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ORIGINAL ARTICLE

Microbial analysis of meatballs cooled with vacuum and conventional cooling

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Abstract Vacuum cooling is a rapid evaporative cooling technique and can be used for pre-cooling of leafy vegetables, mushroom, bakery, fishery, sauces, cooked food, meat and particulate foods. The aim of this study was to apply the vacuum cooling and the conventional cooling techniques for the cooling of the meatball and to show the vacuum pressure effect on the cooling time, the temperature decrease and microbial growth rate. The results of the vacuum cooling and the conventional cooling (cooling in the refrigerator) were compared with each other for different temperatures. The study shows that the conventional cooling was much slower than the vacuum cooling. Moreover, the microbial growth rate of the vacuum cooling was extremely low compared with the conventional cooling. Thus, the lowest microbial growth occurred at 0.7 kPa and the highest microbial growth was observed at 1.5 kPa for the vacuum cooling. The mass loss ratio for the conventional cooling and vacuum cooling was about 5 and 9% respectively.

Keywords Vacuum cooling · Microbial growth · Meatball · Conventional cooling

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Introduction

Nowadays, cooling can probably be considered the most popular form of food preservation. The idea of refrigerating is to slow down the bacterial action to a crawl so that it takes food much longer (perhaps a week or two, rather than half a day) to spoil. The cooling of meat, fruits or vegetables implies removal of the field heat before processing, transporting, or storing. Cooling inhibits growth of decay-producing microorganisms and restricts enzymatic and respiratory activity after the cooking of the meats. The holding period of ready-to-cook meat products may be the relatively short time required to transport and sell or process the product, or it may include a long-term storage period as well. It is significant to mention that slowing down metabolism can give rise to physiological disorders which are called cold storage injuries. For this reason, cooling of ready-to-cook meat products as quickly as possible after cooking is desired. The main objective of this kind of treatment is to reduce the rates of biochemical and microbiological reactions and changes in order to prevent spoilage of produce, maintain its quality (Burfoot et al. 1990; Sun and Wang 2000).

Regulations and guidelines for the meat processing industry recommend that cooked meats should be cooled as quickly as possible. It is widely recognized that slow cooling of meat products can pose a hazard if pathogenic spore forming microorganisms normally associated with meat products are allowed to grow and/or produce toxins (Mc Donald et al. 2000) since at pasteurization temperatures bacterial spores present in the raw product will not be inactivated. The concept of ready-cooked foods for sale is closely connected with urban development. In Turkey, due to the urbanization, high-quality commercial production of ready-to-cook meat products demand has been increasing.

These products include proportioned and pre-marinated fresh meat (especially beef or veal meat) and poultry products, hamburger patties, meatballs, and kebabs. Meatball, known as traditional Turkish-style meatball, is one of the most popular ground meat products in Turkey. Meatballs are prepared from ground beef, bread crumbs, and a mixture of various herbs and spices, including onion, parsley, black pepper, red pepper, and cumin. Meatballs are consumed in large quantity in Turkey and nowadays, ready-to-cook packaged meatballs have been introduced into the Turkish market. Ready-to-cook meat products can cause foodborne illnesses if they are not properly cooked and cooled.

In this study, the experiments were carried out on the vacuum cooling and the conventional cooling for cooling of cooked meatballs. According to the results of this study, it is possible to reduce spoilage bacteria counts and extended the refrigerated shelf life of meatballs using the vacuum cooling methods. Therefore, the use of vacuum cooling methods to cool the meatballs may be useful for consumer health, and may also be a practical application for the producer because of the short shelf life of this product.

Review of the literature

In the industrial practice, conventional cooling methods such as a slow air, air blast and water immersion cooling have been widely used in the cooked meat industry. However, it is difficult to achieve a rapid cooling with the conventional cooling methods. Vacuum cooling is a widely used rapid cooling method, which has been proven to be one of the most efficient cooling methods available and therefore, it is extensively used for cooling some agricultural and food products (Sun and Wang 2000; Wang and Sun 2002; Drummond et al. 2014). Vacuum cooling is an established method of removing field heat from horticultural produce such as lettuce, cabbage, celery, cauliflower, spinach, bean sprouts and mushroom, and production of meat, fish, bread, chicken and sauce (Wang and Sun 2002; Schmidt and Laurindo 2014). Unlike conventional cooling systems, vacuum cooling produces its effect through moisture evaporation from a product. The efficiency of vacuum cooling is dependent on the surface area to volume ratio. Thus, vacuum cooling method can be considered a rapid and evaporative cooling method. Generally, vacuum cooling can be applied to any porous product which has free water (Wang and Sun 2002).

The main requirements for using the vacuum cooling are: (a) the product should have a large surface area for mass transfer, (b) product water loss should not represent an economic or sensory problem, due to weight reduction and possible changes in structure or appearance (Ozturk and Ozturk 2009).

The heat and moisture transfer with the vacuum cooling process is complicated and therefore it has been investigated by many researchers (Sun and Wang 2000; Song et al. 2016). Vacuum cooling has been widely applied in pre-cooling treatment of lettuce (Rennie et al. 2001; Ozturk and Ozturk 2009), cut flowers (Sun and Brosnan 1999), mushrooms (He et al. 2013), purslane (Ozturk et al. 2011), meat production (McDonald and Sun 2001a, b; Drummond and Sun 2012; Zhang et al. 2013; Feng et al. 2013), fish (Everington 1993), chicken breast (Schmidt et al. 2010; Schmidt and Laurindo 2014) and sauces (McDonald and Sun 2001a, b; Feng et al. 2014).

Cooked meat quality is important to both consumers and industrial producers. The increased supply of cooked meat products and the increased perception of quality by buyers has led to a new generation of consumers who base their food choices on quality rather than quantity or cost. Consequently, industrial suppliers of cooked meat products have also become aware of the importance of quality, especially as a means of product differentiation (Bredahl 1998).

Microbial safety is ensured by first heating all regions of the joint to at least 72 °C for at least 15 s and then cooling it to below 10 °C within 150 min (Desmond et al. 2000).

Mc Donald et al. (2000) carried out a study to indicate the influence of vacuum cooling on the quality of large cooked beef, and the results were compared with conventional cooling methods including air-blast, slow-air and water-immersion cooling. Their results showed that vacuum cooling was the most rapid cooling method and it had significant effects on the quality. Also, the microbial analysis indicated that vacuum cooled samples had the best microbiological quality and safety margins.

Cooked beef is a significant sector of the food industry. Pre-cooked beef appears commonly in fast food outlets, sandwich bars and convenience food for domestic use. In order to ensure microbial safety of pre-cooked beef, rapid cooling is essential to stop microbial spores germinating, growing and forming toxins (Jackman et al. 2007).

A lot of studies have been carried out to show the effect of vacuum cooling on the microbial growth and the quality of cooked meats. In order to retard the microbial growth in the cooked meats after cooking, vacuum cooling has been investigated to rapidly cool large cooked meat joints (Burfoot et al. 1990; Wang and Sun 2002; McDonald and Sun 2001a, b; Mc Donald 1999). The rapid decrease in the temperature during the vacuum cooling and the significantly lower water activity in comparison to the other samples could explain the lower total viable counts due to cold shocking of the microorganisms (Mc Donald et al. 2000).

Materials and methods

Samples preparation

In this study, meatballs are prepared from ground veal meat (about 20% fat content) and different seasonings (table salt, parsley, black pepper, cumin, red pepper, and onion) which are purchased local butcher markets in Denizli in Turkey. The veal meat was grounded and different seasonings are mixed with ground meat. The Meatballs were prepared in the laboratory with the following ingredients: Ground veal meat (79.8%), onion (8%), breadcrumbs (4.8%), parsley (3.2%), black pepper (1.6%), red pepper (0.35%), cumin (0.65%), and salt (1.6%). All ingredients were added to the ground meat and the mixture was kneaded by hand for about 30 min.

Colak et al. (2008) pointed out that total bacteria, coliform, and yeast and mold counts were usually high in meatball samples in Turkey, and these products were also usually contaminated with pathogenic bacteria. Therefore, this product mostly poses a risk to consumer health and has a short shelf life (about 3–4 days). In order to control the growth of spoilage microorganisms, the use of natural antimicrobial preservatives has been preferred in the food industry.

Vacuum cooling

The vacuum cooling is based on the rapid evaporation of moisture from the surface and within of the products due to the low surrounding pressure. Water evaporation absorbs heat from the products. Water evaporation directly depends on the surrounding vapour pressure and causes the temperature decrease. Water evaporates at 100 °C at the atmospheric pressure of 1 atm, while, water starts to evaporate at the lower temperature when the pressure is decreased to below 1 atm. When any free water containing product is placed in a closed chamber and the pressure is decreased with a vacuum pump to below the atmospheric pressure, due to the pressure difference between the water in the product and the surrounding will cause evaporation and the vapour moves from the product to the surrounding atmosphere. Heat removed from the product will be equal to the latent heat required for evaporation. As a result, product temperature starts to decrease with decreasing of the pressure and cooling is thus achieved. In order to remove a large amount of water vapour and keep the cooling cycle within a reasonable length of time, the vapour-condenser is used to economically and practically handle the large volume of water vapour by condensing the vapour back to water and then draining it through the drain valve. For maintaining the steady cooling process, it is necessary to evacuate the chamber continuously. Desired final temperature of the product can be controlled by adjusting the final surrounding pressure (Feng et al. 2014; Ozturk and Ozturk 2009).

The process of a vacuum cooling can be given as follows: vacuum chamber is used to keep the food products. After placing the food into the vacuum chamber, the door is closed and the vacuum pump is switched on. When the pressure is reduced and water starts to evaporate, the food temperature begins to decrease. Cooling of the food continues until it reaches the desired product temperature. When the determined temperature is achieved, the pump is stopped, the ventilation valve is opened and atmospheric air is allowed to enter into the chamber. After the process is finished, finally, the products are removed from the chamber (Houska et al. 2003; Huber and Lauringo 2005; Huber and Laurindo 2006).

Vacuum cooling system, measurements and data collection

The basic components of a vacuum cooling system used in this study are a vacuum chamber, vacuum pump and vapour condenser (heat exchanger). The function of the vacuum chamber is to keep the products to be cooled with vacuum cooling. When the vacuum pump starts to run and vacuum established, the pressure inside the chamber is reduced to the saturation pressure corresponding to the initial temperature of the product. Therefore some water boils away from the food until a new equilibrium condition is achieved. Figure 1 shows the experimental setup. The vacuum chamber (Memmert VO-200, Schwabach, Germany) was chosen to keep the food product to be cooled in. The vacuum pump was the rotary vane type and it is used to generate a vacuum of 1.5×10^{-3} mmHg (2×10^{-3} mbar) (Edward, RV8, New Jersey, USA). The flow rate of vacuum pump was 8.5 m^3/h and it evacuates the air and the vapors (evaporated from the products) from the vacuum chamber to the atmospheric pressure. Since a large amount of vapour evaporates during vacuum cooling, a steam condenser is placed between the vacuum chamber and vacuum pumps to discharge steam by condensing it to water.

Variation of the surface and center temperature of the products were measured by two calibrated thermocouples (high precision immersion/penetration probe, ±0.01 °C accuracy, TESTO, Lenzkirch, Germany) and recorded in the data logger. The thermocouples were inserted into the samples and connected the data logger (TESTO 350 M/XL-450, Lenzkirch, Germany) to measure the surface and center temperature of the meatballs. The humidity and temperature in the vacuum chamber were measured with a probe (high sensitivity reference humidity/temperature probe, ±1% accuracy and ±0.4 °C, TESTO, Lenzkirch, Germany) and data were recorded in the data logger. The

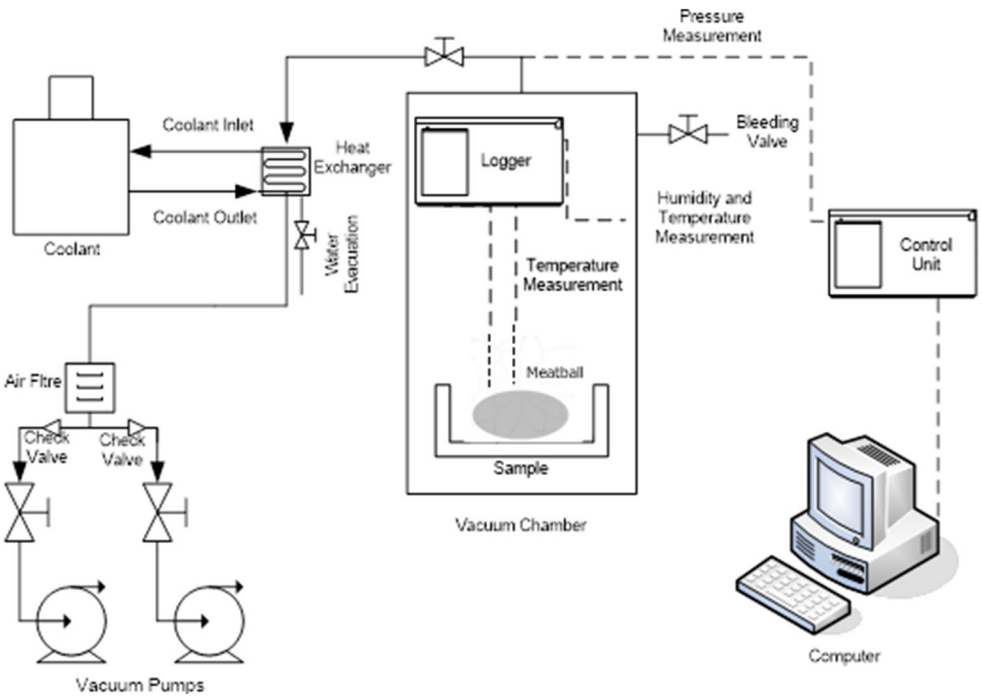

Fig. 1 Schematic diagram of the vacuum cooler system

pressure (low pressure probe, TESTO, Lenzkirch, Germany, accuracy ±0.1%) was measured from the pipe between the vacuum pumps and the vacuum chamber and recorded in the control unit (TESTO 350 M/XL-450, Lenzkirch, Germany). The steam evacuated from the vacuum chamber was condensed in the heat exchanger via the cooler (POLYSCIENCE 9506, Niles, Illinois, USA). Both the data logger and control units measure and save data for each 10 s. Before starting the vacuum cooling, vacuum pump was run for half an hour for warming up for the stability of the system. The experiments were carried out for the vacuum pressures of 0.7, 1 and 1.5 kPa and three repetitions were performed for measurement of data. The experiments for the meatballs were carried out at the Pamukkale University-Clean Energy Center, Denizli, Turkey. The meatballs were cooked in an oven at 160 °C. The meatballs were weighted before and after the cooking and after the cooling for different temperatures and different vacuum pressure. Also, the microbial growth test has been carried out for the meatballs after conventional and vacuum cooling.

Microbiological analyses

The meatballs were cooked at 160 °C in an oven and after cooked, they were cooled to 5 °C with the vacuum cooling (at pressure of 7 mbar, 1 and 1.5 kPa) and the conventional cooling (at the temperature of −20, −16, 2, 5 °C). Microbiological analyses of the meatballs were performed after cooling the meatballs. After cooling with different cooling methods, the meatballs were kept in the etuve for 5 days at the temperature of 5 °C. At the end of 5 days, the samples of the meatballs were taken from the etuve. Twenty-five gram portions of the meatball samples were placed in plastic stomacher bags including 225 ml of 0.1% sterile peptone water, and it was pummeled for 5 min in a stomacher. For bacterial enumeration from the meatball samples, plate count agar (PCA) was used. Total plate count (TPC) (cfu/g) was determined by spread plate method on PCA. 0.1 ml dilution taken from stomacher using a micropipette and it was placed on PCA. The study was carried out with three successive dilutions and with three replications. The plates were incubated for 48 h at the temperature of 37 °C. The plate containing 15–300 colonies on a plate were selected and calculated.

Calculating the number of colonies

$$N = \frac{C}{V(n_1 + 0.1n_2)d} \quad (1)$$

where N is the number of microorganisms, C is the sum of colonies on all plates counted, V is the volume applied to each plate (ml), n_1 is the number of plates counted at the first dilution, n_2 is the number of plates counted at the second dilution, d is the dilution from which the first count was obtained.

Conventional cooling

Conventional cooling was carried out in a no-froze refrigerator (Beko D 9470 NE, Gebze, Kocaeli, Turkey). The average temperature of the refrigerator was set to −20, −16, 2, 5 °C. Three repetitions were performed for each experiment.

Weight measurement

The weights of the foods before and after the cooling process were determined by an electronic balance (Precisa XT 1220 M). The weight difference is the mass loss during the vacuum cooling process. The accuracy of the balance is ±0.001 g.

Thermal view

Before and after the vacuum cooling of the products, thermal views (FLIR Systems, Danderyd, Switzerland) have been taken and views were transferred from thermal camera to the computer by using ThermaCAM QuickView (FLIR Systems, Danderyd, Switzerland).

Results and discussion

The aim of this study is to determine the effect of the pressure on the vacuum cooling of meatballs and comparison of the results with the conventional cooling. The microbial growth rate for vacuum cooling is also compared with conventional cooling. In order to determine the mass loss and mass loss ratio for the vacuum cooling and the conventional cooling, the weights of the meatballs have been taken before and after the cooling.

The variation of the centre and surface temperature of the meatballs, the vacuum chamber humidity and temperature and the pressure during the vacuum cooling in the chamber are examined for set pressure of 0.7 kPa. In Fig. 2, the results are given for 0.7 kPa vacuum pressures. As can be seen from the Fig. 2, the vacuum chamber temperature was constant during the cooling period, and it is nearly equal to ambient temperature. Since the vacuum cooling is an evaporative cooling method and heat removed directly from the product during the cooling process, almost no temperature change occurs at the ambient (in the vacuum chamber). However, as can be seen in Fig. 2, vacuum chamber humidity fluctuates through the process due to the evaporation from the meatballs to the chamber.

It can be seen from the Fig. 2 that vacuum pressure in the vacuum chamber decreased rapidly from atmosphere to about 2 kPa in 200 s (3.33 min), then decline slightly. When it reaches to set pressure, it keeps almost constant value. When the pressure is lower or equal to the saturated pressure at the local temperature, water starts to boil in the meatballs, water evaporates and the evaporation of the water from the meatballs causes to cool.

For the set pressures (0.7 kPa), the surface temperature and the centre temperature of the meatballs decrease together as expected. The cooling effect comes from water boiling from the samples, and therefore evaporation and cooling of the sample start from the surface. However, with decreasing the pressure, evaporation and cooling occur through the meatballs and temperature decreases together.

The total cooling time is dependent on the shape of the product, porosity, pore size and the pore distribution within the samples, and the availability of free water in the pores, and set pressure (Ozturk and Ozturk 2009; Zhang et al. 2013, 2014). However, in this study, the influence of the shape of the product, porosity, pore size, pore distribution within the samples and the availability of free water in the pores were not studied. This study deals with the effect of set pressure and temperature on the cooling time and microbial growth rate. The temperature of meatballs decreases from about 75–80 °C to 5 °C (storage temperature) for both the convention cooling and the vacuum cooling.

Thermal views of the meatballs before and after the vacuum cooling have been given Fig. 3. As can be seen from Fig. 3, the temperature distribution after the vacuum cooling is homogeny through the meatballs.

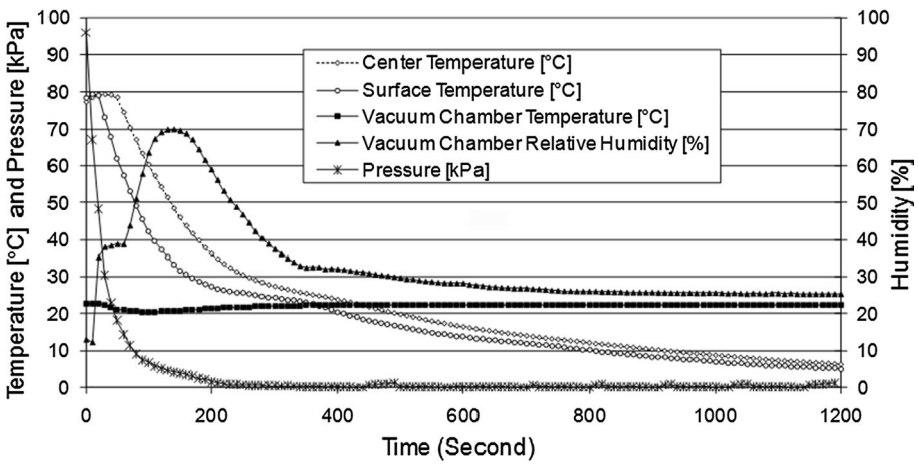

Fig. 2 Variation of pressure, center and surface temperature of meatball, temperature and humidity of vacuum chamber with time for set pressure of 1 kPa

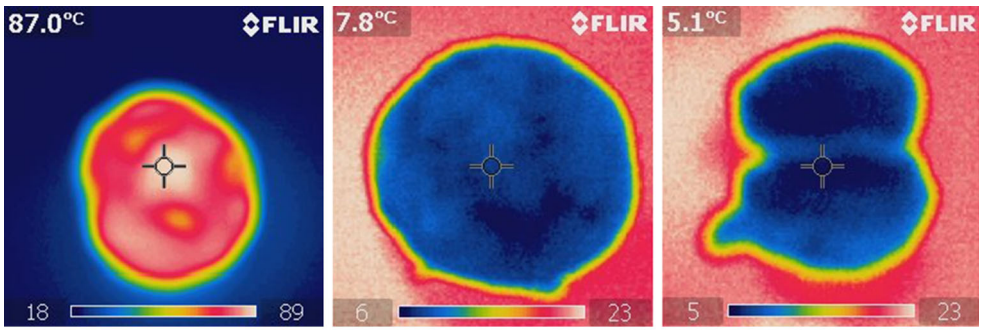

Fig. 3 Thermal view of meatball before and after the vacuum cooling for 1 kPa set pressure

Table 1 Variation of mass loss and mass loss ratio of meatball with pressure and set temperature

Vacuum pressure and set temperature (°C)	0.7 (kPa)	+2 (°C)	+5 (°C)	−16 (°C)	−20 (°C)
Mass before cooking (g)	100,584	100,843	100,172	100,314	100,58
Mass after cooking (g)	82,100	91,588	88,032	88,380	91,810
Mass loss during cooking (g)	18,174	9.255	12,140	11,934	8.770
Mass loss ratio (%)	18	9	12	11	8
Mass after cooling (g)	74,659	86,027	83,192	84,327	87,326
Mass loss during cooling (g)	7440	5561	4840	4053	4484
Mass loss ratio (%)	9	6	5	4	4

The weight loss occurs during the vacuum cooling since cooling effect directly comes from water evaporation (boiling) from the meatballs. The weight losses of meatballs, during the vacuum cooling for three different pressures and four set temperature are given in Table 1. The weight loss and the weight loss ratio are closely related to final set pressure and mass loss ratio during the vacuum cooling is highest for the 0.7 kPa. The conventional cooling was carried out in a refrigerator at the set temperature of −20, −16, 2, 5 °C (see Fig. 4). The conventional cooling in a refrigerator at the set temperatures of −20, −16, 2, 5°C. A comparison of the conventional cooling with the ambient temperature of 6 °C, with the vacuum cooling at 0.7 kPa pressure, shows that the vacuum cooling is about 5 times faster than the conventional cooling for the meatballs (see Figs. 1, 4). It can also be concluded that the conventional cooling is much slower than the vacuum cooling. The mass loss ratio for cooling at a set temperature of −20 and −16 °C has been found 4%. The mass loss of the meatballs has been given for the conventional cooling at Table 1. As can be seen from Table 1, the mass loss is higher at the cooling of −5 °C, 6%. The mass loss ratio is higher for the vacuum cooling than the conventional cooling. However, the cooling time for the vacuum cooling is shorter than the conventional cooling.

Total viable count (TVC) in the meatballs are given in Fig. 5. The meatballs have been cooled for the conventional cooling (−20, −16, 2, 5 °C) and the vacuum cooling (0.7 kPa). It has been recorded that microbial growth is lower for the vacuum cooling than the conventional

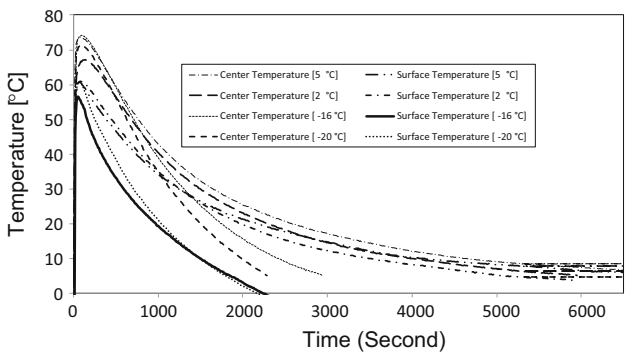

Fig. 4 Variation of center and surface temperature of meatball with time for different storage temperature

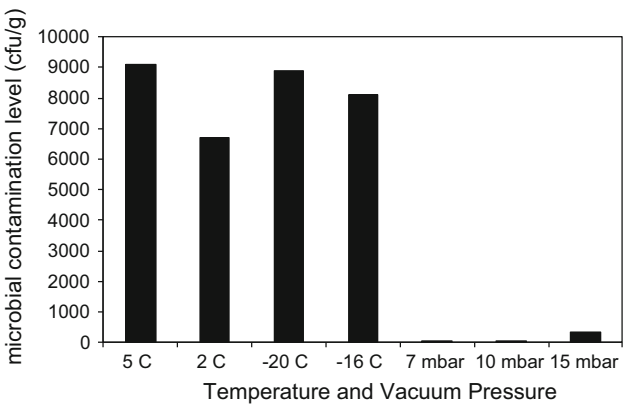

Fig. 5 Microbial growth in meatball for different cooling methods

cooling (see Fig. 5). For the vacuum cooling, it can be easily seen from Fig. 5 that the lowest microbial growth occurs at 0.7 kPa and the highest microbial growth occurs for the vacuum cooling at 1.5 kPa. The reason could be the fact that the temperature of the meatballs could not be decreased below the 10 °C.

Conclusion

In this study, two different cooling methods have been tested the vacuum cooling and the conventional cooling. Results show that the vacuum cooling is a rapid and efficient cooling method when it is compared with the conventional cooling method. On the other hand, it has been noted that the mass loss is higher for the vacuum cooling when it is compared with the conventional cooling. It can be concluded that for the high vacuum pressure it is not possible to achieve desired storage temperature of 5°C. It has been noted that the meatball for the low temperature of −20 and −16 °C is freezing which is not desired. Eventually, this study confirmed that the vacuum cooling is an efficient method and is suitable for cooling of meatballs.

It can be concluded that microbial growth is higher for the conventional cooling than the vacuum cooling. For the vacuum cooling, the lowest microbial growth occurs at 0.7 kPa and the highest microbial growth occurs for the vacuum cooling at 1.5 kPa.

From this study, it can be concluded that the spoilage bacteria counts for the meatballs can be reduced and the shelf life of the meatballs can be extended using the vacuum cooling. Therefore, applying the vacuum cooling for cooling meatballs may be useful for consumer health, and may also be a practical application for the meatball producer because of the short shelf life of this product. The mass loss ratio for the conventional cooling is lower than the vacuum cooling. However, the cooling time for the vacuum cooling is 5 times shorter than the conventional cooling.

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