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MODELLING OF THE PHENOLIC COMPOUNDS PENETRATION DURING SMOKING OF CHEESE

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Abstract

The objectives of this research project were to determine the distribution of smoke throughout a block of cheese over the processing time and during cheese aging, and to determine the diffusivity of phenolics as a smoke compound during cheese processing in a smoke house.

Cheddar cheese blocks (355 × 90 × 90 mm, L × W × H) were smoked for 2.5 h at 21 °C in a smoke chamber. During the smoking procedure a sample of 25 × 90 × 90 mm dimensions was drawn every 30 min and cut into 4.5 mm thick slices which were analyzed for phenol content. Based on the measured distribution of phenol compounds in the block, the effective diffusivity of phenolic compounds during processing in the smoke house was determined using the Fick's law of diffusivity.

During storage the phenol content fluctuated and on day 45 almost doubled. The mass transfer model used in the calculation of the phenol penetration during smoking could not be applied to predict the re-distribution of phenol across the block of cheese because of internal chemical reactions acting against the mass balance approach.

Modelling of the Phenolic Compounds Penetration during Smoking of Cheese

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Introduction

Smoking of food is one of the methods used in preservation of foods and is often accompanied by other processes such as cooking and drying. Smoking technology was developed during the 1880s and it was mainly used to impart color, flavor and aroma to foods (Pszczola, 1995; Vitt et al., 2001).

Chedder cheese is the most popular variety of cheese with per capita consumption of more than 4 kg/year. Smoked cheese is also a very popular food in the market (Elayedath and Barringer, 2002). However, not much scientific information is available regarding the proper development of smoked cheese which is smoked based on experience of producers rather than based on the scientific evidence.

Over the past few decades, different types of smoking processes for foods have been developed to control the concentration of smoke in these foods. The relative concentration of smoke compounds in food products depends on type of wood chips used in the smoking process (Guillen and Manzanos 1996). The method of smoke generation and the smoking process itself greatly influence the sensory characteristics of food products such as smoked salmon (Serot et al. 2004).

Concentration of smoke compounds in foods also depends on the type of equipment used for smoking. Girard et al. (1982) reported that the content of phenolic compounds in electrostatically smoked bacon was higher when compared to smoking bacon in a traditional smoke house. When moist hickory sawdust was used to generate smoke, the concentration of phenolic compounds increased with an increase in smoke temperature up to 75°C. A reverse trend was observed when the smoke temperature exceeded 75EC. Maximum concentration of phenolic compounds was observed at 60% of relative humidity in a smoke house (Chan et al. 1975). Fayed et al. (2002) reported that smoking of cheese by using the smoke solution was better than the traditional method of smoking.

Smoked cheese is relatively new product in the dairy show case in Manitoba and Canada. There is marked demand but available product quality is highly variable. Smoked cheese can be considered at the cottage industry level in Canada. No major dairy establishments smoke cheese in large quantities. Wortzman Foods is the first company in Manitoba that is trying to establish scientific parameters for production of smoked cheese aiming at better understanding of the smoking process, improved product quality and uniformity, and process economics. Therefore, the objectives of this research project

were (i) to determine the distribution of smoke throughout cheese over the processing time and during cheese aging, and (ii) to determine the diffusivity of phenolics as a smoke compound during cheese processing in a smoke house.

Materials and Methods

Full fat Cheddar cheese samples were obtained from a commercial cheese company (Bothwell Cheese, New Bothwell, MB).

Determination of moisture content of cheese:

Moisture content of cheese was determined based on the AOAC (1990) method. Samples of about 1 to 2 g of cheese were transferred into aluminum dishes and placed for 2.5 h in a vacuum oven at 62 kPa under atmospheric pressure (Napco vacuum oven, model 5831, Tualatin, OR) maintained at 100 °C. The dishes with samples were then transferred into a desiccator to allow them to cool down to room temperature and then were weighed and transferred back into the vacuum oven. After further 4 h of drying the dishes were tightly covered, cooled to room temperature and weighed.

Determination of fat content of cheese

Fat content of cheese was determined by following the Babcock method (APHA, 1992). Exactly 9.0 g of shredded cheese was placed in a Babcock bottle. Next, 10 mL of hot water (60 °C) was added and the contents were mixed to create suspension of cheese in water. This was followed by adding 15 mL of concentrated sulfuric acid (specific gravity = 1.82-1.83) in 3 portions of 5 mL each. The addition of the acid was completed in 20 s. The contents were thoroughly mixed to digest the cheese particles by placing the bottles on a mechanical shaker for about 5 min. Following shaking, the bottles were counterbalanced in a Babcock centrifuge (Garver 200 series, Weber Scientific, Hamilton, NJ) and were centrifuged for 5 min. Next, a sufficient amount of water at 60 °C was added such that the final level of the content in the bottles reached the neck of each bottle. The content of the bottles was again centrifuged in a Babcock centrifuge for 2 min. After centrifugation, the bottles were transferred into a water bath and held at 55 °C for 5 min. After the second centrifugation, the fat column formed in the bottle was measured and the fat content was expressed as the percentage fat in cheese.

Smoking of Cheddar cheese

Smoked cheese samples were obtained from a commercial cheese company (Bothwell Cheese, New Bothwell, MB). These samples were used in two sets of experiments: (i) to determine the penetration of phenolic compounds into the block of cheese, and (ii) to determine the distribution of phenolic compounds in the block of cheese during storage.

Penetration of smoke during smoking of cheese

Unsmoked Cheddar cheese blocks (355 × 90 × 90 mm, L × W × H) were placed inside the smoke chamber (McRae Food Processing Equipment, Winnipeg, MB) and

smoked for 2.5 h at 21 °C. During the smoking procedure a sample of (25 × 90 × 90 mm (L × W × H) dimensions was drawn every 30 min. Before taking the sample from the original cheese block, a 90 mm long block was removed from one end each time (Fig. 1). The reason for that was to eliminate the effect of smoke penetration through the end of the block when sampling for the effect of smoke penetration through the side walls. The cut off 25 × 90 × 90 mm sample was then vacuum packed and stored immediately at -5 °C. The same procedure was used for all samples collected at 30 min intervals. Thus, sample M1 with its end E1 was removed at 30 min, sample M2 with end E2 at 60 min. End E3 was discarded because of the same reason as block's end E1. Sample M3 and M4 were taken from the second block at 90 and 120 min of smoking , respectively, following the same procedure as with Block 1. Samples M5 and M6 were obtained from the third block of cheese at 150 and 300 min of smoking. The last sample from the third block was used to determine the maximum saturation with the smoke (equilibrium) after keeping the remaining block of cheese for 5 h in the smoke house. The samples were then transferred to the Department of Food Science at the University of Manitoba where they were stored in the pilot plant freezer at -15°C till analysis. Individual samples were then analyzed for concentration of phenolic compounds.

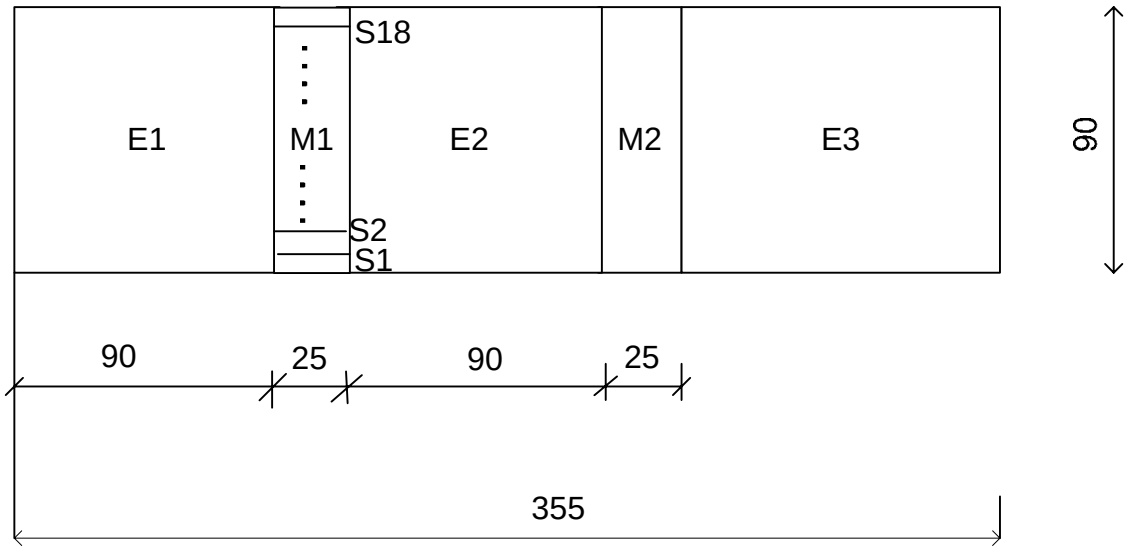

Fig. 1. Dimensions of the block of cheese (Block 1) and drawn samples. Samples E1 to E3 were discarded, samples M1 and M2 were used in the tests and each sample yielded 18 slices (S1 to S18).

The effect of storage on the smoke content of cheese

For this set of experiments, two blocks of cheese were divided into two halves each of 178 × 90 × 90 mm (L × W × H). The half-blocks were placed in the smoke chamber and smoked for 2.5 h at 21°C. At the end of the smoking process, the four half-blocks were removed from the chamber and vacuum packed. The blocks were then stored at 4°C at the manufacturing facility and then transferred under the same storage conditions to the Department of Food Science at the University of Manitoba. The half-blocks were stored in a cooler at 4°C. Each half-block yielded one sample (25 mm thick

and 90 × 90 mm in its cross-section) which was cut out from the middle of the half-block. The two ends of the block (76.5 mm each) were discarded. Samples were drawn every 15 d. The 25 mm thick samples were sliced following the procedure described above for the smoked samples. These samples were analyzed for the phenolic compounds.

Measurement of phenol content in smoked cheese to analyze penetration of smoke

Standard curve with known phenol content was prepared and was used to calculate the phenol content in smoked cheese samples (Chan et al. 1975). Stock solution of phenol was prepared by dissolving 1 g phenol into 100 mL of water. Then the required amount of phenol solution was taken and was further diluted in water such as to obtain final concentration of 0.02, 0.04, 0.06 and 0.08 g phenol per 10 g of water. After adjusting the concentration of phenol, the water and phenol mixture was then transferred into a blender jar containing 100 mL of 85% (v/v) ethanol. The mixture was blended for 15 min. Then, it was filtered through Whatman No. 2 filter paper. The filtrate was poured into a 100 mL glass beaker. Five mL of filtrate was then transferred into a 15 mL capacity test tube. To this extract, 5 mL of 0.5% sodium borate solution was added. The content was vortexed for 2 min. Then, 1 mL of Gibb's reagent (Sigma-Aldrich, Oakville, ON) was added. The content was again mixed for another 2 min. The test tube along with its content was then allowed to stay at room temperature for at least 1.5 h for color development. After that the content was taken into a separatory funnel containing 15 mL of N-butanol. The content was mixed and allowed to stand at room temperature. The water layer was separated from the N-butanol layer. The N-butanol layer was then transferred into a test tube and 2 mL of N-butanol saturated with ammonia was added. The mixture was thoroughly mixed. After that the phenol content was read using a spectrophotometer (Novaspec Plus Biochem Corp., Cambridge, England) at 635 nm wavelength. The absorbance readings for different phenol contents were plotted against phenol content and standard curve was created.

The frozen samples of cheese (25 × 90 × 90 mm) were cut into 9 slices (4.5 mm each) starting from each end of the 90 mm wide sample (Fig. 2). Due to handling, the two middle slices were discarded.

A power operated Hobart slicer (Hobart, Troy, OH) was used for making cheese slices. One slice had a mass slightly over 10 g. Exactly 10 g of slice sample was then taken into a blender jar. To this sample, 100 mL of 85% ethanol was added. The contents were blended for 15 min. The mixture was then filtered through Whatman No. 2 filter paper. The filtrate was transferred into a glass beaker and the beaker was covered with Petri film. The beaker along with the filtrate was then transferred into a refrigerator at 2 °C and kept there for 16 h. After that, the content was again filtered through Whatman No. 2 filter paper to remove the fat. The filtrate was again transferred into a 150 mL capacity beaker and was covered with Petri film. Exactly 5.0 mL of filtrate was taken into a 15 mL capacity test tube. To this extract, 5 mL of 0.5% sodium borate was added. The contents were thoroughly mixed for 2 min. Then 1 mL of Gibb's solution was added and again the contents were mixed for about 2 min. The test tube containing the mixture was allowed to stand at room temperature for at least 5 h to allow for the development of the color (Chan et al. 1975). After that, the content was transferred into a separatory funnel

containing 15 mL of N-butanol. After mixing, the contents were allowed to stand at room temperature. The water layer separated from butanol layer was removed from the funnel. The N-butanol layer containing phenol was then taken into a measuring cylinder and the final volume was adjusted to 21 mL. This volume was then transferred into a screw cap test tube. To this content, 2 mL of N-butanol saturated with ammonia was added. After thorough mixing, three samples of that mixture were used and the absorbance was read at 635 nm wavelength using the spectrophotometer. The phenol content was then calculated from the standard curve prepared before.

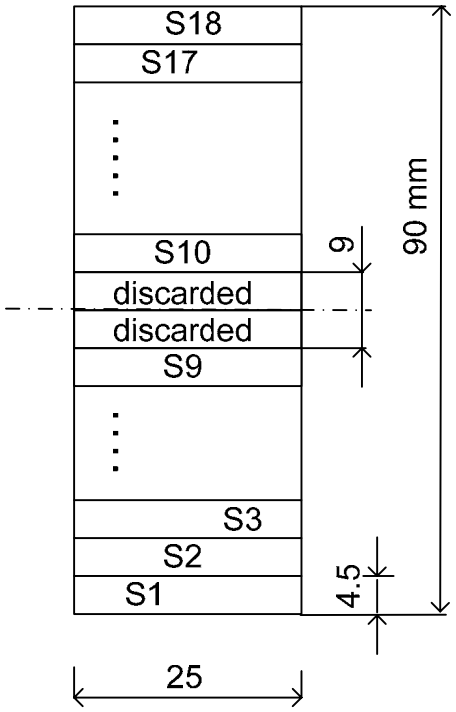

Fig. 2 Slicing of samples M1 to M5

Determination of mass diffusivity of smoke phenol in cheese during smoking

The effect of smoke penetration throughout a block of cheese was evaluated mathematically based on an equation analogous to Newton's Law of cooling (Lewis, 1921). The fundamental assumption was that the rate of change in phenolic compounds of the smoked samples is proportional to the instantaneous difference between phenolic compounds of the smoked sample and the phenolic compounds content in cheese upon attaining equilibrium with the surrounding smoke. The effective diffusivity of the smoke phenol compound was calculated using Fick's law of diffusion originally describing the moisture movement through plate geometry (Pabis et al. 1998). In this case moisture movement was replaced with mass movement of the phenolic compounds through a block of cheese during the smoking process. It was reasonable to assume a plate configuration as the ends of the block of cheese were discarded in the experiments eliminating the effect of penetration from the side wall. An equation describing the ratio of the average concentration in a plate configuration is:

$$\frac{\bar{P}(\theta) - Pe}{Po - Pe} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \left(\frac{1}{(2n+1)^2} \exp\left(-\frac{\pi^2 (2n+1)^2}{4} \right) Fo_m \right) \quad (1)$$

and

$$Fo_m = \frac{Deff}{S^2} \theta \quad (2)$$

Where:

$P(\theta)$ = Average concentration of the phenolic compounds in the block of cheese at time θ, mg/g

Pe= Concentration of the phenolic compounds at equilibrium, mg/g

Mo = Initial concentration of phenolic compounds, mg/g

n = Number of terms in equation. We used 4 terms.

$Deff$ = Effective diffusivity coefficient of phenolic compounds, cm^2/min

Fo_m= Fourier number

S = Half-thickness of the block of cheese, cm

θ = Processing time, min

Based on Eq. 1, the coefficient of effective diffusivity (*Deff*) was calculated and used to determine the phenolic compounds distribution across the thickness of the block of cheese using the following mathematical model (Pabis et al. 1998):

$$\frac{P(x,\theta) - Pe}{Po - Pe} = \frac{4}{\pi} \sum_{n=1}^{\infty} \left(\frac{(-1)^n}{(2n+1)} \cos\frac{(2n+1)\pi\, x}{2S} \exp\left(-\frac{\pi^2 (2n+1)^2}{4} Fo_m \right) \right) \quad (3)$$

where

$P(x,\theta)$ = Concentration of the phenolic compounds in the block of cheese in mg/g at the x location and at time θ

x = location of a slice in the block, cm

Measurement of phenolic compounds in cheese during storage

The smoked samples stored at 4°C were taken every 15 days for the determination of the content of the phenolic compound. Every sampling time, a cheese sample of 25 × 90 × 90 mm dimensions was cut out from the original half-block smoked cheese (178 × 90 × 90 mm) following the same sampling procedure as with samples drawn during smoking and described above. The obtained cheese sample was then sliced using the power operated Hobart slicer and 18 slices of 4.5 mm thickness were obtained from each block (Fig. 2). The slices were analyzed for their phenol content as descried in the previous section.

Results and Discussion

Determination of moisture and fat content of cheese

Cheese samples were at 40.0 ±0.1% moisture wb (wet basis) and contained 28.0±0.1% of fat.

Determination of smoke penetration during smoking process

In this set of experiment, the samples were drawn after every 30 min. Total smoking time was 150 min. The results of the phenol content (smoke or phenolic compounds) in individual slices over the smoking time are given in Table 1. The average values of phenol with associated standard deviations are given for individual slices which locations in a block are shown in Fig. 2 The deposition of phenol (smoke compounds) increased with an increase in the smoking time. Table 2 gives the average values of phenol content for the entire sample (sample 25 × 90 × 90 mm) calculated based on Table 1. The average concentration of phenol in a sample that was taken after initial 30 min of smoking was 0.709 mg/10 g wb (wet basis of cheese) (range from 0.629 to 0.79 mg/10 g wb). This increased with an increase in the smoking period, reaching the average value of 1.285 mg/10g wb after 150 min of smoking. The samples were smoked for additional 150 min until the total smoking time was 5 h (300 min). The phenol content for slice S1 did not change between 150 and 300 min and the increase in the phenol content was observed for the slices drawn from the middle portion of the cheese block. Eventually, all slices from S1 to S18 (Table 1) became quite uniform in the phenol content after 5 h of smoking. The deposition of smoke reached its maximum after 120 min of smoking and then declined and reached a uniform concentration across the block after 5 h. A similar observation was recorded by Serot et al. (2004). They observed a decrease in the absorption rate of smoke compounds on the surface of fish fillet when smoked using a traditional smoking method. They reported that this might be due to partial drying of a sample during smoking process. We suspect that in our experiments the increase in the concentration of the smoke compounds on the surface layer may have increased the resistance of that layer to penetration of smoke compounds to further layers.

It was observed that the concentration of smoke compounds was higher on the surface layer. The concentration decreased in the cheese slices drawn from the centre of the block (Table 1). This indicated low penetration rate of smoke compounds and low diffusivity of smoke phenols in cheese. The color of surface layer was darker than that of layers from inside of the cheese block. This also confirmed more deposition of smoke phenols on the surface than inside of the cheese block.

As the smoking time increased, the concentration of smoke compounds in slices 2 to 6 became almost equal (Table 1). This was especially evident in samples drawn at the end of 90 and 120 min of the smoking process.

Samples smoked for 5 h had an average smoke concentration of 1.773 mg/10 g wb. The concentration of smoke compounds of each slice was quite uniform throughout the cheese block. However, the concentration of smoke compounds was too high for these samples and the samples were deemed organolaptically unacceptable.

Determination of mass diffusivity of smoke compounds in cheese during smoking

Fig. 3 shows the results of computation of the phenol ratio based on Eq. 1. The ratio is 1 at the beginning of the smoking process and drops over the smoking time following an exponential function. It was assumed that after 5 h of smoking, the phenolic compounds in a block of cheese would reach their equilibrium. The average value of phenol in the block at that time was measured to be 1.773 g/10g wb with a standard deviation of ± 0.028 (Table 1). Therefore, the left hand side of Eq.1 gives the value of zero as the final phenol content is equivalent to the phenol content at equilibrium. By rearranging the right hand side of Eq. 1, the Fourier number was calculated and the effective diffusivity was determined to be 0.1 cm^2/min which was determined based on Eq. 2. The calculated (based on Eq. 1) average phenol ratio is shown in Fig 3 as the solid line. The symbols indicate the average measured values.

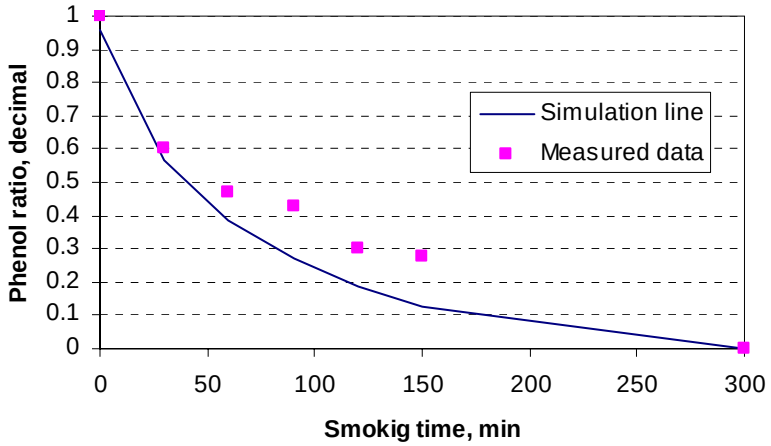

Fig. 3 The average phenol ratio $\left(\frac{\bar{P}(\theta) - Pe}{Po - Pe}\right)$ change over the smoking period. The symbols indicate the average measured values. The solid line was created based on Eq. 1 and calculated based on the effective diffusivity of 0.1 cm^2/min.

The effective diffusivity coefficient determined based on Eq. 1 was then used in Eq. 3 and the results of calculations were plotted (solid lines in Figs 4 and 5) for two specific locations in the block of cheese. These were: (i) the outer layer of the block and (ii) the layer in the geometrical centre of the block. These locations correspond to slices 1 and 18 (outer layer) and slices 9 and 10 adjacent to the centre line marked by the symbols in Figs. 4 and 5. The results indicate a reasonable agreement of the predictions with the data measured in the individual slices. More discrepancies between the calculations and the measurements are being seen for the outer layer of the block. This could be caused by a number of reasons including external conditions of mass transfer such as local velocity

of the smoke around the block of cheese, the consistency in the concentration of smoke around the block or the possible loss of moisture in the outer layer of cheese due to drying.

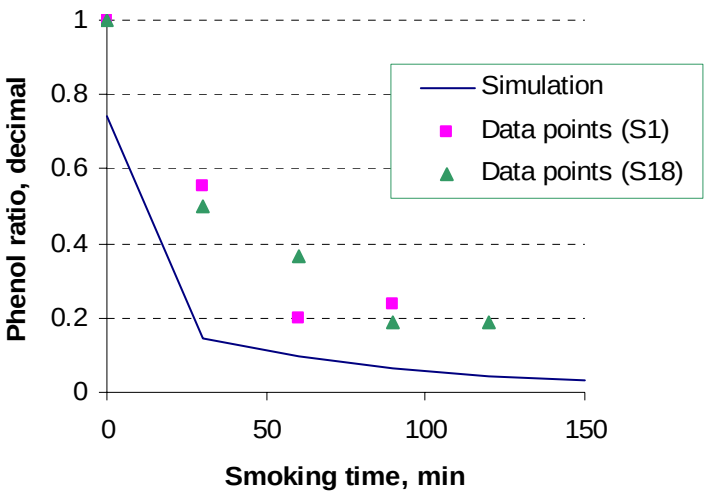

Fig. 4 The change in the phenol ratio over the smoking time. The data points are the measured (n=3) average phenol ratios in the outer layer of a block of cheese (slices 1 and 18). The line shows the prediction results determined based on Eq. 3.

The simulation results of the calculations of the phenol distribution across a block of cheese exposed to smoking are given in Fig 6. The three lines correspond to three locations inside the block of cheese, ie; 0, 2.5, and 4.1 cm from the centre of an 8 cm thick block. The calculations were conducted at the effective diffusivity of 0.1 cm^2/min.

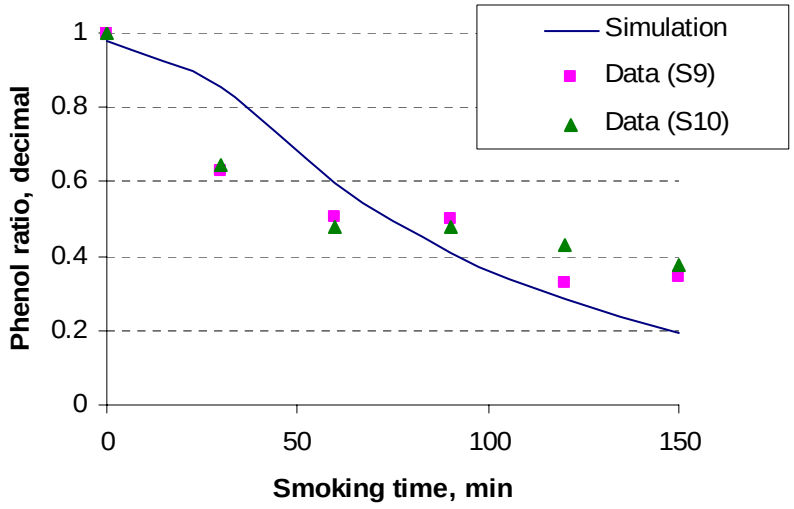

Fig. 5 The change in the phenol ratio over the smoking time. The data points are the measured (n=3) average phenol ratios in the middle of the block of cheese (slices 9 and 10. The line shows the prediction results determined based on Eq. 3.

As expected, the difference in the phenol distribution across the block slowly diminishes with increased smoking time. At the end of smoking process (150 min), there is no difference in phenol concentration between the outer layer and the layer 2 cm into the block. There is still approximately 0.2 mg/10g wb difference between the outer layer and the layer in the center of the block.

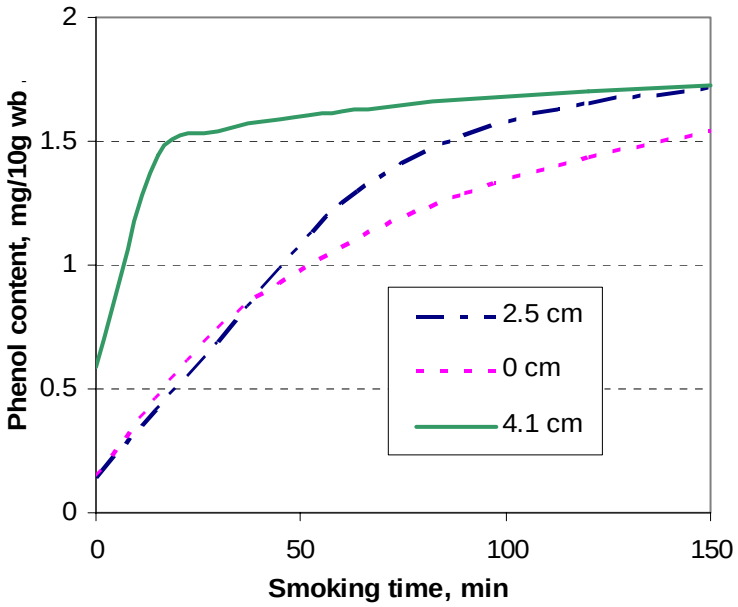

Fig. 6. Simulation results of the phenol distribution across a 9 cm block of cheese. The dotted, dashed-dot, and solid lines show the phenol content change during smoking in a layers located 0, 2,5, and 4.1 cm from the centre of the 9 cm thick block of cheese. The simulation was conducted for the effective diffusivity of 0.1 cm^2/min.

Fig. 7 shows the results of a simulation when the effective diffusivity coefficient was increased to 0.2 cm^2/min. The difference in the phenol content between the outer and the inner layer diminished much faster in comparison to the simulation results shown in Fig. 6. At the end of 150 min of smoking the 9 cm block of cheese had very uniform distribution of smoke across the block. As the coefficient of diffusivity cannot be simply increased, this change in the diffusivity may take place when a different kind of cheese is used in the smoke house.

Computer simulation of penetration of phenolic compounds in smoking of cheese can be useful to predict the distribution of phenol if a block of cheese of different dimensions is used. This computer simulation could be used to optimize the dimension of the block of cheese used in smoking with the objective to determine the smoking time that would yield uniform distribution of the phenolic compounds across the block of cheese.

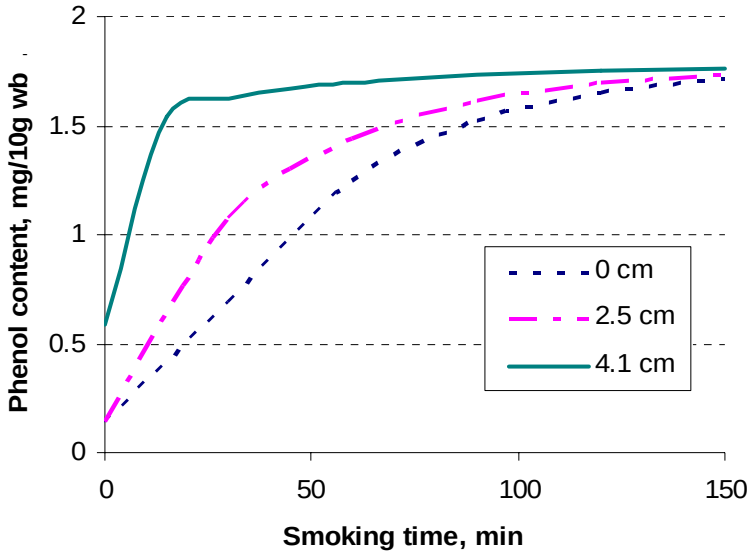

Fig. 7. Simulation results of the phenol distribution across a 9 cm block of cheese. The dotted, dashed-dot, and solid lines show the phenol content change during smoking in a layers located 0, 2.5, and 4.1 cm from the centre of the 9 cm thick block of cheese. The simulation was conducted for the effective diffusivity of 0.2 cm^2/min.

Effect of storage on the concentration of smoke compounds in cheese

The changes in the concentration of phenolic compounds in smoked cheese in storage were monitored every 15 days. Table 3 gives the results for individual slices and Table 4 gives the average values for all the slices in one sample of 25 × 90 × 90 mm dimensions. The average phenol concentration of smoked cheese on day 0 was 1.158 mg/10 g wb (Table 3). It reduced to 1.049 mg/10 g wb after the first 15 days of storage. However, upon subsequent storage, it increased to 1.126 and 2.183 mg/10 g wb on day 30 and 45, respectively. El-Shabrawy et al. (2002) also observed an increase in the smoke phenol content of smoked Ras cheese during first 2 months when stored at 12°-15°C and 80-85% relative humidity for 4 months. The increase in the phenol concentration during first two months was higher in the smoked cheese samples than in the unsmoked cheese samples.

Computer simulation of the smoke distribution in a block of cheese during storage

In mass transfer models when a sample is completely sealed the basic assumption is that a compound cannot change its mass and the compound's magnitude decrease or increase. During storage the phenol content fluctuated and on day 45 almost doubled. Our mass transfer model cannot be applied here to predict the redistribution of phenol across a block of cheese because of internal chemical reactions acting against the mass balance. Therefore, further redistribution of phenol during sealed storage could be only analyzed with empirical relationships.

Conclusions

The average concentration of phenol in a block of cheese sample after initial 30 min of smoking was 0.709 ±0.020mg/10 g wb (range from 0.629 to 0.79 ±0.022 mg/10 g wb). The average value of phenolic compounds increased to 1.285 mg/10g wb after 150 min of smoking. Smoking cheese samples for additional 150 min until the total smoking time was 300 min did not change the phenol content on the outer layer of the block of cheese between 150 and 300 min but the increase in the phenol content was observed for the slices drawn from the middle portion of the cheese block.

The effective diffusivity of smoke through Cheddar cheese calculated based on Fourier number and was determined to be 0.1 cm^2/min.

The average phenol concentration of smoked cheese stored at 4EC on day 0 was 1.158 ±0.026 mg/10 g wb and it reduced to 1.049 ±0.002 mg/10 g wb after the first 15 days of storage. However, upon subsequent storage, it increased to 1.126 ±0.017 and 2.183 ±0.021 mg/10 g wb on storage day 30 and 45, respectively.

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Table 1. Uptake of smoke phenol (mg/10 g wb of cheese) by individual slices in a cheese sample over the smoking time

Block 1, sample M1, smoking time = 30 min								
Slice #	Phenol	Std. Dev.	Slice #	Phenol	Std. Dev.	Slice #	Phenol	Std. Dev.
S1	0.79	0.039	S7	0.674	0.022	S13	0.660	0.011
S2	0.745	0.028	S8	0.667	0.016	S14	0.685	0.016
S3	0.71	0.031	S9	0.66	0.011	S15	0.735	0.028
S4	0.699	0.006	S10	0.629	0.032	S16	0.777	0.032
S5	0.671	0.011	S11	0.629	0.021	S17	0.822	0.016
S6	0.668	0.006	S12	0.653	0.006	S18	0.889	0.034
Block 1, sample M2, smoking time = 60 min								
S1	1.423	0.085	S7	0.921	0.016	S13	0.845	0.022
S2	0.899	0.016	S8	0.882	0.011	S14	0.963	0.0034
S3	0.877	0.016	S9	0.879	0.025	S15	0.906	0.105
S4	0.907	0.006	S10	0.928	0.048	S16	0.9	0.016
S5	0.886	0.013	S11	0.9	0.034	S17	0.893	0.027
S6	0.917	0.016	S12	0.819	0.018	S18	1.121	0.012
Block 2, sample M3, smoking time 90 min								
S1	1.353	0.006	S7	0.882	0.011	S13	1.033	0.03
S2	0.945	0.011	S8	0.875	0.022	S14	0.97	0.012
S3	0.893	0.022	S9	0.882	0.011	S15	0.96	0.022
S4	1.11	0.0158	S10	0.921	0.005	S16	1.026	0.016
S5	1.015	0.006	S11	1.044	0.016	S17	0.963	0.012
S6	0.956	0.018	S12	0.977	0.011	S18	1.44	0.022
Block 2, sample M4, smoking time 120 min								
S1	2.13	0.08	S7	1.31	0.022	S13	1.033	0.015
S2	1.335	0.028	S8	1.237	0.037	S14	1.019	0.011
S3	1.283	0.038	S9	1.187	0.018	S15	1.054	0.012
S4	1.359	0.05	S10	1.008	0.028	S16	1.096	0.024
S5	1.395	0.016	S11	0.952	0.0121	S17	1.128	0.016
S6	1.405	0.024	S12	0.963	0.012	S18	1.444	0.016
Block 3, sample M5, smoking time 150 min								
S1	1.795	0.037	S7	1.184	0.016	S13	1.148	0.016
S2	1.187	0.018	S8	1.198	0.009	S14	1.149	0.016
S3	1.152	0.016	S9	1.166	0.022	S15	1.177	0.011
S4	1.487	0.042	S10	1.106	0.022	S16	1.195	0.005
S5	1.205	0.064	S11	1.04	0.011	S17	1.433	0.022
S6	1.184	0.016	S12	1.029	0.011	S18	2.294	0.038
Block 3, sample M6, smoking time 300 min								
S1	1.75	0.022	S7	1.943	0.058	S13	1.711	0.016
S2	1.718	0.05	S8	1.789	0.029	S14	1.634	0.022
S3	1.837	0.04	S9	1.816	0.054	S15	1.841	0.036
S4	1.764	0.006	S10	1.764	0.031	S16	1.757	0.018
S5	1.806	0.006	S11	1.721	0.033	S17	1.827	0.037
S6	1.823	0.0218	S12	1.665	0.005	S18	1.746	0.028

The standard deviations were determined based on three reading of the absorbance.

Table 2: Uptake of smoke phenol by cheese during smoking process

Smoking time (min)	Average concentration* of smoke phenol (mg/10 g wb of cheese) per block of cheese**
30	0.709 ±0.020
60	0.937 ±0.027
90	1.014 ±0.015
120	1.241 ±0.026
150	1.285 ±0.022

* Values are based on average of concentration of phenol in 18 layers of one cheese block with their corresponding average standard deviations.

** Dimension of cheese block is 25 × 90 × 90 mm (L × W × H)

Table 3. Smoke phenol distribution (mg/g wb of cheese) in individual cheese slices of a $25 \times 90 \times 90$ mm cheese sample over the storage period of 45 days.

Sample # 1, Day 0								
Slice #	Phenol	Std. Dev.	Slice #	Phenol	Std. Dev.	Slice #	Phenol	Std. Dev.
S1	1.353	0.030	S7	1.139	0.005	S13	1.085	0.042
S2	1.271	0.031	S8	1.018	0.013	S14	1.112	0.051
S3	1.263	0.006	S9	0.993	0.095	S15	1.127	0.045
S4	1.215	0.025	S10	1.010	0.033	S16	1.131	0.071
S5	1.173	0.064	S11	1.040	0.107	S17	1.268	0.074
S6	1.158	0.051	S12	1.043	0.072	S18	1.451	0.069
Sample # 2, Day 15								
S1	1.353	0.026	S7	0.935	0.011	S13	0.949	0.006
S2	1.128	0.006	S8	0.935	0.018	S14	0.099	0.021
S3	0.931	0.016	S9	0.896	0.012	S15	1.131	0.016
S4	0.896	0.012	S10	0.864	0.011	S16	1.235	0.056
S5	0.907	0.016	S11	0.864	0.012	S17	1.476	0.006
S6	0.876	0.013	S12	0.914	0.011	S18	1.595	0.022
Sample # 3, Day 30								
S1	1.346	0.011	S7	0.991	0.012	S13	1.072	0.011
S2	1.134	0.028	S8	1.040	0.021	S14	1.065	0.016
S3	1.082	0.021	S9	1.051	0.011	S15	1.181	0.013
S4	0.977	0.021	S10	1.037	0.022	S16	1.251	0.011
S5	0.938	0.016	S11	0.973	0.016	S17	1.507	0.026
S6	0.921	0.022	S12	1.058	0.016	S18	1.672	0.011
Sample # 4, Day 45								
S1	3.081	0.016	S7	1.886	0.016	S13	1.897	0.022
S2	2.520	0.027	S8	1.781	0.022	S14	1.985	0.026
S3	2.575	0.016	S9	1.904	0.021	S15	2.130	0.023
S4	2.125	0.011	S10	1.883	0.018	S16	2.409	0.018
S5	2.125	0.038	S11	1.781	0.012	S17	2.562	0.025
S6	1.992	0.022	S12	1.816	0.016	S18	2.849	0.037

Table 4: Effect of storage on the level of smoke phenol in cheese

Storage time (days)	Average concentration* of smoke phenol (mg/10 g wb of cheese) per block of cheese**
0	1.158 ±0.026
15	1.049 ±0.002
30	1.126 ±0.017
45	2.183 ±0.021

* Values with standard deviations are based on average of concentration of phenol in 18 layers of one cheese block

** Dimension of cheese block is 25 × 90 × 90 mm (L × W × H)