Oil migration in chocolate and almond butter confectionery systems

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ABSTRACT

Oil migration from high oil content almond confections into adjacent chocolate causes changes in product quality. The objective of this study was to quantify the oil migration from almond butter and cream products to dark chocolate. Magnetic resonance imaging (MRI) was used to monitor spatial and temporal changes of liquid lipid content. A multi-slice spin echo pulse sequence was used to acquire images with a 7.8 ms echo time and a 1000 ms repetition time using a 1.03T Aspect AI MRI spectrometer. Samples were prepared as a 2-layer model system of chocolate and almond confection. Four different almond products and one type of dark chocolate were used. Samples were stored at 30°C over a time frame of one month. Rates of migration were quantified by a kinetic expression based on the linear dependence of oil uptake and the square root of the time. Samples showed distinctly different rates of oil migration, as evidenced by quantitative differences in the kinetic rate constants and equilibrium uptake for the different sample types. This work will be helpful to design formulations, processing conditions and storage environments for almond use in confections.

Keywords: diffusion, magnetic resonance imaging (MRI), modelling, oil migration,

INTRODUCTION

Oil migration is a major contributor to product quality loss in composite chocolate products. In particular, liquid oil migrates between the two primary domains, the high fat filling and the enrobing chocolate, resulting in softening of the chocolate and hardening of the filling. This study continues research that characterizes oil migration in chocolate using the spatially and temporally resolved information obtained through magnetic resonance imaging (MRI) techniques. A thorough discussion of recent work is given by Lee et al. [2].

This study examined uptake of almond nut oil in chocolate in a 2-layer system. The objective was to quantify the oil migration from the almond butter and cream products to dark chocolate using a mass transfer model based on Fickian diffusion.

MATERIALS & METHODS

Dark chocolate (Solitaire) was purchased in bulk from Guittard Chocolate Company (Burlingame, CA, USA). The dark chocolate was semi-sweet, ingredients included sugar, chocolate liquor, cocoa butter, soy lecithin and pure vanilla. The cocoa solids content of the dark chocolate was 63%. Unblanched almond butter was provided by Blue Diamond Growers (Sacramento, CA, USA). Almond praline, filling cream and cream turnover were provided from La Morella Nuts, S.A. (Tarragona, Spain). These four products were low moisture, with moisture contents less than 1%. Unrefined almond oil was donated by California Oils Corp (Woodland Nut Oils Division, Woodland, CA, USA).

Sample preparation

Samples were prepared as a model system for filled chocolates, a layer of chocolate and a layer of almond product. Four different almond products and 1 type of dark chocolate were used. Commercial dark chocolate was tempered using a tempering machine (Revolution2, ChocoVision Corp., Poughkeepsie, NY, USA). The dark chocolate was melted by gradually increasing the temperature from 21 to 42.2°C. The appropriate amount of seed chocolate crystals (0.16 g seed/g chocolate) was then added to the chocolate. The temperature was decreased from 42.2 to 32.2°C. The chocolate was gradually cooled to 31.5°C.

Plastic cylindrical containers were used for individual samples. The dimensions of the sample container were 2.29 cm ID and 3.78 cm in height. A layer of tempered chocolate was deposited in the sample container. The samples were stored at 30°C for 7 days to fully crystallize and equilibrate the chocolate. A layer of almond product was then deposited on the chocolate layer. The thickness of each layer was approximately 1 cm. The mass of chocolate was 6.14 ± 0.01 g; the mass of almond product ranged from 6.49 to 7.39 g, depending on the product type. All samples were made in replicate and stored in a controlled temperature chamber at...
The sample containers were removed from the chamber and evaluated at room temperature (20°C) using a magnetic resonance imaging technique. The samples are illustrated in Figure 1.

![Figure 1](image-url)

**Figure 1.** Four samples types described in Materials & Methods.

**MRI measurements**

MRI measurements were performed on a 1T Aspect AI magnet with 44 MHz for 1H-resonance frequency (Aspect AI, Netanya, Israel), using a 60 mm ID solenoid coil. A multi-slice spin echo pulse (MSSE) sequence was used to acquire images with a 7.8 ms echo time and a 1000 ms repetition time. The field of view was 50 mm for a 128x128 pixel image; eight images in the sagittal plane were acquired, each with a slice thickness of 5 mm. For data analysis, signal intensity values from the central slice (slice 5) were evaluated. Data were corrected for day-to-day signal variations of the spectrometer. Image analyses were performed using MatLab v.7.10 (The MathWorks, Inc., Natick, MA, USA).

**RESULTS & DISCUSSION**

Similar to the peanut butter filling/chocolate systems reported by Lee et al. [2], diffusion was expected to be the dominant mechanism for oil migration in the almond product/chocolate systems. Following the same approach, one dimensional mass transfer of nut oil to chocolate was characterized by Fick's 2nd law. The concentration profile was integrated to yield a mass uptake of liquid almond oil, \( M_t \), by the chocolate. Typically given as a dimensionless quantity, \( \frac{M_t}{M_\infty} \), where \( M_\infty \) is the uptake at long times, the analytical solution given as a series in [1] can be approximated by

\[
\frac{M_t}{M_\infty} = kt^{1/2}
\]

where \( k \) is a rate parameter. In order to evaluate the rate parameter, MR images that yield spatially resolved signal of liquid oil were acquired over a time frame of one month for each of the four types of samples. Figure 2 illustrates a representative MR image; this sample was unblanched almond butter over a layer of chocolate.

High signal intensity, given as bright or light on the grey scale, indicates high signal from liquid oil. The unblanched almond butter has high signal due to the fat content at over 57%, all fat being in the liquid state. Chocolate has lower signal intensity and is visible directly beneath the almond butter layer. Although also a high fat content product at 33%, it has fat in both liquid and solid states. Under the MR imaging conditions, only liquid fat contributes to the MR signal. The internal almond oil reference is seen at the left of the image. At the right in Fig. 2, signal intensities from the center section of the sample were averaged to create a one dimensional profile; the profile illustrates the high signal intensity in the almond layer and the lower signal in the chocolate layer. Over time the distribution of signal changes as the liquid almond oil moves into the chocolate region.

Figure 3 illustrates data taken over the first week after sample preparation for the four sample types (a-d). The open symbols indicate the signal intensity per volume for the almond products. At the initial time (\( t=0 \)), the signal intensity is different for each product; the highest signal intensity/volume values were for the unblanched almond butter, which had a fat content of 57%. In contrast the signal intensity/volume for almond praline reflected the lower fat content at 30%. The initial signal intensity/volume for the chocolate layer reflected the lower liquid fat content of that region.
Figure 2: At left, the MR image of the two layer unblanched almond butter and chocolate sample, immediately after preparation \((t=0)\). Axes represent pixel numbers (1-128). At right, the 1D profile is the signal intensity profile of the sample in the vertical direction from top (almond butter, rows 48-76) to bottom (chocolate, rows 77-98), averaged over columns 50-80.

To quantify oil uptake in the chocolate region, the differences in signal intensity/volume at time \(t\) and at \(t=0\) were evaluated. The uptake at long times, \(M_\infty\), was determined by the same difference at \(t \to \infty\) (e.g. one month). The normalized uptake values \((M_t/M_\infty)\) were plotted against the square root of time to determine the best fit for the rate parameter, \(k\). The values of this rate parameter varied from 0.064 to 0.078 hr\(^{-1/2}\) and are given in Table 1 with the 95% confidence interval values and the coefficient of determination, \((R^2)\). Given that the almond oil was penetrating the same type of chocolate, the values of the rate parameter are relatively close. However the extent of migration was significantly different for the different almond products. The greatest amount of oil migrated from the unblanched almond butter and the almond praline to the chocolate, quantified by \(M_\infty\) at 1.56 (Table 1). These two almond confections are more similar to each other in composition and consistency than the creams (e.g., Cream turner and Filling cream) which are considered 4th range products formulated from finely ground nuts mixed with selected cocoa and other ingredients.

Table 1. Rate parameter \((k)\) and equilibrium uptake \((M_\infty)\) for samples stored at \(T=30^\circ C\).

<table>
<thead>
<tr>
<th>Almond product</th>
<th>(k) (hr(^{-1/2}))</th>
<th>(R^2)</th>
<th>95% CI (low)</th>
<th>95% CI (high)</th>
<th>(M_\infty) (expt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almond praline</td>
<td>7.7 x10(^{-1})</td>
<td>0.81</td>
<td>1.1 x10(^{-1})</td>
<td>1.3 x10(^{-1})</td>
<td>1.56</td>
</tr>
<tr>
<td>Cream turner</td>
<td>7.8 x10(^{-1})</td>
<td>0.94</td>
<td>0.88 x10(^{-1})</td>
<td>0.97 x10(^{-1})</td>
<td>1.18</td>
</tr>
<tr>
<td>Filling cream</td>
<td>7.3 x10(^{-1})</td>
<td>0.79</td>
<td>0.59 x10(^{-1})</td>
<td>0.70 x10(^{-1})</td>
<td>0.88</td>
</tr>
<tr>
<td>Unblanched almond butter</td>
<td>6.4 x10(^{-1})</td>
<td>0.93</td>
<td>0.93 x10(^{-1})</td>
<td>1.04 x10(^{-1})</td>
<td>1.56</td>
</tr>
</tbody>
</table>

CONCLUSION

This work describes the rate and extent of oil migration from four almond products to dark chocolate using a kinetic expression based on Fick’s 2nd law. The storage temperature of 30\(^\circ\)C represents conditions of accelerated shelf life and resulted in significant oil migration in less than one week for the model systems. This work is a step toward the design of confectionery products based on knowledge of the kinetics of oil migration during storage.

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Figure 3. The MR signal intensity per volume over time is given for the four sample types (a-d); the replicates for the almond region are given as open symbols, the replicates for the chocolate region are given as closed symbols. The solid horizontal line is the average signal intensity per volume for the entire sample.

REFERENCES