Modeling the structural changes of tortilla chips during frying

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Abstract

Monte Carlo simulation was used to model structure changes in tortilla chips during frying. The results were analyzed using Ensight™ (CEI, Morrisville, NC), a Scientist’s, plotting tool. Cluster identity (oil, water, air, solid), number of clusters, cluster size, and mean size were determined. Cluster statistics were further provided for different frying conditions.

The model predicted maximum oil absorption in a control tortilla chip during the first 10 s of frying, which coincided with maximum water evaporation also observed during the first 10 s of frying. Maximum pore expansion occurred between 30 and 40 s of frying. Steam baking the tortilla chip prior to frying caused the formation of a tight barrier on the surface due to starch gelatinization. This surface prevented water evaporation as well as oil absorption. Higher initial moisture contents provided for an increasing porosity in the product, from 47.12% to 54.04%.

Freeze-dried tortilla chips had higher internal oil content because smaller pores spread over the matrix provide a larger surface area and higher capillary pressures. The smaller pores are due to the absence of a tight barrier along the tortilla’s surface, as freeze-drying does not cause starch gelatinization (no heat treatment prior to frying).

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1. Introduction

Deep fat frying is a complex process involving simultaneous mass and heat transfer. The quality of products produced by deep fat frying is mainly dependent on the frying conditions, which determine the oil distribution within the product and its texture and flavor characteristics.

Several simplified models of the frying process incorporating different frying conditions have been developed. One-dimensional models of fried food materials were developed using finite difference techniques (Farkas, 1994; Yansaengsung & Moreira, 2002). The fact that the physical properties of the material vary with different frying conditions including temperature of the oil has made theoretical treatment of deep-fat frying process very difficult. The energy and mass conservation equations governing the frying process are highly nonlinear, as a result analytical solutions are oversimplified and one must resource to numerical and stochastic analysis.

Stochastically modeling a fried product and simulating its three-dimensional structure during frying will enable a better control of the frying process. Simultaneously, product quality can be enhanced by a better understanding of the spatial distribution of the several components (oil, water, air, and solids) within the product.

The snack food industry represents $19 billion annually and tortilla chips represent 31.5% of the market. Recently consumer demand for fat free snacks has led to the development of low fat alternatives for snack production. The production of fat free snacks relies upon three-dimensional modeling of oil absorption within the porous media in the food product as frying takes place.

Porous media has been characterized and modeled in the areas of ground water contamination, reservoir characterization for hydrocarbon production, and polymer injection. Three-dimensional modeling of porous media in food materials can be very useful for understanding permeability, thermal conductivity, and other tensorial properties of the product. The stochastic model of a tortilla chip can be used to better understand oil distribution within the product to design it better.

This paper presents: (a) a stochastic realization of the three-dimensional structure of a tortilla chip including the spatial distribution of its major components (oil,
water, air, and solid matrix); and (b) an analysis of the effect of different frying conditions upon the cluster size and frequency of the tortilla chip components (oil, water, air and solid matrix) within this 3-D structure.

2. Theory

2.1. Percolation theory

Percolation theory is defined as the “study of clusters”. A porous media can be defined by a set of abstract objects called sites and by bonds (or paths) connecting these sites. A medium consisting of two or more types of material randomly distributed is considered as a network. A material (fluid) wets a site when it succeeds in reaching it through the bonds. A porous medium can be represented as a two- or three-dimensional lattice. The number of nearest neighbor sites to any site in the network is called the coordination number, \( Z \). It can also be defined as the number of bonds incident to a site. In a square network, \( Z = 4 \), and in a simple cubic network, \( Z = 6 \). Based on percolation theory, the following assumptions were made in the conceptualization of the model (Moreira & Barrufet, 1996).

1. The components within the tortilla chip follow certain pre-determined distributions.
2. A cluster is a set of sites of the same kind that are linked to each other by connecting bonds.
3. Two or more sites are considered neighbors if they have an adjacent bond.
4. Oil and water in the matrix have a constant density throughout the frying process.
5. Solid density in the matrix refers to its carbohydrate density and it also remains constant throughout the frying process.

2.2. Lattice labeling system

A three-dimensional mesh of \( 90 \times 90 \times 10 \) dimensions was generated using a Monte Carlo technique and a normal probability density function was used to allocate the different tortilla chip components to the nodes within this matrix.

The allocation of components was constrained to satisfy the volumetric balance provided by Eq. (1):

\[
V_{TC} = \frac{m_{\text{water}}}{\rho_{\text{water}}} + \frac{m_{\text{oil}}}{\rho_{\text{oil}}} + \frac{m_{\text{solid}}}{\rho_{\text{solid}}} + \frac{m_{\text{air}}}{\rho_{\text{air}}}
\]

where \( V_{TC} \) is the control volume of the tortilla chip, \( m_{\text{water}} \), \( m_{\text{oil}} \), \( m_{\text{solid}} \), and \( m_{\text{air}} \) are the masses of water, oil, solids, and air contained in this volume \( V_{TC} \); \( \rho_{\text{water}} \) is the density of water (kg/m\(^3\)), \( \rho_{\text{oil}} \) the density of oil (kg/m\(^3\)), \( \rho_{\text{solid}} \) the density of solid (kg/m\(^3\)), and \( \rho_{\text{air}} \) the density of air (kg/m\(^3\)) in the tortilla chip.

The following occupational rules were established:

1. Water molecules that escape the porous matrix during frying can be replaced only by oil or by air (pore).
2. Oil, water, and air (pore) clusters are dynamic, and change in size and location during frying but are constrained to satisfy Eq. (1).
3. Solid clusters are fixed throughout the process, i.e. a solid site cannot be replaced either by air, water, or oil.
4. Existing pore space can be invaded only by air or oil.
5. Oil initially present in the matrix (from raw material composition) cannot be replaced.

A node (site) with the identification and labeling of neighbors is given by Fig. 1.

2.3. Multi-cluster analysis

As the sites of the lattice are being occupied a multi-cluster analysis takes place concurrently. The code written to carry out these computations was based on a technique to label and count clusters of the same component using percolation distribution by Hoshen and Kopelman (1976). This algorithm was modified and expanded later by Moreira and Barrufet (1996) to include clusters of different identity (oil, water, solid, air). Once the lattice size and structure is determined, the random numbers of each site of the lattice are checked against pre specified probabilities to determine whether the site is classified as oil, solid, water, or gas and it searches for neighbors according to the nature of the occupied site. If no neighbors are found, the site receives a new cluster number. If neighbors are found a cluster number is assigned to the site. The lowest cluster numbers is assigned to the current site. This procedure requires storing the cluster numbers of oil, water, solids
and air sites and updating and relabeling them based on cluster coalescence using the definition of neighboring sites (or nodes). Each cluster is characterized as a vector with three attributes. One indicates the cluster identity (oil, water, solid, air), the second indicates the number of sites belonging to that cluster, and the third is an identification number that allows for cluster coalescence. Once the whole lattice and its contents have been defined this number indicates the number of existing clusters of a particular size and identity. That is, 
\[ C(x, n, k) \]
where \( x = \text{oil, water, solid, air}; n = \text{number of sites in cluster } C; k = \text{number of clusters of size } 'n' \) — also known as the cluster number.

If two oil clusters are found to be neighbors through one (or more) site these coalesce and form a new cluster. The number of sites of each cluster is updated and the new cluster identification number is taken as the smallest number. The following substitution would take place for two neighboring clusters.
\[ C(\text{oil, 3, 4}) \cup C(\text{oil, 5, 8}) \Rightarrow C(\text{oil, 8, 4}) \]

From this procedure, a larger number of clusters indicates a lesser spread of the component in the matrix. The total number of sites in the lattice is provided by Eq. (4).

\[ N = \sum_x N_x \quad x = \text{oil, water, air, solid} \]

Knowing the number of clusters and the cluster size, the total number of nodes (sites) occupied by a component in the three-dimensional matrix can be calculated using Eq. (5):

\[ N_x = \left( \sum_k C_k \times n_k \right)_x \]

where \( C_k \) is the cluster size, and \( n_k \) is the number of clusters of size \( C_k \). The mean cluster size can be determined using Eq. (6):

\[ \bar{C}_x = \frac{N_x}{(\sum n_k)_x} \]

where \( \bar{C}_x \) is the mean cluster size of component \( x \) in the three-dimensional lattice. A low mean cluster size indicates poor connectivity with many isolated and small clusters, while large mean cluster values indicate a higher degree of wetting for the particular element. The fraction occupied by a component using the 90 \( \times \) 90 \( \times \) 10 matrix of this study is calculated using Eq. (7):

\[ v_x = \frac{N_x}{N} \]

The sites were filled with different components consecutively by generating pseudo random numbers between 0 and 1. The spatial allocation of individual components was based on conditional probabilities satisfying the material and volumetric balance of Eq. (1). That is the probability of a given site to be occupied with a component cannot be greater than the volumetric percentage of that particular component. Once the contents of a site have been determined they cannot be occupied by other components, thus there is no interference or spatial overlapping. This process was carried out individually for all the components and the resulting three-dimensional lattices were stored in separate files to be visualized.

2.4. Normally distributed components

To normally distribute components within a matrix, routine RNNOA from the IMSL library for FORTRAN 77 was used. The routine is available with Visual Numerics Inc. (Houston, Texas). The routine generates pseudorandom numbers from a standard normal (Gaussian) distribution using an acceptance/rejection technique developed by Kinderman and Ramage (1976). The routine represents the normal density as a mixture of densities over which a variety of acceptance/rejection techniques based on the work by Marsaglia (1964).

2.5. Simulations and isosurface generation

The entire lattice of dimensions 90 \( \times \) 90 \( \times \) 10 was visualized using an Engineer’s plotting software called ENSIGHT developed by Computational Engineering International, Inc. (Morrisville, North Carolina).

The individual components were loaded on the mesh as variables. The variables were visualized by generating Isosurfaces on the surface of the cubic mesh. Isosurfaces are surfaces that follow a constant value of a variable through three-dimensional elements. Isosurfaces are to three-dimensional elements what contour lines are to two-dimensional elements. At each node of the three-dimensional variable the isosurface’s variable has a value. The isosurface creates elements across the nodes that share the same isosurface value.

Ensight™ Gold data consists of case, geometry, and variable files. The variable files are contained on disk files, one variable per file. Additionally, for multiple time steps, a set of disk files for each time step (transient multiple file-format) is used.

The Ensight™ Gold format supports both structured as well as unstructured data. There is no global coordinate array that each part references, but instead—each part contains its own local coordinate array. Thus, node numbers in element connectivities refer to the coordinate array index, not an id or label. Fig. 2 illustrates a three-dimensional view of the tortilla chip using a mesh of 90 \( \times \) 90 \( \times \) 10.
Fig. 2. Three-dimensional mesh with 81,000 cubes of equal size.

Fig. 3. The 3-D micro-structure of a control tortilla fried from 0 to 60 s.

Water sites  Solid sites  Pore sites  Oil sites

Fig. 3. The 3-D micro-structure of a control tortilla fried from 0 to 60 s.
3. Results and discussion

Several frying conditions were set according to the experiments performed by Kawas (2000). The code was run on a Power Challenge 10000 XL supercomputer, a shared memory parallel machine based on a MIPS R10000 processor. The processor is a 64-bit superscalar CPU running at 200 megahertz, capable of performing up to 2 integer and 2 floating-point simultaneous operations per clock cycle, for a peak performance of 400 MegaFLOPS. The system also has 100 Gigabytes of disk, organized as 33 drives. The results were in confirmation with the experimental data.

3.1. Nodal and mean cluster volume

The average weight of a control tortilla chip after frying was 3 g (Kawas, 2000) with a density of 660 kg/m³. Based on the data the volume of the tortilla chip is given by Eq. (8):

\[ V_{TC} = \frac{M}{\rho} \quad (8) \]

where \( V_{TC} \) is volume, \( M \) is mass, and \( \rho \) is density of the tortilla chip. The volume of the tortilla chip given by Eq. (8) is 4.55 cm³. The volume occupied by each node of our lattice (81,000 nodes) is calculated using Eq. (9):

\[ v = \frac{V_{TC}}{N} \quad (9) \]

Based on this calculation the node volume \( v \) is 0.5617 μm³. The mean cluster size in terms of volume is given by Eq. (10):

\[ \bar{C}_v = \bar{C}_x \times v = 0.5617 \times \bar{C}_x \quad (10) \]

where \( \bar{C}_v \) is the mean cluster volume for the \( x \) component in μm³.

3.2. Control tortillas

The three-dimensional realizations for the tortilla chips fried for 0, 10, 40, and 60 s are shown in Fig. 3. From the simulated results, oil nodes occupied 1.14% and 15.98% of the total volume at the start and end of frying, respectively (Table 1). An increase in the mean oil cluster size from 0.85 to 1.02 μm³ was observed from 0 to 60 s of frying.

At the start of frying, most of the oil is concentrated along the surface of the product. The inner moisture is converted to vapor creating a pressure gradient. During the first 10 s of frying, the maximum oil absorption was

<table>
<thead>
<tr>
<th>Component</th>
<th>( N_N )</th>
<th>( \text{Vol}(N_N) ) [%]</th>
<th>( M_C )</th>
<th>( M_{CV} ) (μm³)</th>
<th>( \text{Vol}(M_C) \times 10^3 ) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 s of frying</td>
<td>\begin{tabular}{l} Water \ Oil \ Pores \end{tabular}</td>
<td>\begin{tabular}{l} 26,985 \ 924 \ 27,079 \end{tabular}</td>
<td>\begin{tabular}{l} 33.31% \ 1.14% \ 33.43% \end{tabular}</td>
<td>\begin{tabular}{l} 2.3 \ 1.5 \ 7.4 \end{tabular}</td>
<td>\begin{tabular}{l} 1.30 \ 0.85 \ 4.19 \end{tabular}</td>
</tr>
<tr>
<td>10 s of frying</td>
<td>\begin{tabular}{l} Water \ Oil \ Pores \end{tabular}</td>
<td>\begin{tabular}{l} 10,764 \ 12,940 \ 31,324 \end{tabular}</td>
<td>\begin{tabular}{l} 13.28% \ 15.97% \ 38.67% \end{tabular}</td>
<td>\begin{tabular}{l} 1.6 \ 1.8 \ 11.8 \end{tabular}</td>
<td>\begin{tabular}{l} 0.91 \ 1.02 \ 6.69 \end{tabular}</td>
</tr>
<tr>
<td>20 s of frying</td>
<td>\begin{tabular}{l} Water \ Oil \ Solids \end{tabular}</td>
<td>\begin{tabular}{l} 5100 \ 11,816 \ 25,910 \end{tabular}</td>
<td>\begin{tabular}{l} 6.29% \ 14.58% \ 31.98% \end{tabular}</td>
<td>\begin{tabular}{l} 1.2 \ 1.7 \ 30.4 \end{tabular}</td>
<td>\begin{tabular}{l} 0.68 \ 0.97 \ 17.23 \end{tabular}</td>
</tr>
<tr>
<td>40 s of frying</td>
<td>\begin{tabular}{l} Water \ Oil \ Pores \end{tabular}</td>
<td>\begin{tabular}{l} 1386 \ 12,259 \ 41,273 \end{tabular}</td>
<td>\begin{tabular}{l} 1.71% \ 15.13% \ 50.95% \end{tabular}</td>
<td>\begin{tabular}{l} 1.0 \ 1.8 \ 40.6 \end{tabular}</td>
<td>\begin{tabular}{l} 0.57 \ 1.02 \ 23.02 \end{tabular}</td>
</tr>
<tr>
<td>60 s of frying</td>
<td>\begin{tabular}{l} Water \ Oil \ Pores \end{tabular}</td>
<td>\begin{tabular}{l} 931 \ 12,943 \ 41,154 \end{tabular}</td>
<td>\begin{tabular}{l} 1.14% \ 15.98% \ 50.81% \end{tabular}</td>
<td>\begin{tabular}{l} 1.0 \ 1.8 \ 44.6 \end{tabular}</td>
<td>\begin{tabular}{l} 0.57 \ 1.02 \ 25.28 \end{tabular}</td>
</tr>
</tbody>
</table>

\( N_N \) is total nodes, \( \text{Vol}(N_N) \) is volume occupied by nodes, \( M_C \) is mean cluster size, \( M_{CV} \) is mean cluster size in terms of μm³, \( \text{Vol}(M_C) \) is volume occupied by mean cluster size in terms of %.
observed, given by an increase in oil nodes from 924 to 12,940. Volumetrically oil occupied 1.14% and 15.97% of total volume at 0 and 10 s of frying respectively (Table 1).

Initially, moisture evaporates at a rapid rate. The decrease in moisture is accompanied by a simultaneous increase in temperature. Starch gelatinizes resulting in an expansion of capillary pores. Oil adheres to the surface and flows into the product through the dented parts. As frying progresses, most of the water evaporates and oil absorption decreases due to a decrease in interfacial tension. Oil content and volumetric fractions do not change considerably at the latter stages of frying. When the chips are removed from the fryer, an increase in surface tension, and consequently capillary pressure, causes the surface oil to be absorbed into the product.

From simulated results, water nodes occupied 33.31% and 13.28% of the total volume at the start and 10 s of frying respectively (Table 1). The fastest water evaporation rate was observed at this time. The phenomenon can be observed effectively by an abrupt decrease in water nodes between 0 and 10 s of frying followed by a gradual decrease. The mean water cluster size decreased from 1.3 to 0.91 μm³ in 10 s of frying (Table 1). After 10 s of frying, water evaporation rate decreased due to depletion of moisture in the matrix. At 60 s of frying water occupied 1.14% of the total volume (Table 1) with a mean cluster size of 0.57 μm³ (Table 1).

The bulk density of the chip decreases with frying time while the solid density remains the same (Moreira, Castell-Perez, & Barrufet, 1999). The decrease in bulk density is due to the loss of water resulting in an increase of air sites. This reduction is accompanied by an increase in porosity from 32% to 55% (Moreira et al., 1999). This is validated by this simulation which indicated that pores occupied 33.4% and 50.8% at the start and end of frying (Tables 1 and 2). The steepest increase in pores occurred between 20 and 40 s of frying due considerable mass loss of the tortilla. The volumetric fractions occupied by pores were 47.12% and 50.95% for the frying times, respectively (Table 1). The mass reduction is due to the escaping moisture which is partly replaced by oil and air.

<table>
<thead>
<tr>
<th>Frying time</th>
<th>Mean pore size (μm³)</th>
<th>Vol. fraction (oil)</th>
<th>Vol. fraction (water)</th>
<th>Mean moisture cluster size (μm³)</th>
<th>Vol. fraction (pores)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freeze-dried tortilla</td>
<td>Control tortilla</td>
<td>Steam baked tortilla</td>
<td>Freeze-dried tortilla</td>
<td>Control tortilla</td>
</tr>
<tr>
<td>0</td>
<td>1.19</td>
<td>4.19</td>
<td>43.77</td>
<td>37.92%</td>
<td>33.31%</td>
</tr>
<tr>
<td>10</td>
<td>1.25</td>
<td>6.69</td>
<td>81.36</td>
<td>25.27%</td>
<td>15.97%</td>
</tr>
<tr>
<td>20</td>
<td>1.78</td>
<td>17.23</td>
<td>156.61</td>
<td>32.34%</td>
<td>4.92%</td>
</tr>
<tr>
<td>40</td>
<td>2.04</td>
<td>23.02</td>
<td>252.48</td>
<td>33.41%</td>
<td>6.16%</td>
</tr>
<tr>
<td>60</td>
<td>2.21</td>
<td>25.98</td>
<td>282.64</td>
<td>35.36%</td>
<td>7.08%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vol. fraction (oil)</td>
<td>Freeze-dried tortilla</td>
<td>Control tortilla</td>
<td>Steam baked tortilla</td>
<td>Freeze-dried tortilla</td>
<td>Control tortilla</td>
</tr>
<tr>
<td>0</td>
<td>1.95%</td>
<td>1.14%</td>
<td>1.40%</td>
<td>37.92%</td>
<td>33.31%</td>
</tr>
<tr>
<td>10</td>
<td>25.27%</td>
<td>15.97%</td>
<td>5.24%</td>
<td>20.74%</td>
<td>13.28%</td>
</tr>
<tr>
<td>20</td>
<td>32.34%</td>
<td>14.58%</td>
<td>4.92%</td>
<td>16.04%</td>
<td>6.29%</td>
</tr>
<tr>
<td>40</td>
<td>33.41%</td>
<td>15.13%</td>
<td>6.16%</td>
<td>4.25%</td>
<td>1.71%</td>
</tr>
<tr>
<td>60</td>
<td>35.36%</td>
<td>15.98%</td>
<td>7.08%</td>
<td>1.67%</td>
<td>0.92%</td>
</tr>
</tbody>
</table>

Table 2
Comparison of mean pore sizes in a freeze-dried, steam baked and control tortilla chip and comparison of volumetric fractions occupied by oil and water in a freeze-dried, steam baked, and control tortilla chip

The largest increase in mean pore size occurred between 10 and 20 s of frying. The mean pore size increased from 6.69 to 17.23 $\mu$m$^3$ due to a decrease in oil absorption and an increase in temperature at this stage (Table 1). The chips started to puff resulting in an increase in mean pore size. After 20 s of frying, the increase in mean size was consistent. From the results, maximum pore connectivity and percolation occurred above a threshold volumetric fraction of 31.16% (Fryer & Davies, 2001).

### 3.3. Freeze dried Tortillas

Freeze-drying the chips before frying resulted in no gelatinization of the starch. Fig. 4 gives the simulated results. The pores along the surface remained unaffected as no barrier was formed. Consequently, a larger amount of small pores in the freeze-dried chip facilitated oil absorption during frying and cooling resulting in higher final oil content. Table 2 gives a comparison of the mean pore sizes for the control tortilla chip and the freeze-dried tortilla chip. The results clearly indicate smaller pores in the freeze-dried tortilla chip.

As explained, the smaller pores result in higher total oil content in the freeze-dried tortilla chip. A comparison between the volumetric fractions occupied by oil in a control tortilla and freeze-dried tortilla chip (Table 2) at different stages of frying validates these results.

While frying, water leaves the three-dimensional matrix creates puffs and subsequently pores. Oil enters the matrix through the pores created. Kawas (2000) showed that the final oil content is dependant on the initial moisture content of the tortilla. The higher the initial moisture content, the higher the oil uptake by the tortilla’s structure. Freeze-drying does not aid in moisture removal during the pre-frying phase. Higher moisture content before frying, results in higher internal oil content in the freeze-dried tortilla chip. A comparison of the volumetric fractions occupied by water in a control and freeze-dried tortilla chip (Table 2) validates these results. The mean water cluster size for different frying times is also considerably higher for the freeze-dried tortilla chip (Table 2) indicating larger quantities of accumulated moisture clusters in the freeze-dried tortilla.

### 3.4. Steam baked tortillas

Steam baked tortilla chips are subjected to starch gelatinization prior to frying. Steam baking formed a

![Fig. 4. The 3-D micro-structure of a freeze-dried tortilla fried from 0 to 60 s.](image-url)
tight barrier on the outer surface of the chips due to severe starch gelatinization. This outer layer formed a seal that blocked the oil from flowing into the chips during cooling resulting in low oil content. Subsequently, the volumetric fractions occupied by oil in the steam-baked tortilla (Table 2) are considerably lower than the control tortilla. Fig. 5 provided the 3-D microstructure realizations of a steam-baked tortilla chips for 0–60 s.

Steam baking causes moisture removal from the tortilla's structure. The initial moisture content is considerably lower in comparison to the control tortilla (Table 2). The decreased initial moisture leaving the matrix prevents an abundance of the oil from penetrating the tortilla chip. Thus, the final internal oil content is considerably lower in the steam-baked tortilla. Most of the oil is concentrated along the surface of the product.

Steam baking caused starch gelatinization and a strong barrier was formed during steaming and baking. While frying, the barrier prevented moisture from escaping the matrix. The vapor escaping the matrix created large “pockets” of air. Subsequently, the steam baked tortilla had larger pores in the matrix. A comparison of mean pore sizes in the control and steam-baked tortilla (Table 2) indicates larger pores in the steam-baked tortilla. As the mean pore sizes increase considerably, the pore volumetric fractions are larger than those of the control tortilla chip (Table 2).

4. Conclusions

A stochastic model to represent the spatial distribution of tortilla chip components was developed using a Monte Carlo simulation methodology. The allocation of air, water, oil, and pores to a three-dimensional mesh with 81,000 followed a normal probability distribution function and satisfied material and volumetric balances. Cluster identity, number of clusters, size, and mean size were provided for different frying times and conditions including freeze-dried tortilla chip and steam-baked tortilla chip. Three-dimensional structures and iso-surfaces were plotted using Ensight™ (CEI, Morrisville, NC), a Scientist’s, plotting tool. The following conclusions were obtained:
1. The percentage of the components within the tortilla chips is determined experimentally and material balance is satisfied. Our technique transforms mass percentages into volumetric percentages and these components are distributed within a three-dimensional lattice following a Monte Carlo simulation approach with a probability from a Gaussian distribution function. The uniqueness of our cluster statistics analysis is the determination of the most likely spatial configuration of all elements within a 3-D lattice. Components can be present in a variety of cluster sizes. Small cluster sizes indicate poor connectivity or lack of spreading within the structure, while larger clusters indicate good connectivity and wetting of the structure.

2. The geometrical configurations were visualized using iso-surface plotting. Iso-surfaces can be generated for each individual component to analyze how and where in the structure is a component distributed.

3. Freeze-dried and steam-baked tortilla chips prior frying exhibit significant differences, both in terms of contents and oil and pore size configuration identified as mean cluster sizes. Pores represented 35–55% of the tortilla volumetrically.

References


