth of *L. monocytogenes* (Hwang & Sheen, 2009).

The temperatures of other ready-to-eat products than vacuum packed fish products were not observed to exceed the temperature limit by more than 3 °C for 30 min. The reason why the temperature of ready-to-eat products complied much better with the temperature regulations was probably because it is easier to reach the 6 °C limit than the 3 °C limit. It is also possible that the refrigeration equipment is not always effective enough to reach the lower temperatures or that its settings are incorrect.

The temperatures of the refrigeration equipment as measured by the fixed thermometer and temperatures of the products measured with the logger were significantly different for all product groups. Furthermore, the temperature of the fixed thermometer did not significantly correlate with the temperature of the product with the exception of minced meat. These results strongly suggest that the temperature of the equipment's fixed thermometer does not display the temperature of the product in a reliable way. The mean differences between the temperatures of the fixed thermometer and the product temperatures ranged from 1.4 to 2.0 °C the biggest difference being 6 °C. Such temperature differences can have huge effects on microbial growth (Hwang & Sheen, 2009). FBOs should not rely on the fixed thermometers, but ensure that the products are at the correct temperature. Discrepancies between the temperatures shown on the refrigeration equipment's display and the actual temperature of the products have been observed at retail level earlier (González et al., 2013). Furthermore, Morelli et al. (2012) observed that 70% of products were occasionally above the temperature limits. The reasons for the temperature violations were suggested to be due to poor design of open front refrigeration equipment and poor practices (Morelli et al., 2012).

Poor practices regarding temperature settings were observed in this study. The temperature setpoints of the equipment were below or the same as the temperature limit of the food products in all cases, but clearly this did not ensure compliance. No significant

Table 4
Food stores ($n = 32$) awareness of temperature and alarm settings of refrigeration equipment.

Refrigeration equipment (number of equipment)	Awareness of the settings of equipment (%)			
	Temperature of the equipment	Temperature setpoint	Alarm setpoint	Time from reaching the alarm setpoint to forwarding the alarm
Fresh fish equipment (19)	17 (89.5)	13 (68.4)	12 (63.2)	13 (68.4)
Processed fish equipment (9)	8 (88.9)	2 (22.2)	4 (44.4)	4 (44.4)
Minced meat equipment (31)	27 (87.1)	13 (41.9)	16 (51.6)	18 (58.1)
Ready-to-eat equipment (27)	22 (81.5)	10 (37.0)	13 (48.1)	12 (44.4)
Total (86)	74 (86.0)	38 (44.2)	45 (52.3)	47 (54.7)

correlations between the temperatures of the fixed thermometers of the equipment and the temperature setpoints of the equipment were found. It would be logical to assume that there would be a significant correlation between the setpoint and the temperature of the fixed thermometer, but this was not the case. At the time of recording the temperature of the fixed thermometer, the refrigeration equipment could have been in a defrosting or a cooling cycle, which would explain the differences in some of the cases. Nevertheless, the results highlight the fact that the setpoint alone should not be relied upon.

The alarm setpoint and the delay for the alarm to go off are important parameters in temperature control of refrigeration equipment. The alarm setpoints were clearly above the temperature limits of the products and the time interval for the alarm to go off after the temperatures were exceeded was more than 15 min for all equipment studied. The alarm setpoints and the alarm delays should be adjusted so that possible problems would be recognised before the temperature can rise too much. In the worst case, the vacuum packed processed fish equipment's alarm setpoint was 12 °C and the alarm was set to go off after one hour of the temperature violation. In several cases the alarm setpoint was 6 °C over the product temperature limit. In such cases the products can be at excessively high temperatures for the whole storage time without the FBO noticing it and without any corrective actions being taken.

Effective temperature control requires that the FBO is not only aware of the temperature of the equipment, but also aware of the temperature and alarm settings of the equipment. However, the results show that there was a considerable lack of awareness of these settings in the food stores. The temperature setpoints were known for fewer than half of the equipment. Similarly, the alarm setpoints and the times for the alarm to go off were known for only about half of the equipment. Lack of awareness was found in all chain-store groups which indicate that the problem is common. Because the stores were not aware of the temperature settings they did not seem to know that some of the settings were not adequate. The situation was also complicated by the fact that the automatic temperature control of the equipment was outsourced to other companies, which managed the alarms. Although automatic temperature control systems should effectively control temperatures it can also decrease the awareness of the FBOs and lull them into a false sense of security about the responsibility of monitoring temperatures.

This study did not notice any significant difference in temperature compliance or awareness of temperature settings according to the store size. Likar and Jevšnik (2006) observed that temperature compliance of stores of different size varied between product groups, but could not conclude that any particular store size would perform better. The stores in this study, despite of store size, were part of chain-store groups which means that they were provided with own-check instructions and support in own-check matters. This can be an explanatory factor why the performance in temperature control and awareness of temperature settings of small stores did not differ significantly from larger stores.

The results showed that there was no significant difference in product temperature compliance between those food stores for which the FBO had stated that they measured product temperatures occasionally (about once a week) and the food stores in which product temperatures were not measured. If the product temperature measurement had been efficient, then violations would have been noticed and corrective measures probably taken by the FBO. The temperature measurement of products is not obligatory (Anonymous, 2011), thus the FBOs may not appreciate the importance of monitoring product temperatures. It is easier and less laborious for FBOs to rely on automatic monitoring. Effective temperature control should establish the product temperatures in different parts of the equipment.

The results show that there are severe weaknesses in the management and control of the temperature of the cold holding equipment and the products they contain. The 24 h follow-up period of this study was no different from other days, which suggests that the violations were recurrent from day to day. According to the results of the inspections the FBOs had not reacted to the temperature violations which show that the temperature control system is not working optimally. In the present situation only the very severe temperature violations would have been noticed.

The results suggest that possible actions taken by official control earlier has not lead to compliance in temperatures. It appears that the official control should improve the enforcement at least in the very severe cases of temperature violation. The inspector's first control action is usually in the form of advice, but if that advice and negotiation is not successful appropriate enforcement methods should be used (Anonymous, 2004; Lundén, 2013).

The use of open front refrigeration equipment seems to be quite challenging in terms of maintaining low temperatures. Poor design of equipment has been observed to lead to problems in maintaining correct temperatures (Morelli et al., 2012). There seems to be too many uncertainties in temperature management and control of open front equipment. It is important to enable an easy and reliable automatic temperature measurement of products, in addition to the equipment. The manufacturers of the refrigeration equipment and temperature measurement devices should examine whether the design of the equipment and measurement of temperatures of equipment and the products they contain could be improved. Research done in the optimisation of the performance of open front equipment (Wu et al., 2014) should be used by manufacturers if possible.

To conclude, the temperature control of refrigeration equipment and the products they contain is not thoroughly done in all food stores. The equipment's temperature settings are poorly known and the settings lead to product temperature violations in half of the equipment inspected. It appears that many FBO think that the outsourced automatic temperature control and alarm system ensure temperature compliance. However, the FBOs should also actively monitor the temperature of the products. Temperature violations, particularly, of high risk products such as vacuum packed processed fish should be avoided. It should be seriously considered whether the most sensitive products requiring low storage temperatures should not be stored in open front equipment. The FBOs and official control authorities should take proactive measures to improve the situation.

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