Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 123 (2017) 62–69

Energy Procedia

www.elsevier.com/locate/procedia

1st International Conference on Sustainable Energy and Resource Use in Food Chains, ICSEF 2017, 19-20 April 2017, Berkshire, UK

Unwrapped food product display shelf life assessment

Abas Hadawey[a]*, Savvas A. Tassou[b], Issa Chaer[a], Raveendran Sundararajan[a]

[a]*London South Banks University, London SE1 0AA, UK*
[b]*Brunel University London, Institute of Energy Futures, Center for Sustainable Energy Use in Food Chains, Uxbridge, Middlesex UB8 3PH, UK*

Abstract

Chilled foods have been available since the 1960s. However, over the past 20 years, the market has been driven by the huge social, economic and demographic changes that have influenced our eating habits. This has contributed to making the chilled food production and retail in the UK one of the world's fastest-growing food sectors with food retail stores, restaurants and cafeterias. One very important fixture in these commercial establishments is the display cabinet where food is chilled and displayed. Many guidelines & regulations exist regarding displaying of food in cabinets. Amongst these are ones that relate to food deterioration such as the Food Hygiene Regulations 1995 (updated in January 2006), which related specifically to the retail sale and distribution of chilled foods. The most important point of these regulations was a requirement for sensitive foodstuffs to be maintaining at 8°C or below (Part II). These regulations were focused on reducing the risk of bacterial spoilage associated with chilled foods. The Regulations did not engage in the deterioration problems associated with moisture transfer and evaporating loss of unwrapped chilled foods displayed in delicatessen cabinets. This paper present result from theoretical and experimental investigation into the display shelf life in terms of bacterial spoilage and weight loss for some unwrapped sandwiches components including vegetables, tuna, cheese and beef. The output of this work showed that the display shelf life in terms of weight loss is shorter compared to the shelf life in terms of bacterial spoilage and it's related to food drying rate. Surface drying, increases the weight loss and leads to colour changes that are undesirable and results in shorter display shelf life. Weight loss was affected by air relative humidity, velocity and temperature. Therefore, more consideration should be given to environmental boundary conditions, which have direct impact on the quality and shelf life of unwrapped product.

Peer-review under responsibility of the scientific committee of the 1st International Conference on Sustainable Energy and Resource Use in Food Chains.

Keywords: Unwrapped Chilled Food; Display Shelf Life; Drying Rate; Weight Loss; Bacterial Spoilage.

---

* Corresponding author. Tel.: +44-20-7815-7537.
E-mail address: hadaweya@lsbu.ac.uk

Peer-review under responsibility of the scientific committee of the 1st International Conference on Sustainable Energy and Resource Use in Food Chains.
10.1016/j.egypro.2017.07.233

1. Introduction

Shelf life represents the useful storage life of food, which is determined by changes in taste, smell, texture, or appearance that are considered to be unacceptable or undesirable. The underlying causes of these changes may be microbiological, chemical or physical. Different types of spoilage are associated with chilled delicatessen food, such as Abiotic spoilage, which is caused by chemical and physical changes in the product, and Biodeterioration spoilage that is caused by bacteria, yeast and mould. Surface drying has been identified as the main reason for commercial loss from unwrapped chilled food in display cabinets [1]. Weight loss has also been identified as the most important cause for the end of display shelf life of meat, fish and their products [2]. It was found by [3] that discoloration is the most important limiting factor controlling the display shelf life of pre-packed meat and a relationship was established between weight loss during display and colour changes. Many investigations have been carried out to establish the variation of drying rate as a function of the environmental boundary conditions. Some of these investigations were experimental and involved mainly meat and meat products and resulted in recommendations for increasing product shelf life and minimizing weight loss [4-5]. Other investigations attempted to develop mathematical models to calculate the drying rate as a function of the environmental conditions and product variables such as shape and water activity [6- 7]

The presence and growth of bacteria often determine the quality and shelf life of foods. Monitoring the sensory quality of the food product and the growth of spoilage microorganisms can be used to develop a mathematical model to determine the shelf life of a food product based on the growth of a specific microorganism.

Spoilage due to bacteria growth is most rapid in proteinaceous foods such as meat, poultry, fish and some dairy products. These foods are highly nutritious, possess a neutral or slightly acidic *pH* and high moisture content and therefore permit growth of a wide range of bacteria. Changing the storage conditions is the only way to delay spoilage and provide longer shelf life for these types of food.

Unwrapped food products such as sandwiches are one of the most popular fast foods in the UK. The classic baguette sandwich consists of a baguette with different fillings in the middle, such as meat, fish, egg, cheese and vegetables. Sandwiches available in local shops are mostly made fresh on the day. It was reported by [8] that meat sandwiches occupy around 31.1 % of the total sandwich market, followed by fish 22.2%, cheese 17.7% and egg 8.8%. For this reason beef, vegetables (Lettuce, tomato, cucumber, pepper), cheese and tuna were considered in this study. Moreover this study is interested in refrigerated display conditions such as temperature, relative humidity and air velocity.

2. The Mechanism of Bacterial Spoilage and the Specific Spoilage Organism (SSO)

Bacteria, mould and yeast cause Biodeterioration spoilage. Bacteria are very simple forms of plant life. Under ideal conditions, bacteria can grow and reproduce at high rate in some cases, in as little as 20 minutes [9]. Bacterial growth is influenced by many factors, such as Intrinsic factors (e.g. *pH*, water activity), Extrinsic factors (e.g. refrigeration, modified atmosphere packaging) and Implicit factors (e.g. specific growth rate of the micro-organisms and microbial interactions) [10]. Bacterial growth on food changes as it passes through a succession of stages. Microbiologists, base bacteria counting on the assumption that one single bacterium can give rise to one colony on solid media. Each colony is referred to as a Colony Forming Unit (*cfu*) for short.

Evaluation of the maximum number of spoilage microorganism cells at the point when the food product reaches the final stage of its life can be used as indicator of the food product shelf life. Therefore the shelf life of specific food product in terms of bacterial spoilage can be defined as the time required by the spoilage microorganism to reach maximum density of cells. The number of bacteria cells will start to increase at the beginning of the growth phase, but before that happens some time is required to prepare for the growth (Lag phase). Therefore, the shelf life basically represents the lag phase time and the time required by the bacterium during the growth rate to reach maximum density. Almost all groups of microorganisms under some conditions can contribute to spoilage of foods. It was suggested by [11] that predictive models for spoilage should be developed only after knowing the microorganism responsible for the reactions that are important in the process of spoilage and the range of environmental conditions under which these organisms cause spoilage. Authors of [12] emphasised that spoilage models based on the responses of the dominant organism are valid only in the specific range of conditions. Out of this range, different bacteria or metabolites may be responsible for the spoilage, making the model no longer valid. The most important element in the implementation of the SSO concept is the ability to use mathematical models that quantitatively describe the growth of the SSO, [13]. This study considers bacterial growth from the theoretical point of view only. Some assumptions have been made to facilitate predictions of growth curves such as steady state conditions, no interactions between different bacteria that could be present on the food, no chemical substances have been used to preserve the food item, the food product is free of mould and yeasts and finally because of uncertainty about the initial contamination state, the lag time will not be included in the calculation of the shelf life.

2.1 Limitation Number of Bacteria in Food Products

It was reported by [14] that the initial contamination of the various raw vegetables generally exceeds a level of 10^6 *(cfu/g)* of viable microbial cells, depending on the source of the product. Cleaning the product and washing it with cold water will reduce that number significantly. Also [14] reported initial counts of psychrotrophs bacteria of $1.07x10^5$ *(cfu/g)* in salads stored at 4°C. It was reported by [15] that initial levels of psychrotrophs bacteria in the range of $1.8x10^5$ *(cfu/g)* was found in cabbage, $2.7x10^5$ *(cfu/g)* in lettuce and $9.5x10^4$ *(cfu/g)* in carrot salads. It was stated by [16] that the initial mesophilic bacteria are different from one type to another type of food. Mesophilic bacteria counts on meat and meat products are about 10^2-10^3 *(cfu/g).* Only 10% of the bacteria initially present are able to grow at refrigeration temperatures, and the fraction causing spoilage is even lower. It was mentioned by [17] that a $1x10^{2.22}$ *(cfu/g)* of psychotropic bacteria as initial contamination for cheese. It is difficult to identify the initial bacteria contamination in food because of the variety of variables involved. Therefore, the maximum initial number of bacteria reported will be considered as the initial number of contamination bacteria in this study. During the aerobic storage of meat and meat products, *Pseudomonas spp*. may increase to 10^5 *(cfu/g)*. The maximum population of bacteria that can be reached before the end of the microbiological shelf life of the product is 10^7 *(cfu/g)* [16]. At levels of 10^7 *(cfu /g)* off-odours may become evident in the form of a faint "dairy" type aroma. Once the surface population of bacteria has reached 10^8 *(cfu/g)* the supply of simple carbohydrates has been exhausted and recognisable off-odours develop leading to bacterial spoilage [18]. Moreover, [5] has reported that in some foodstuff (rich in amino acids), spoilage because of *Pseudomonas* becomes evident as their number approaches 10^6 *(cfu/g)*. In this study the lowest number of bacteria reported to cause spoilage will be considered as the maximum number of bacteria that can be reached before the end of the product shelf life. A guideline was published by [19], to assess the quality of some ready to eat food, where it mentioned that some type of pathogen should not be detected in 25g sample of food, such as *Salmonella spp., E. coli O157* and *Campylobacter spp*.

2.2 Predictive Modeling for the Estimation of Bacteria Growth Rate

Different types of microorganisms could grow on specific food, but only one will be responsible for the spoilage of that type of food. Therefore all the growth rates of the dominant bacteria for spoilage of specific food will be investigated. The fastest Bacteria will be considered to be responsible for the spoilage and will be used to assess the shelf life. Table 1 shows the most common spoilage bacteria for different types of food.

Table 1. Most common spoilage bacteria for different types of food

Food item	***Contamination Bacteria***	***References***
Beef	*Pseudomonas spp., Escherichia Coli, Listeria Monoeylogene, Loctobacillus Curveus, Staphylococcus Aureus, Shewanell Putrefaciens, Aeromonas*	*[12, 18,21]*
Tuna	*Pseudomonas spp., Shewanell spp.*	*[12- 13]*
Cheese	*Pseudomonas spp., Aeromonas Bacillus Cereus, Listeria Monoeylogene Staphylococcus Aureus*	*[12,23]*
Vegetable	*Pseudomonas spp.,Escherichia Coli Bacillus Cereus, Loctobacillus Curveus, Aeromonas*	*[14, 22]*

Predictive modeling is currently accepted as a useful method for describing quantitatively the effects of ecological determinants (e.g., temperature, water activity) on bacterial growth. In particular, predictive microbiology has been used to predict the growth of specific spoilage microorganisms in order to determine the shelf life of various food products. Models proposed by various researchers, to predict growth rates of a number of bacteria and the characteristics of the food that are of interest in this study including the acidity level and water activity, were reported by [20].

2.3 Growth Curves of Different Bacteria on Different Types of Food

In this study, the dominant spoilage bacterium has been chosen based on the results of the comparison of different growth curves for different types of bacteria that could contaminate the food. Figure 1 shows growth curves for different types of food product. For Beef, *Pseudomona* has the highest growth rate and therefore was considered as the dominant spoilage bacterium. For *tuna*, the most dominant spoilage bacterium was reported to be *Pseudomonas* [24].

For cheese, *Pseudomonas* has the highest growth rate in the temperature range 0°C to 6°C. Above 6°C *Listeria monocytogenes* has the highest rate but because it is not allowable for it to exceed 20 cells in the food [19], *Pseudomonas* was used to assess the shelf life of cheese. The average water activity of the vegetables listed in Table 2 was used in the calculation of bacteria growth curves on vegetables. Figure 1 shows that *Pseudomonas* has the highest growth rate amongst the other contamination bacteria and was used in the calculation of the shelf life of vegetables.

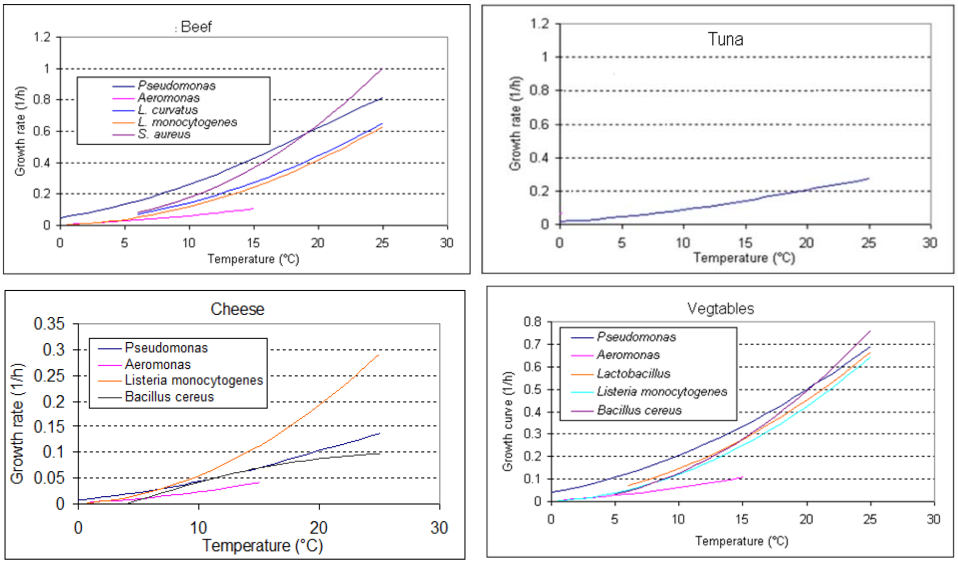

Fig. 1. Growth curves for different types of bacteria on different types of food product

2.4 Assessing the Shelf Life in Terms of Bacterial Spoilage

The shelf life of a food product is the time required by the bacteria population to reach a given maximum number. It can be established from publications given in section 2.1 that the value of initial numbers of the spoilage bacterium N_1 for beef, vegetables and cheese was taken as $1x10^3$ *(cfu/g)* and for tuna as $1x10^{3.23}$ *(cfu/g)*. The value of the final numbers of the spoilage bacterium N_2 was taken as $1x10^6$ *(cfu/g)* for beef and $1x10^7$ *(cfu/g)* for all the other types of food considered in this study. The growth rate is taken as the slope of the exponential growth phase curve.

$$shelf\ life = (\log N_2 - \log N_1)/(growth\ rate) \tag{1}$$

Figure 2 shows the shelf life in terms of bacterial spoilage for the considered food product. It can be seen that the shelf life is affected significantly by temperature. At 4°C the shelf life of beef was around 25h, while at 18°C the shelf life reduced to 7h. At 4°C the shelf life for tuna was around 97h and at 18°C, 29h. At 4°C the shelf life of cheese is over 300h and reduces to 25h at 18°C. The shelf life of vegetables was found to reduce from 300h at 4°C to 25h at 18°C. The sensitivity of shelf life to temperature is much higher in the low temperature range, below 8°C than above 10°C. Raising the temperature from 4°C to 5°C reduces the shelf life from 370h to 187h.

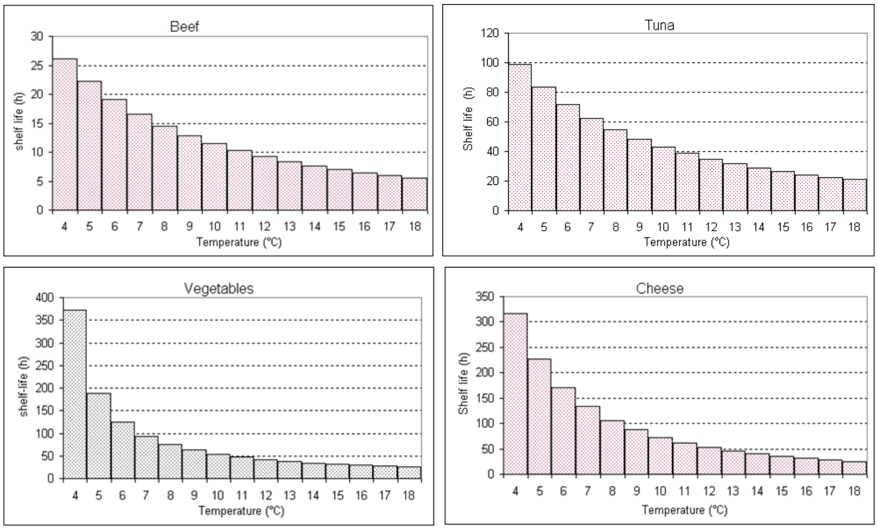

Fig. 2. Shelf life / bacterial spoilage variation for different types of food product

3. Surface Drying and Display Shelf Life

An experimental study was carried out over a temperature range between 7 and 13°C, relative humidity between 50 and 90 %RH and air velocity between 0.1 and 0.9 m/s to evaluate the display shelf life as a result of weight loss for the considered food product. The experiments were carried out in a closed circuit controlled environmental chamber. The weights of the samples were recorded by using a load cell having a total error of around 0.0067% of the rated output of mV/V. A data acquisition system recorded the weight of the samples continuously. A sample of tuna was tested in Petri dishes. The samples had a constant weight of 50g and surface area of 0.005026 m² and the top surface was exposed to environmental conditions. Cucumber was chosen to represent the vegetables because of its sensitivity compared to other vegetable food components considered in this study (high water activity and low *pH*); cucumber samples had a weight of 75g, and thickness of 6 mm. Cheese & beef samples were cylindrical in shape of 80 mm diameter and 1mm thickness (constant surface area). Twenty-seven different combinations of boundary conditions of temperature (7 °C, 9 °C, 13 °C), relative humidity (50 %, 70 %, 90 % RH) and air velocity (0.1 m/s, 0.45 m/s, 0.9 m/s) were used in the test chamber to obtain the drying rate of each sample. The initial surface product temperature of the sample was maintained approximately at the test air temperature to obtain steady state conditions.

3.1 Weight loss curves and drying rate

Plots of weight as a function to time were used to derive weight loss versus time curves. The drying rates for each sample were calculated from the weight-loss versus time graph by obtaining the slope of the weight-loss curve during the steady state period. It was observed that weight loss occurred at a constant rate for the first 350min; see Figure 3a for the food components considered in this study. Calculations were therefore based on the measurements from the steady state period. Samples of beef, tuna, cheese, cucumber showed very similar trends; therefore result from only one sample, i.e. beef will be discussed.

Beef: The drying rate was related to the three environmental boundary conditions relative humidity, temperature and air velocity as shown in Figure 3b. It can be observed that the relative humidity is the most effective factor on drying rate. Increasing the relative humidity from 70 to 90 % RH at 13°C and 0.1 m/s, reduced the drying rate from 3.07x10^{-5} to 1.68 x10^{-5} kg/s.m^2. This equates to a reduction of 46%, while reducing the air velocity at 13°C, 90% RH from 0.45 to 0.1 m/s reduced the drying rate by 25% from 2.3 x10^{-5} to 1.68 x10^{-5} kg/s.m^2. Reducing the temperature from 13 to 9°C at 70% RH, 0.9 m/s the drying rate reduced by only 7% from 4.82 x10^{-5} to 4.45 x10^{-5} kg/s.m^2. It was also observed that the effect of air velocity on the weight loss and drying rate is dependent on the relative humidity. At 13°C and air relative humidity 50%, increasing the air velocity from 0.1 to 0.45 m/s increased the drying rate by 33.5% from 5.6 x10^{-5} to 7.48 x10^{-5} kg/s.m^2. At the same temperature and at 90% RH and the same variation in air velocity the drying rate increased by 21% from 1.68 x10^{-5} to 2.3 x10^{-5} kg/s.m^2. Hence the magnitude of the effect increases as relative humidity decreases.

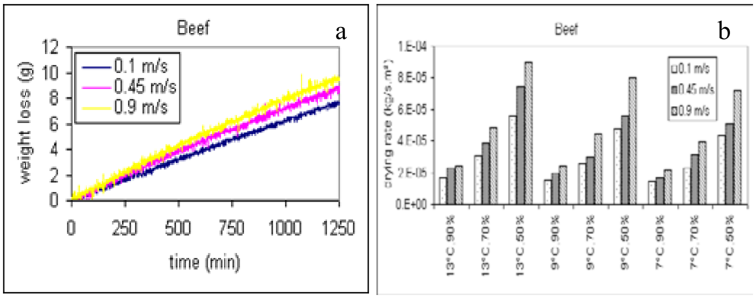

Fig. 3. (a) Weight loss versus time curve; (b) Drying rate versus test conditions

3.2 Display Shelf Life

It has been reported that the visual appearance of food and food products is of major importance when consumers assess product quality [25]. The first change in the appearance of the samples, such as change of colour, drying or shrinkage were considered to be the factors that decide the end of display shelf life of the food samples. The display shelf life of the considered food components was established based on observations of food samples under test by a panel of five members. The display shelf life of all the samples considered ranged from 60 to 600 minutes at different boundary conditions as shown in Figure 4.

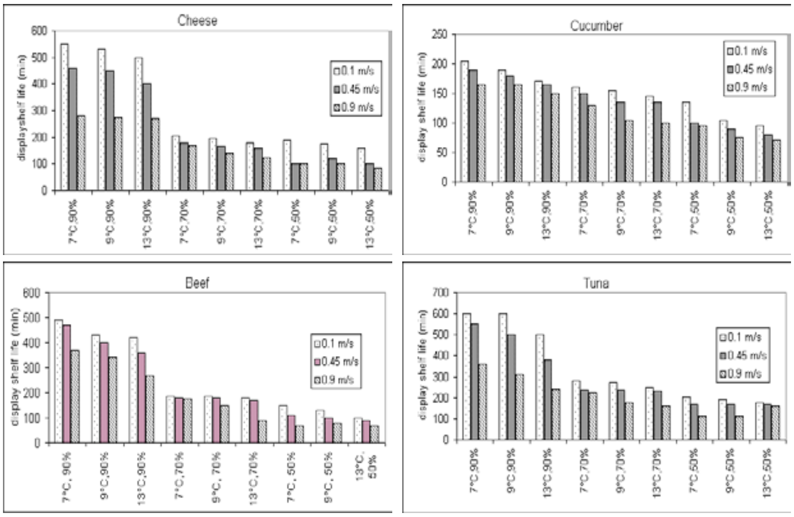

Fig. 4. Display shelf life/weight loss versus test conditions for different types of food product

The tuna sample showed the longest display shelf life, followed by cheese, beef, and cucumber. Also from Figure 4, it can be seen that the highest display shelf life was recorded at high relative humility of 90 % RH and low temperature of 7 °C. The results showed that the relative humidity had the greatest effect on display shelf life. In general all the considered food samples showed similar trend so only the beef will be discussed. The beef display shelf life variation showed that reducing the relative humidity at 13 °C, 0.1 m/s from 90 % to 70 %RH reduced the display shelf life from 420 min to 180 min while reducing the temperature from 13 to 9 °C at 90 %RH, 0.1 m/s only increased the display shelf life from 420 to 430 min. The velocity also showed an effect on the display shelf life. Increasing the air velocity from 0.1 to 0.9 m/s reduced the display shelf life from 420 to 270 min. High relative humidity, low temperature and low air velocity achieve longer display shelf life. Moreover, for all the food samples, it has been determined that the display shelf life in terms of weight loss is related to the drying rate as shown in Figure 5. Increasing the drying rate led to an increase in the weight loss and reduction of the display shelf life. Reducing the drying rate provided longer display shelf life.

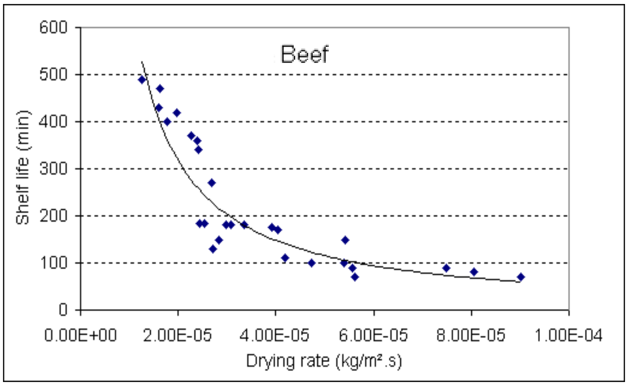

Fig. 5. Display shelf life/weight loss versus drying rate

4. Conclusions

The investigation into the shelf life of the most common components of unwrapped sandwiches showed that the display shelf life in terms of weight loss is shorter compared to the shelf life in terms of bacterial spoilage. Therefore, more consideration should be given to environmental boundary conditions, which have direct impact on the quality and shelf life of unwrapped product. Based on the experimental work that was carried out, the following conclusions are derived:

1. Surface drying, increases the weight loss and leads to colour changes that are undesirable and results in shorter display shelf life. Weight loss was affected by air relative humidity, velocity and temperature. Weight loss occurred at constant rate for a finite period of time, after which the rate of weight loss decreases.
2. Tuna, beef, cucumber and cheese showed similar trends in drying rate and display shelf life.
3. The relative humidity had the most prevalent effect on the drying rate. Temperature changes had smaller effect on drying rate compared to the changes in either relative humidity or air velocity. Air velocity directly affects the drying rate and this is related to the relative humidity. The magnitude of the effect increases as relative humidity decreases.
4. A direct relationship was found between the drying rate and display shelf life. Reducing the drying rate provides longer display shelf life.
5. The display shelf life was mostly affected by air relative humidity and velocity. Changes in air velocity at high relative humidity had more effect on display shelf life than at low relative humidity.
6. The tuna sample showed the longest display shelf life, followed by cheese, beef and cucumber. The most sensitive sandwich component to the environmental boundary condition is determining the display shelf life of the whole sandwich.

References

[1] Maidment G.G., Missenden J.F., James R.W., Tozer R.M. "Influence of thermal radiation on weight loss in delicatessen cabinets". IIF-IIR-Commission D2/3, with D1- Cambridge, UK- (1998), pp. 226-234.

[2] James S.J. , Fulton G.S., Swain M. and Burfoot D. "Modelling the effect of temperature and relative humidity fluctuations on weight loss in retail display". IIR Commissions C2, D1, D2/3, E1-Brisbane Australia. (1998), pp.111-119.

[3] Fulton, G. S., Burfoot, D., Bailey, C. and James, S. J." Predicting weight loss from unwrapped chilled meat in retail display". XVI th Int.Cong. Refrig. Vienna Commission C2, (1987), pp.555-562.

[4] McMullen L.M., and Stiles M.E. "Quality of fresh retail pork cuts stored in modified atmosphere under temperature conditions simulating export to distance markets". Meat Science. (1994), Vol.38, pp.163-177.

[5] Gill C. O." Extending the storage life of raw chilled meats". Meat Science, (1996), Vol. 43, No.S, pp. S99-S109.

[6] Sawitri C., Wells C. M. and Cleland A. C." Predication of chilling times of foods insituation where evaporative cooling is significant- Part1. Method development". Journal of food engineering (1998-a), Vol. 37, pp.111-125.

[7] Delgsdo, A. E. and Sun, D. W." Heat and mass transfer models for predicting freezing processes – a review". Journal of Food Engineering, (2001), Vol. 47, pp. 157-174.

[8] IRN Research Market Research on the Web 2000

[9] Gibson D. M., "Microbiology in chilled foods – Is refrigeration enough?" Proceedings of the Institute of Refrigeration, (1990- 1991).

[10] Mossel D. A. A., "Physiological and metabolic attributes of microbial groups associated with foods". J. Appl. Bacteriol. Vol.34, (1971), pp. 95-118.

[11] Dalgaard P. "Modelling of microbial activity and prediction of shelf life of packed fish". Int. Food Microbial. Vol. 26, (1995), pp. 305-318.

[12] Ross T. and McMeekin T. A. "Shelf life prediction; status and future possibilities". Int. J. Food Microbial. Vol. 33, 1996, pp. 65-83.

[13] Gram L. and Dalgaard P. "Fish spoilage bacteria- problems and solutions". Department of seafood research, Current opinion in Biotechnology. Vol.13, (2002), pp.262- 266.

[14] Garcia-Gimeno R. M and Zurera-Cosano G. "Determination of ready-to-eat vegetables salad shelf-life". International Journal of Food Microbiology. Vol. 36, (1997), pp. 31-38.

[15] Garg N., Curey J. and Splittstoesser D. "Effect of processing conditions on the micro flora of fresh cut vegetables". Journal of Food Prot. Vol. 33, (1990), pp. 701- 703.

[16] Borch E., Kant-Muermans M. and Blixt Y."Bacterial spoilage of meat and cured meat products". ". International Journal of Food Microbiology. Vol. 33, (1996), pp. 103-120.

[17] Agnihotri M.K. Pal U.K. " Quality and shelf life of goat milk paneer in refrigerated storage". Small Ruminant research. Vol. 20, (1996), pp.75-81.

[18] Ellis D. I. and Goodacre R." Rapid and quantitative detection of the microbial spoilage of muscle foods: current status and future trends". Trends in Food Science & Technology. Vol. 12, (2001), pp. 414-424.

[19] Food Safety Authority of Ireland FSAI. "Guidelines for the interpretation of results of Microbiological analysis of some ready-to-eat foods samples at point of sale". Guidance Note No. 3 (ISBN 0-9539183-5-1), 2001

[20] A. Hadawey, "design of chilled food display cabinets for better temperature integrity and longer product shelf life". PhD thesis, 2006, Brunel University.

[21] Devlieghere F., Lefevere I., Magnin A. and Debevere J. " Growth of Aeromonas Hydrophila in modified atmosphere-packed cooked meat products". Food Microbiology. Vol.17, (2000), pp. 185- 196.

[22] James. M. J. "Modern food microbiology". (1992). 4th Edition, Van Nostrand Reinhold, Chapter 3.

[23] Jos H.J. Veld H. "Microbial and biochemical spoilage of foods: an overview." International Journal of Food Microbiology. Vol. 33, (1996), pp. 1-18.

[24] Rasmussen S.K.J., Ross T., Olley J. and McMeekin T. " A process risk model for the shelf life of Atlantic salmon fillets". International Journal of Food Microbiology. Vol. 73, (2002), pp. 47-60.

[25] Pexara E. S., Metaxopoulos J. and Drosinos H. E. " Evaluation of shelf life of cured, cooked, sliced turkey fillets and cooked pork sausages 'piroski' stored under vacuum and modified atmosphere at +4 and +10 °C". Meat Science, volume 62, Issue1, (September 2002), pp. 33-43