Shear strengthening of masonry wallettes resorting to structural repointing and FRCM composites

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Evaluation of drying of edible coating on bread using NIR spectroscopy

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Keywords:

NIR, drying behaviour, PLS regression, Process monitoring

Abbreviations

1L	Single layer of coating
2L	Two layers of coating
a_w	Water activity
B	Bottom crust of the bread
T	Top crust of the bread
EC	Edible Coatings
EF	Edible Films
LV	Latent variable
MC	Moisture Content
PC	Principal Components
RH	Relative Humidity
HSI	Hyper-spectral Imaging
MSC	Multiplicative Scatter Correction
NIR	Near Infrared
PCA	Principal Component Analysis
PLS	Partial Least Square
SVN	Standard Normal Variate
TSS	Total Soluble Solids
RMSE	Root Mean Square Error
RMSEC	Root Mean Square Error Calibration set
RMSECV	Root Mean Square Error Cross Validation set
RMSET	Root Mean Square Error Test set
SAVGOL	Savitzky–Golay derivate

Abstract

Edible coatings are recently gaining attention for potential applications in bakery products to extend the shelf-life and incorporate functional characteristics, like probiotics, antimicrobial or an antioxidant compound, for which drying of the coating is an essential step. The aim of this work was to utilize near infrared (NIR) spectroscopy as a tool to rapidly monitor and develop predictive model for the drying of edible coating on bread (mini-burger buns) surfaces. The buns coated with edible coating were dried at two different temperature regimes, at 25 °C and 60 °C for one layer of coating and one temperature regime at 60 °C for two layers of coating. NIR spectra were collected and moisture content was determined at different drying times. The spectral data were pre-treated and subjected to Principal component analysis (PCA) for discrimination of drying times and subsequently to Partial least squares (PLS) regression for moisture prediction for given temperature, time and surface. Results show that NIR spectroscopy was able to reflect the drying process and discriminate between the various surfaces of bread and times of drying, primarily by the differences in water and protein absorption bands (1940nm, 1500nm, 2050nm). Also, the subsequent PLS regression of the spectral data was found to describe satisfactorily the drying behaviour and the optimal drying moment with RMSE values ≤ 3% for the calibration and cross validation data sets. The procedure proposed could be used for faster quantification of moisture during drying process.

1. Introduction

Bread is a staple food and an important commodity in daily nutrition of many cultures, generally viewed as a perishable product with limited shelf-life that is affected by staling and mould spoilage (Amigo et al., 2016; Licciardello et al., 2017). Staling is a complex phenomenon influencing the textural quality and consumer acceptance of bread contributing to economic losses besides mould growth (Besbes et al., 2014; Chin et al., 2011; Licciardello et al., 2014). Staling of bread is linked strongly to the retrogradation of starch, moisture loss and redistribution resulting in decreased softness, cohesiveness and loss of fresh flavour (Gray and Bemiller, 2003; He and Hoseney, 1990). The objective of bread packaging is to prevent rapid loss of moisture and ensure longer shelf- life. An efficient packaging system not only effectively maintains quality characteristics, but also has lower environmental and cost impacts (Licciardello et al., 2017).

Edible films (EF) and edible coatings (EC) have garnered increasing attention in the past decade as a novel alternative to lower synthetic packaging and improve biodegradability. They can be described as thin layers or films of material formed on the surface of the food or used as stand-alone films that provide protection to food products by acting as moisture, gas and aroma barriers as well as provide secondary functions like anti-oxidant or antimicrobial activity (Falguera et al., 2011; Galus and Kadzińska, 2015). Edible coatings can constitute one or more proteins, polysaccharides and lipids or a combination thereof resulting in composite coatings applied as bi-layer systems or emulsions (Debeaufort et al., 1998; Kester and Fennema, 1986). Edible films and coatings have been proven to improve the quality and shelf-life of foods as shown in various studies and mentioned extensively in reviews (Baeva and Panchev, 2005; Bartolozzo et al., 2016; Campos et al., 2011; Costa et al., 2018; Debeaufort et al., 1998; Dehghani et al., 2018; Ferreira Saraiva et al., 2016; Guldas et al., 2010; Ncama et al., 2018; Otoni et al., 2017; Tongnuanchan and Benjakul, 2014; Yousuf et al., 2018).

In recent studies, application of active films directly onto sliced bread and use of edible coated films for packaging of sliced bread were found to be effective in reducing the mould growth and preserving freshness of bread (Balaguer et al., 2013; Otoni et al., 2014). In few studies related to crumb firming kinetics of cake and cake type products it was observed that the textural changes related to staling were delayed by the use of edible coatings (Baeva and Panchev, 2005; Bartolozzo et al., 2016; Ferreira Saraiva et al., 2016).

These edible coatings are singular or composite materials, generally in their liquid form that are spread or sprayed and dried to render an individual layer on the product surfaces. Hence, drying is considered an important step in the formation of edible coating that influences the water activity of the food. In a study on probiotic breads by Soukoulis et al., (2014) two different temperature and time regimes, a low temperature drying at 60°C for 10 min and high temperature drying at 180°C for 2 min, were utilized to dry coating. Ferreira Saraiva et al., (2016) in their study on efficacy of active coatings dried the coating on *mini-panettone* at 180°C for 5 min. In another study on effect of coating on muffin quality a temperature of 40°C was utilized (Bartolozzo et al., 2016). A significant effect of drying temperatures was found on the crust and crumb moisture contents, which decreased by drying at higher temperatures. However, in our knowledge, no available study relates to the monitoring of drying process and kinetics of edible coat drying when applied onto bread. Thus, it is of importance to understand the drying process in order to dry the coating applied on surface but not of the internal product.

In general, the drying kinetics of foods are evaluated by weight loss and moisture loss during drying for a given temperature and humidity (Di Scala & Crapiste, 2008; Lahsasni, Kouhila, Mahrouz, & Jaouhari, 2004; Planinić, Velić, Tomas, Bilić, & Bucić, 2005). However, analyzing moisture content by oven-drying or vacuum-drying is destructive and time consuming requiring extensive sample preparation, unsuitable for large number of samples and also contributes to product wastage. Different non-destructive techniques based on the electrical, magnetic properties; spectral-scattering and imaging have been developed in the past few years as tools for measuring moisture content and recently for online quality monitoring (Büning-Pfaue, 2003; Chen et al., 2013; He et al., 2014; Mohammadi-Moghaddam et al., 2018; Özdemir et al., 2018; Todt et al., 2006; Wu et al., 2013). Near Infrared (NIR) spectroscopy is one such tool widely applied, with increasing interest in recent times, for online quality monitoring of various food products, particularly cereal and cereal products (Cevoli et al., 2015; Czaja et al., 2018; Foca et al., 2011; Huang et al., 2008; Jirsa et al., 2007; Osborne, 1996; Sørensen, 2009). It is a physical, non destructive method for measuring the physico-chemical properties of foods with high precision and minimal sample preparation.

Several studies utilized NIR spectroscopy in the determination of moisture, protein and other constituents in cereal grains and their products as stated; in which the weak absorption of water molecules facilitates also for the analysis of high moisture foods (Osborne et al., 1984). Suzuki, McDonald, & D'Appolonia (1986) applied NIR to evaluate the moisture, protein and lipid fractions of both dried and fresh bread and found that sample preparation does not increase the accuracy of readings. Sørensen, (2009) in his extensive study described the feasible use of NIR spectroscopy to analyze the composition of wheat and rye breads and found values comparable to that of chemical analyses. Several studies show successful application of NIR for moisture analysis of intact products as well as their evolution during storage, particularly, for factors related to staling in products like cereals, bread, flat breads, biscuits and cakes (Cevoli et al., 2015; Osborne, 1996; Osborne et al., 1984; Wilson et al., 1991; Xie et al., 2003). Other studies related to osmo-air dehydration of blueberries, sulphured drying of Apricots used NIR spectroscopy as a tool to evaluate the drying process and differentiate the pre-treatments (Özdemir et al., 2018; Sinelli et al., 2011). Moreover, the perceived advantages of this method like minimal sample preparation, rapid assessment and scope for assembly in production line make it a suitable choice to provide continuous monitoring of the conditions and detect changes in the product characteristics in a production line. These attributes of NIR spectroscopy can also be extended for evaluating the surface moisture of coated breads during drying.

In this context, the objective of the present study is to use NIR spectroscopy as a tool to evaluate the drying time of coating on the selected bakery product (mini-burger buns) and develop a predictive model for the drying of the utilized edible coating on bread surface.

2. Materials and methods

2.1 Materials

Sodium alginate (Sigma-Aldrich, St. Louis Missouri USA); pectin (derived from Citrus peel, Sigma-Aldrich, St. Louis Missouri USA); whey protein concentrate (80% protein, Products-Gianni SRL, Milan Italy) were used to prepare edible coating solution. Glycerol (≥99.5%) (Sigma-Aldrich, St. Louis Missouri USA) and Tween® 20 (Sigma-Aldrich, St. Louis Missouri USA) were used as plasticizer and surfactant respectively. Industrially manufactured "mini-burger buns" were procured from the local market (Ipercoop, Cesena, IT). The ingredients of the mini-burger buns as per the packaging were wheat flour, water, rapeseed oil, yeast, Glucose-Fructose syrup, sugar, salt and emulsifiers.

2.2 Preparation of coated bread

The film forming solution was prepared by dispersing 1.5% w/w each of pectin, alginate and whey protein concentrate with addition of 33% of glycerol and 3.5% Tween®20 for 100g biopolymer. The dispersion was heated up to a temperature of 75°C for 45 minutes while being continually stirred on a hot plate with magnetic stirrer (ARE Heating Magnetic stirrer, Velp Scientific USA). The solution was subsequently cooled to room temperature and homogenized at 6000 rpm for 1 minute with a homogenizer (Model Ultra-Turrax T-25 digital, IKA). Further, the solution was placed under vacuum (100mb,10 minutes) using a pump (SC 920, KNF ITALY, Milan) in order to degas the solution (Javanmard and Golestan, 2008). The coating solution (pH - 4.7± 0.01, TSS – 5.4 ± 0.06, a_w – 0.97 ±0.001) was then spread onto the surface of mini-burger buns (Height- 30 mm, Diameter – 70 mm, Weight – 25.65 ± 0.7g) with the aid of a clean confectionery brush as a single layer (1L) or two layers (2L) with a 3-minute interval between applications. The average weight of the coating before drying was 2.4 (± 0.2) g for 1L and 3.6 (± 0.2) g for 2L of coating.

2.3 Drying Time Evaluation

The coated bread samples were dried by use of drying equipment (CLW 400 TOP+, POL-EKO Apparatus SP. J) and the moisture content of the Top (T) and bottom (B) surfaces of the breads were evaluated separately. In order to identify the optimal drying time, two temperature regimes were examined, 25°C (50% RH) and 60°C (10% RH) to dry the coating. The samples with single layer of coating (1L) were dried at 25°C and 60°C, while those coated with two layers (2L) only at 60°C (10% RH). The samples were subjected to NIR spectroscopy and moisture content was monitored subsequently at predetermined time intervals, in particular 1L at 25°C every 30 min; 1L at 60°C every 5 min and 2L at 60°C every 10 min.

The moisture content of at least five breads in batches was calculated by carefully separating approximately 1g of bread crust from both top and bottom surfaces, individually onto the aluminium pans of Thermo balance (i-Thermo 163M, Exacta-Optech, Italy). The samples were dried at 130°C until constant weight was achieved. A set of bread samples without coating (Control) at time zero were analyzed in order to identify the initial moisture content of the bread surfaces (T, B) which were considered as the moisture contents to be reached approximately at the optimum drying time of the coated samples.

2.4 NIR spectroscopy

The control and coated samples were submitted to near-infrared spectroscopy (NIR) for acquisition of the spectra using a FT-NIR spectrophotometer (MATRIX ™ -F, Bruker Optics) in diffuse reflectance in the range of 12,000 and 4,000 cm^{-1} (8 cm^{-1} resolution). A schematic representation of the measurement with NIR probe is shown in figure 1. An average of 32 scans were obtained for each sample and for each drying time by placing the optical fiber probe (IN 261, Bruker Optics, Mass., USA) in direct contact with the coated bread surface. The probe is characterized by a diameter of 10 mm and uses a bifurcated fiber bundle to illuminate the sample and collect the refracted light. For each spectrum acquired, the background was acquired by placing the probe in the specific support covered with quartz under the same environmental conditions as the sample (25°C) which was subtracted. The bread was scanned at 3 central points of the top and bottom crust; and subsequently for each surface, the average spectrum of the three acquisitions was calculated.

2.5 Data analysis

Significant differences (at p-level <0.05) between means of the moisture content at different drying times were explored by means of the analysis of variance (ANOVA with post-hoc Tukey HSD); and Kruskal-Wallis test was used if significant differences emerged between variance of means of the Levene test (Statistica-StatSoft, version 7). The NIR spectra acquired on the different bread samples were analyzed by multivariate analyses (The Unscrambler ver. 9.7, CAMO, Oslo, Norway). The first part of the spectra until 1,100 nm was deleted before processing because it contains no useful chemical information, but only instrumental noise. To remove the scatter effects from spectra, the data were normalized by Standard Normal Variate (SNV) or Multiplicative Scatter Correction (MSC); following this the spectra were pre-treated by the Savitzky–Golay derivate, (SAVGOL) to enhance resolution. Spectral data were subjected to Principal Component Analysis (PCA) and Partial Least Square (PLS) regression.

PCA was applied as an exploratory analysis in order to define a possible discrimination among samples dried for different times. PLS, predictive analysis of the water content (dependent variable) was then carried out for both drying temperature and bread surfaces (top and bottom). The predictive power of the obtained models were tested by analyzing the calibration results and by performing the full cross and test set validation. For the test set validation, the dataset was randomly divided into two sub-sets, one to calibrate the system (70% of the entire dataset) and the other (30%) to validate it. To avoid the model over-fitting, the optimal number of latent variables (LV) was chosen by plotting the root mean square error (RMSE) as a function of the number of components and by identifying where the curve reaches a minimum.

3. Results & Discussions

Concerning the drying at 25 °C, the mean moisture content values (%) over the drying time are reported in figure 2, for the top (grey diamond) and bottom (black triangle) surfaces, respectively. The dotted lines identify the moisture content of the control samples at time zero without coating for the top (grey) and for the bottom (black). It can be seen that the moisture content decreased rapidly for about 90-120 minutes and after that tended to reach an equilibrium state. This value was however observed to be influenced by the relative humidity of the drying cabinet (RH=50%). This is because of the proportionality between the humidity ratio at the product surface and the rate of moisture evaporation (Kozempel et al., 2003).

The dispersion around the mean value, especially for the partially dried samples, is probably due to the sample preparation and the non-uniform evaporation of the water from the surface. The crust and crumb separation from the whole bread is not perfect and when the coating is in semi-liquid form (during initial stages of drying), the operation of crust separation was rendered even more complicated. The dotted lines in figure 2 point the moisture content value of the control samples at time zero without coating (top: 19.2±0.2%; bottom: 20.5±0.9%). Comparing these values with those measured at different drying times (table 1), it is possible to observe that these initial values were achieved within 90-120 minutes and at around 120 minutes, for the top and bottom surfaces respectively. However, due to the high variance of the moisture content at same drying time, the optimal drying time for the top surface ranged from 90-120 min and for the bottom surface was at 120 min.

For drying at 60 °C, both one and two layers of coating have been considered and the moisture values are reported in table 1. The moisture content at different drying times are shown in figure 3, for the top (a) and bottom (b) surfaces, respectively. Considering the low relative humidity set up in the cabinet (RH=10%), a rapid decrease of moisture was observed for all samples. This trend is better observed for the samples with 2 layers of coating that dried for longer time. It can be observed clearly, that at any given drying time, the moisture content of the 2L samples is higher than 1L samples until 30 min of drying with the percentage difference being 25.8±10.5% and 26.0±5.1% for the top and bottom surfaces, respectively. After this time, the moisture content of the samples with one layer was not measured as the reference value of the control (top: 19.2±0.5%; bottom: 20.5±0.6%) was achieved. Also in this case, the dotted lines in figure 3 (3a, 3b) indicate the moisture content of the samples at time zero without coating. At the top surface, the optimal drying time was achieved at about 20 min for one layer and 30 min, for two layers; while at the bottom, the time was about 25-30 min and 40-50 min, for one and two layers, respectively. The drying time decreased by about 80% when the drying temperature increased from 25°C to 60 °C, both for the top and bottom surface (1L). Whereas, for the drying temperature of 60 °C, the drying time increased by 50% from one layer to two layers of coating for both the top and bottom surfaces evaluated.

The FT-NIR spectral band characterization was accomplished by comparing wavelengths with published infrared region data (Cevoli et al., 2015; Giangiacomo, 2006; Osborne et al., 1984; Suzuki et al., 1986). The NIR light molecular absorption of coated bread provided characteristic broad and overlapping peaks between 1100 and 2400 nm spectral region. All the analyzed samples show same spectral behaviour and are featured by the main absorption bands of water, protein and fat, as depicted in the representative spectra in figure 4. The

Savitzky–Golay first derivative clearly allowed the extraction of useful spectral band information. As reported by Cevoli et al (2015), at about 1,450 and 1,940, the resonance bands of the O–H bonds related to water and starch were observed, while at about 1,500–1,570 and 2,050– 2,070 nm the presence of N–H bonds can be hypothesized. The absorption peaks at 1,730 1,770 and 2,310 nm correspond to lipids and can be ascribed to the first overtone of a C–H stretch and to C–H_2 group.

The PCA score plots for the NIR spectra concerning the drying at 25°C was performed to discriminate between samples at different drying times. The best results were obtained by using the SNV spectral pre-treatment. As reported in figure 5, for both the bread surfaces (top (5a) and bottom (5b)), a clear separation along the drying time was observed. The samples were arranged along the PC1 (explained variance: 93% and 79%) from right to left, on the basis of the drying time (from 0 to 210 min). The loading plots suggested that the discrimination might be attributed to spectral regions associated with moisture and protein contribution. However, the protein information is submerged in the water bands, for the first overtone concerning 1,500nm (Wu et al., 2013). During the drying, the water evaporates and the protein fraction of the coating remains on the surface of the bread, resulting in the decrease of the moisture fraction and increase of the protein fraction. Similar inference has been found by Bouman et al., (2015) on drying of protein coatings using magnetic resonance imaging. However, a clear distinction was not observed, probably due to the variable moisture content at the same drying time related to non-uniform evaporation of water from the surface. This similar interference of spectra between samples was observed by Sinelli et al., (2011) and Wu et al., (2013) in their studies on dehydration of food products using NIRS and Hyper-spectral imaging (HSI). Moreover, it can be seen that the control samples (C) are placed along the PC1 in the same zone (grey area) of the samples dried for 90-120 minutes and 120-150 minutes, for the top and the bottom surfaces, respectively. These times are very similar to those previously reported in figure 2 and are comparable to the moisture content values.

The score plots obtained from the PCA of the NIR spectra acquired on the samples dried at 60 °C, are reported in figure 6 (6a, 6b). Also for 60 °C, the samples are arranged along the PC1 (explained variance 86% and 94%) from right to left, on the basis of the drying time (from 0 to 30 min for one layer (figure 6a) and from 0 to 60 min for two layers in (figure 6b)). A clear separation between samples at different drying times was observed, especially in the first 20 (1L) and 30 (2L) min of drying. In fact, the moisture content of the top and bottom crust continued to decrease also after these times, which is indicative of moisture loss from the product.

In view of the obtained results, it could be more interesting to define the optimal drying moment rather than the exact drying time, by determining the moisture content using NIR spectroscopy. Following this the spectral data to estimate the moisture content, were subjected to PLS regression and the results are reported in table 2. In general, satisfactory results were achieved for both the temperature and bread surfaces with a R^2 in test set ranging from 0.902 to 0.963. Analyzing the calibration, the full cross and the test set validation, the best model concerns the sample dried at 60 °C and covered by two layers of coating (top: R^2=0.963, RMSET=2.87%; bottom: R^2=0.937, RMSET=3.15%). The errors may be attributable to the moisture reference data that were affected by the samples preparation operations.

4. Conclusion

The results of the presented study show the application of NIR spectroscopy to monitor and identify the drying behaviour of coating on bread surfaces. In particular, PCA analysis of the spectral data was able to differentiate samples on the basis of decrease in moisture content along the drying time. The technique was useful to track the variances evolving mainly from the event of water evaporation, as the spectral differences reflect the resonance bands of the O–H stretch of water. Also, a clear differentiation of different bread surfaces was observed. Furthermore, PLS regression built on the basis of drying temperature and type of surface was found to provide satisfactory results for estimating the optimal drying moment within the tested parameters. The developed method is fast and able to predict in a satisfactory way the moisture decrease of the coating and can be a potential technique to estimate drying times. However, further studies will be needed to verify the drying of the coatings alone and the effect on interaction with substrate.

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Figure Captions

Figure 1: Schematic representation of the NIR measurement: 1) personal computer, 2) NIR device, 3) fiber probe, 4) bread sample.

Figure 2: Moisture content (%) for 1L of coating against the drying time for temperature of 25 °C.

Figure 3: Moisture content (%) for 1L and 2L of coating against the drying time for temperature of 60 °C; a) top surface, b) bottom surface.

Figure 4: Representative NIR spectrum of coated bread and the relative first derivate

Figure 5: PCA Score plots of the NIR spectra of the top (a) and bottom (b) surfaces of the samples dried at 25 °C (C: control samples; 0, 30, 60, 90, 120, 150, 180 and 210 min: samples at respective drying times).

Figure 6: PCA Score plots of the NIR spectra of the top surface of the samples with one layer of coating (a) and two layers of coating (b) dried at 60 °C (C: control samples; 0, 5,10, 15, 20, 25, 30, 40, 50 and 60 min: samples at respective drying times).

Table 1. Moisture content (%) during drying for coated bread with 1 Layer (1L) at 25°C, 1 Layer (1L) at 60°C and 2 Layers (2L) at 60°C

	Time (min)	Moisture content (%)	
		Top	Bottom
25°C	0	49.2±3.4 ^{a}	54.2±5.4^{a}
	30	38.1±2.5 ^{b}	46.5±1.6^{b}
	60	24.7±4.7 ^{c}	39.0±1.4^{c}
	90	21.4±3.4 ^{cd}	25.5±3.0^{d}
	120	17.6±1.4^{d}	22.0±2.4^{de}
	150	16.5±1.6^{d}	17.5±1.3^{e}
	180	15.7±1.2^{d}	17.1±0.4^{e}
	210	16.4±0.4^{d}	18.4±1.2^{e}
60°C 1L	0	47.1±1.5 ^{a}	48.4±4.4^{a}
	5	41.6±0.9 ^{a}	47.8±3.2^{a}
	10	28.5±4.9^{b}	38.1±4.0^{b}
	15	25.0±3.2^{b}	32.2±2.7^{c}
	20	19.7±2.1^{c}	27.8±2.0^{c}
	25	17.3±1.1^{c}	20.9±1.2^{d}
	30	16.0±1.1^{c}	20.0±1.1^{d}
60°C 2L	0	53.5±4.4^{a}	57.9±3.8^{a}
	10	44.8±3.2^{b}	51.9±2.8^{b}
	20	32.0±4.0^{c}	39.9±3.5^{c}
	30	19.2±2.7^{d}	28.8±2.7^{d}
	40	16.7±2.0^{de}	23.9±3.8^{de}
	50	15.1±1.2^{e}	18.7±2.3^{ef}
	60	13.6±1.1^{e}	16.6±1.9^{f}

Mean ± SD in a column without a common superscript letter differ significantly (P<0.05)

Table 2: PLS regression calibration parameters of the NIR spectra for predicting moisture content (%) in coated bread.

		Calibration			Full Cross Validation			Test set		
		LVs	R^2	RMSEC (%)	LVs	R^2	RMSECV (%)	LVs	R^2	RMSET (%)
25°C 1L	Top	1	0.927	2.25	1	0.921	2.45	2	0.918	2.51
	Bottom	8	0.986	1.07	8	0.933	2.28	7	0.922	2.66
60°C 1L	Top	5	0.968	1.58	5	0.950	2.04	5	0.932	2.26
	Bottom	2	0.924	2.84	2	0.914	3.08	2	0.902	3.12
60°C 2L	Top	1	0.973	2.29	1	0.969	2.49	1	0.963	2.87
	Bottom	2	0.958	2.91	2	0.954	3.08	2	0.937	3.15

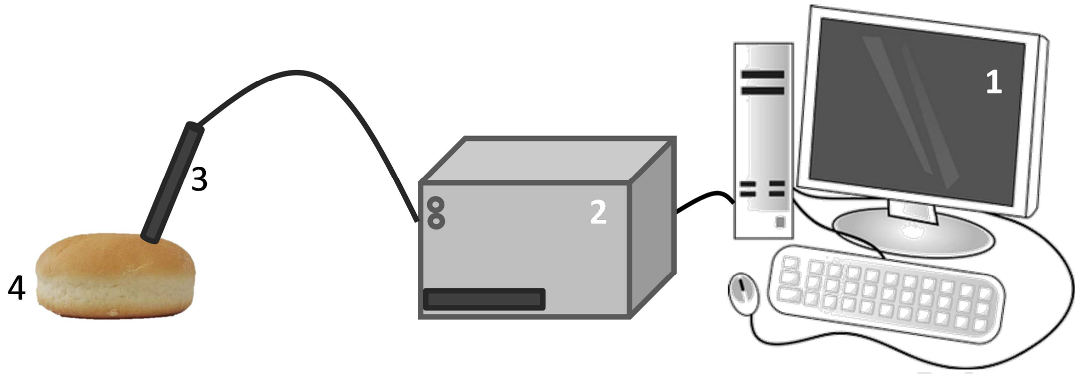
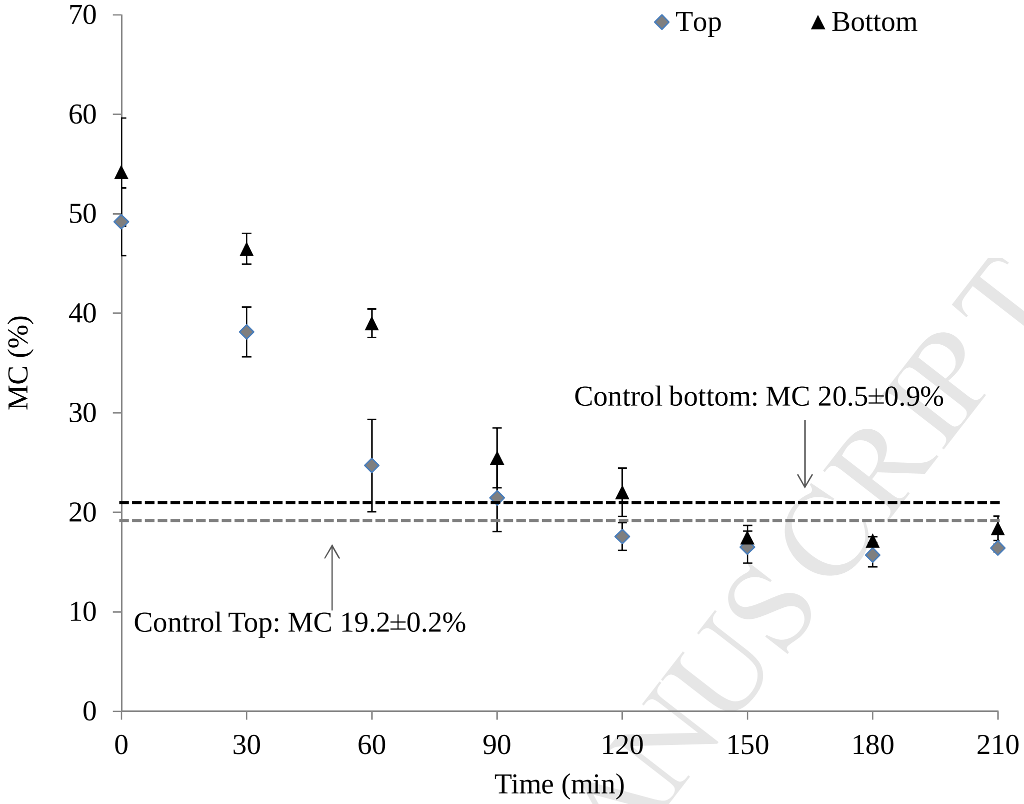


Figure 1



Top
Bottom
MC (%)
Time (min)
70
60
50
40
30
20
10
0
0
30
60
90
120
150
180
210
Control bottom: MC 20.5±0.9%
Control Top: MC 19.2±0.2%

Figure 2.

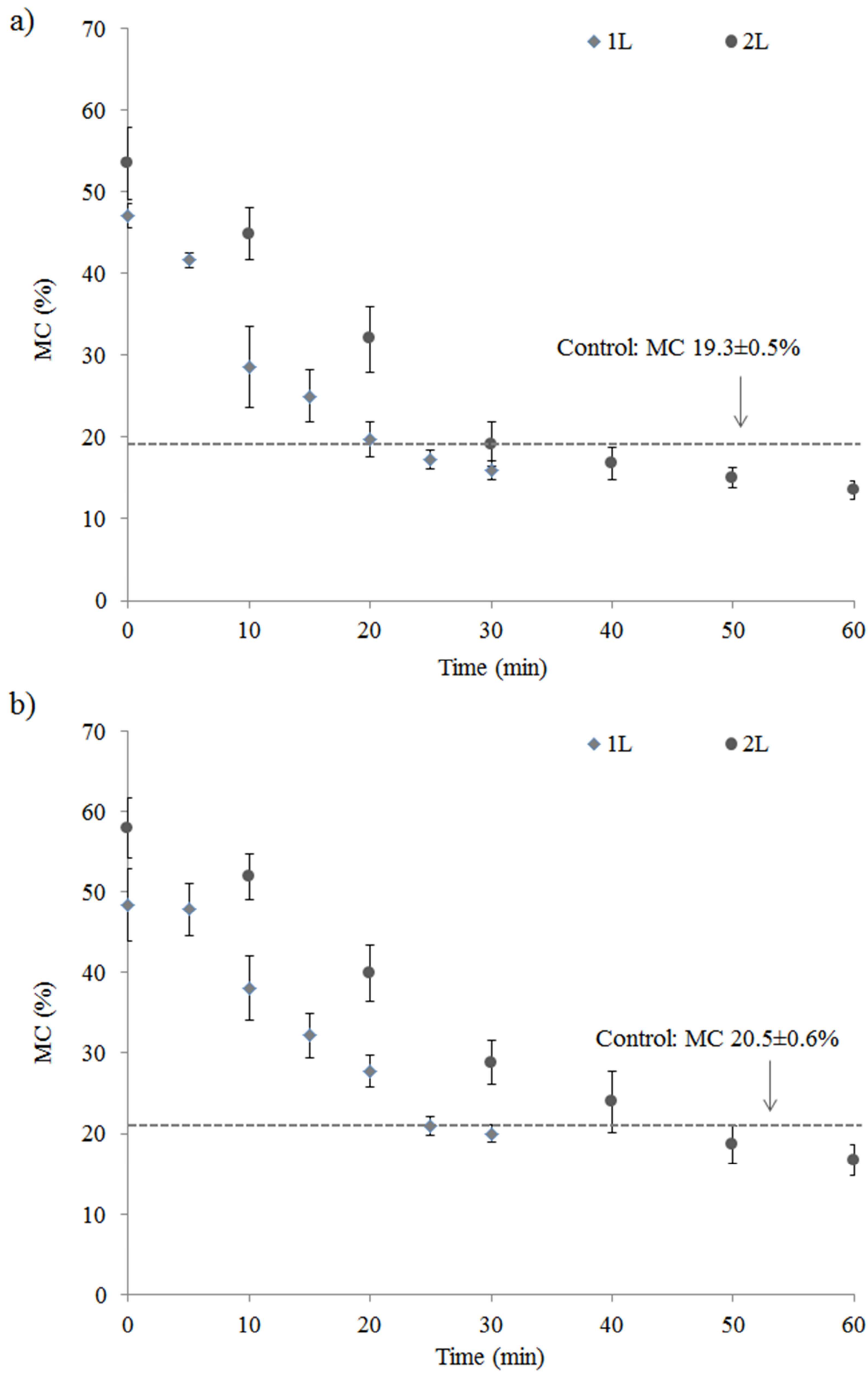
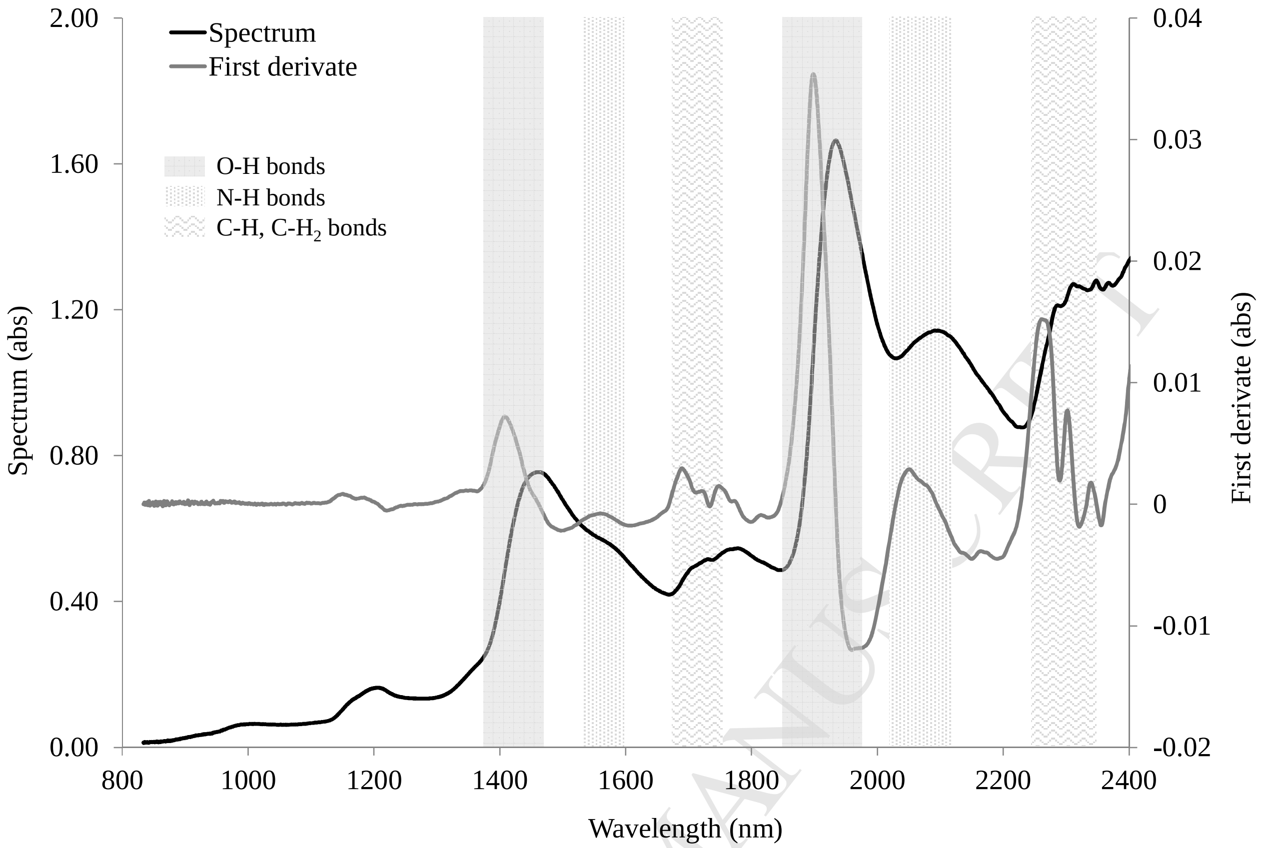

a)
70
60
50
40
30
20
10
0
MC (%)
1L
2L
Control: MC 19.3±0.5%
0
10
20
30
40
50
60
Time (min)
b)
70
60
50
40
30
20
10
0
MC (%)
1L
2L
Control: MC 20.5±0.6%
0
10
20
30
40
50
60
Time (min)

Figure 3.



Spectrum
First derivate
O-H bonds
N-H bonds
C-H, C-H2 bonds
2.00
1.60
1.20
0.80
0.40
0.00
0.04
0.03
0.02
0.01
0
-0.01
-0.02
800
1000
1200
1400
1600
1800
2000
2200
2400
Spectrum (abs)
First derivate (abs)
Wavelength (nm)

Figure 4.

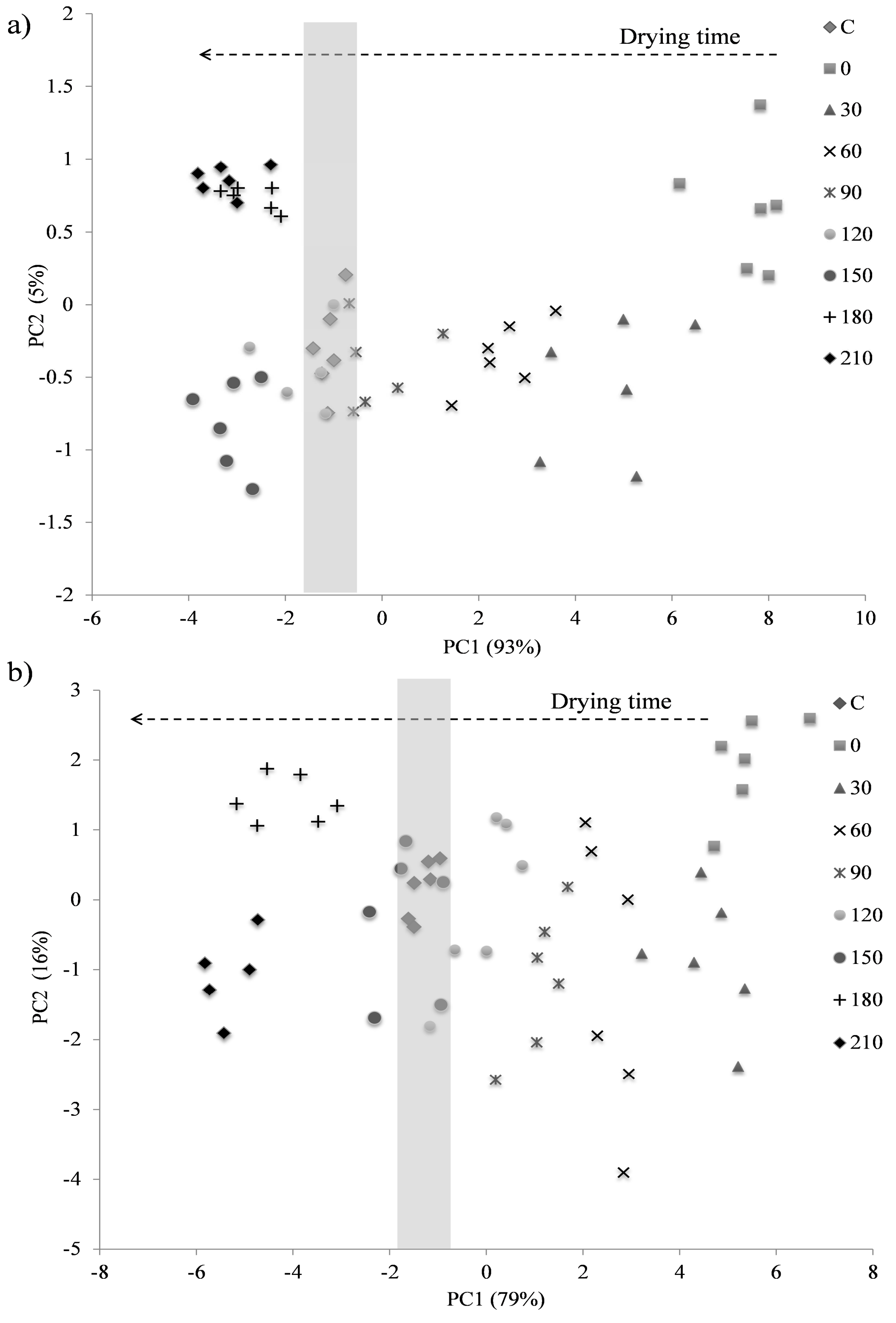
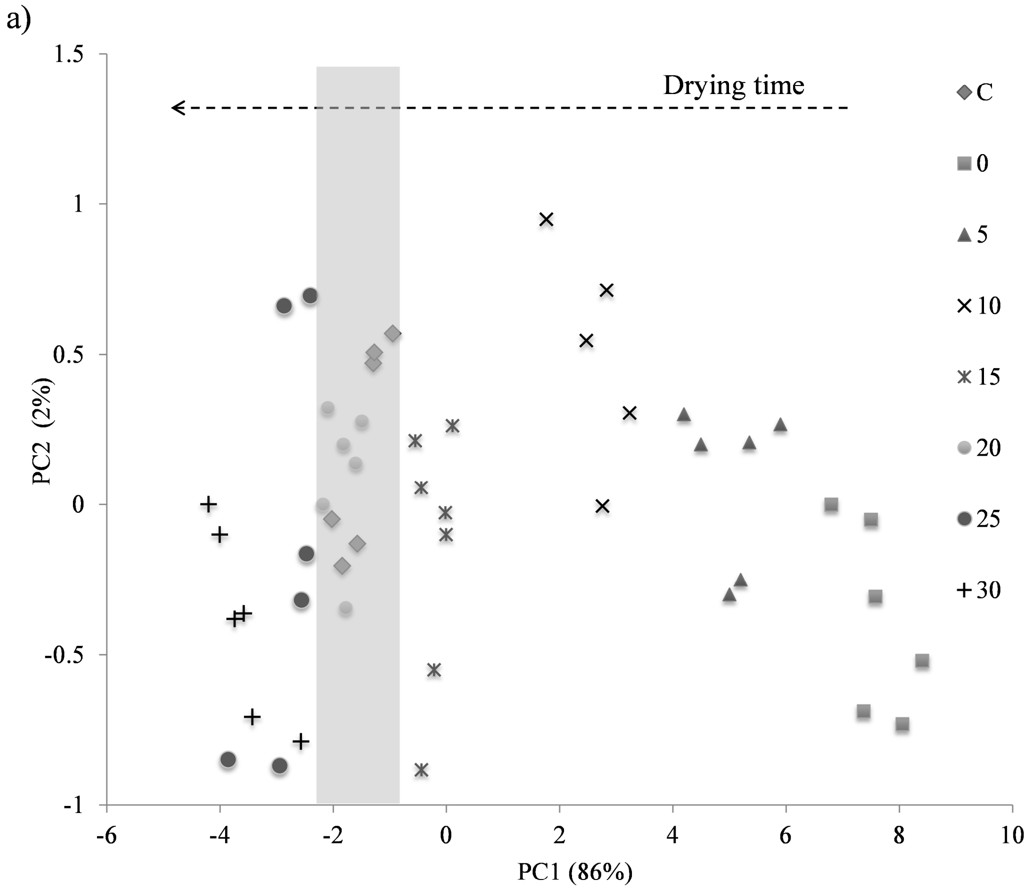

a)
Drying time
C
0
30
60
90
120
150
180
210
PC2 (5%)
PC1 (93%)
b)
Drying time
C
0
30
60
90
120
150
180
210
PC2 (16%)
PC1 (79%)

Figure 5.


a)
Drying time
PC2 (2%)
PC1 (86%)
1.5
1
0.5
0
-0.5
-1
-6
-4
-2
0
2
4
6
8
10
C
0
5
10
15
20
25
30

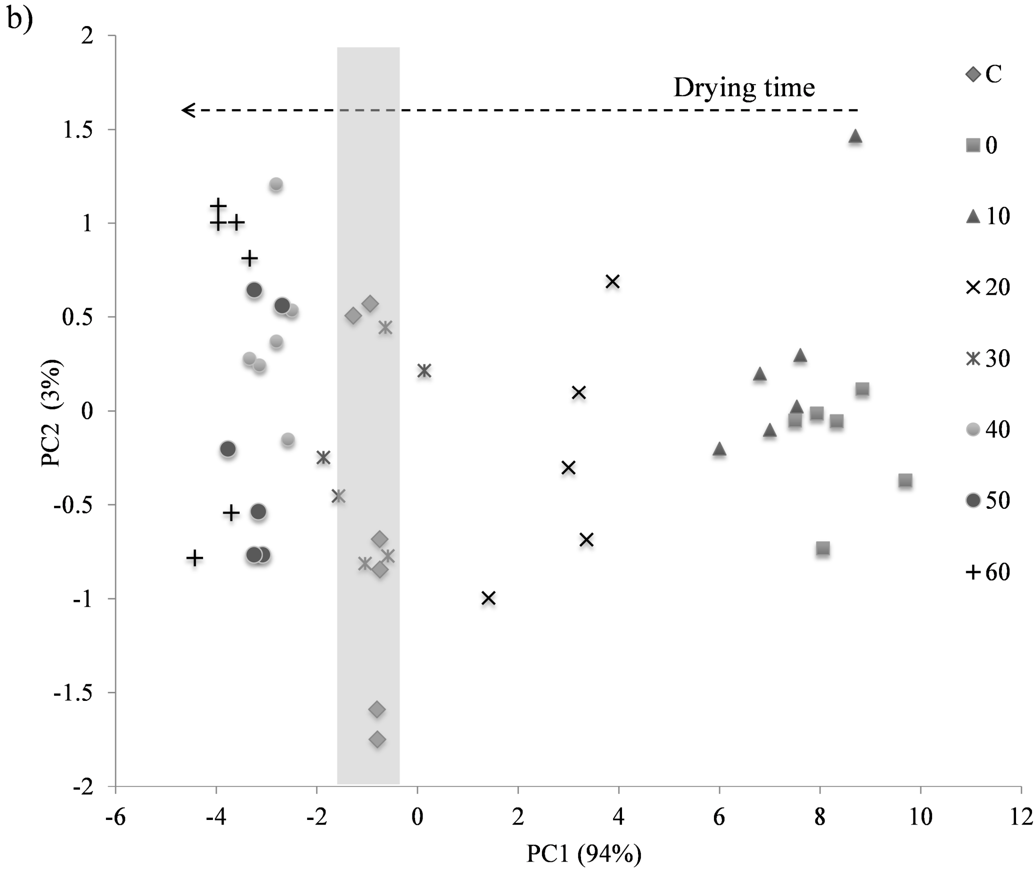

b)
Drying time
PC2 (3%)
PC1 (94%)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-6
-4
-2
0
2
4
6
8
10
12
C
0
10
20
30
40
50
60

Figure 6.

Highlights

- Edible coating drying behavior at different temperatures and levels of coating considered.
- Near Infrared spectra useful for monitoring coating process.
- Drying time discrimination based on time and surfaces by PCA.
- PLS regression models estimate optimal drying moment.