Rapid assessment of quality changes in French fries during deep-frying based on FTIR spectroscopy combined with artificial neural network

Running title: Detection of quality changes in French fries by FTIR

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Abstract: Fourier transform infrared (FTIR) spectroscopy combined with back propagation artificial neural network (BP-ANN) were utilized for rapid and simultaneous assessment of the lipid oxidation indices in French fries. The conventional indexes (i.e. total polar compounds, oxidized triacylglycerol polymerized products, oxidation products, and triacylglycerol hydrolysis products, acid values and peroxide values), and FTIR absorbance intensity in French fries were determined during deep-frying process, and the results showed the French fries had better quality in palm oil, followed by sunflower oil, rapeseed oil and soybean oil. The FTIR spectra of oil extracted from French fries were correlated to the reference oxidation indexes determined by AOCS standard method. The results of BP-ANN prediction showed that the model based on FTIR fitted well ($R^2 > 0.926$, RMSEC < 0.614, RMSEP< 0.550) compared with partial least-squares model ($R^2 > 0.876$, RMSEC < 1.144, RMSEP< 1.257). This facile strategy with excellent performance has great potential for rapid characterization quality of French fries during frying.

Keywords: French fries; Polar compounds; Oxidation indexes; BP-ANN; FTIR

Chemical compounds studied in this article

Acetone (PubChem CID: 180); Petroleum ether (PubChem CID:8900); Diethyl ether

(PubChem CID:3283); Tetrahydrofuran (PubChem CID: 8028); Toluene (PubChem CID:1140); Hexane (PubChem CID:8058)

Abbreviations: TPC, total polar compounds; TGP, oxidized triacylglycerol polymerized products; OTG, oxidation products; THP, triacylglycerol hydrolysis products; PV, peroxide values; AV, acid values; HCA, hierarchical cluster analysis; BP-ANN, back propagation artificial neural network; SD, standard deviation; PO, palm oil; SuO, sunflower oil; SO, soybean oil; RO, rapeseed oil.

1. Introduction

Deep frying is a traditional and convenient cooking method for producing palatable and desirable foods with unique characteristics of flavor, color and texture (Sumnu & Sahin, 2008). Frying oils, exposed to high temperature (150–200 °C), are subject to complex reactions such as hydrolysis, oxidation, and thermal alteration (Erickson, 2007). These reactions produce polar compounds including oxidized triacylglycerol polymerized products (TGP), oxidized triacylglycerol monomers (OTG), and triacylglycerol hydrolysis products (THP) (Gupta, Warner, White, Gupta, Warner, & White, 2004; Choe, Min, 2007). Therefore, those polar compounds were absorbed by the food during frying, which reduced the nutritional quality of the fried foods and might jeopardize human health (Tabee, Jägerstad, & Dutta, 2009; Li, Yu, Sun, Li, Wang, Cao, Liu, 2016). Numerous attentions have been paid on the oxidation degree of frying oils and ignored the lipid oxidation of fried food during deep-frying (Li, Li, Wang, Cao, & Liu, 2017; Liu, Wang, Cao, & Liu, 2018). Li et al., (2017) found the polar compound compositions were different in frying medium and substance: the TGP content was higher in French fries while OTG and THP contents were higher in deep-fried oils. Therefore, more attention should be paid to the quality of fried food. Currently, the traditional determination of lipid oxidation degree during deep-frying process is characterized samples by acid values (AV), peroxide values (PV), total polar compounds (TPC) and the main fractions of polar compounds. However, these conventional methods are laborious and time-consuming with toxic chemicals, and fail to achieve the facile application in the frying industry (Li, Cai, Sun, & Liu, 2016; Li, Chen, Huyan, Kou, Xu, Yu, & Gao, 2018).

For rapid and simultaneous determination of lipid oxidation in food, Fourier transform infrared (FTIR) spectroscopy can provide a solution for this challenge. FTIR spectroscopy was widely applied in the food detection due to environmental-friendliness, low-cost, and tiny sample and easy preparation for determination (Nenadis and Tsimidou, 2017; Sow, Kong, & Yang, 2018; Sow, Chong, Liao, & Yang, 2018). FTIR spectroscopy, using the association between the bond vibrational motion and the relative molecular structure, has been suggested as a feasible approach being successfully used in the fat and oil industry. FTIR has also been used to determine TPC content of frying oil (Chen, Zhang, Ma, Tuchiya, Miao, 2015; Talpur, Hassan, Sherazi, Mahesar, Kara, & Kandhro, 2015; Chen, *et al.*, 2018). Artificial neural network (ANN) is an algorithm that models non-linear relationships by mimicking the functionality of a neural network. ANN has been applied successfully to the automation and intelligent control of food drying process (Sun, Zhang, & Mujumdar, 2018), and food authentication (Goyal, 2013; Esteki, Simal-Gandara, Shahsavari, Zandbaaf, Dashtaki, & Vander Heyden, 2018), due to its self-learning ability, adaptive nature, strong fault tolerance (Ordukaya & Karlik 2016; Winiczenko, Górnicki, Kaleta, Martynenko, Janaszek-Mańkowska, & Trajer, 2018). Karaman, et al., (2012) estimated the oxidation parameters (peroxide value, free fatty acids and iodine value) of sunflower oil added with some natural byproduct extracts combined with ANN. However, to the best of our knowledge, there is limited research about FTIR spectroscopy combined with artificial neural network for the rapid and simultaneous determination of oxidation indexes in French fries.

In this study, FTIR spectroscopy in association with the back propagation artificial neural network (BP-ANN) model were developed for the routine analysis of TPC, TGP, THP, OTG, AV and PV of French fries fried in palm oil (F-PO), sunflower oil (F-SuO), soybean oil (F-SO) and rapeseed oil (F-RO). The feasibility and sensitivity of the method was evaluated and compared with partial least-squares (PLS) model. The FTIR spectroscopy method will provide an alternative approach for monitoring the quality changes of French fries rapidly, contributing to the safety of fried food and scientific frying during deep-frying.

2. Materials and methods

2.1 Materials and reagents

Fresh potatoes (Solanum tuberosum L, Helan15 cultivar), were obtained from a farm in Shandong Province, China. The frying experiments were conducted with soybean oil (SO), rapeseed oil (RO), palm oil (PO), and sunflower oil (SuO) (without additives) donated by Wilmar, and stored at 4 °C for further use. Acetone, diethyl ether, petroleum ether, toluene, hexane (analytical reagent grade) and Tetrahydrofuran (chromatography grade) were purchased from Sinopharm Chemical Regent Co., Ltd (Shanghai, China) and Sigma (St. Louis, MO, USA), respectively.

2.2 Preparation of French fries and oil extraction from French fries

A stainless deep fryer (Aigoli, China) with a maximum capacity of 2.5 L was used for frying. Potatoes were washed and cut into pieces (1 × 1× (6±0.5) cm) with a manual cutter. Firstly, 2.0 L of fresh oil was heated to 168 ± 3 °C in the fryer. Then, a batch of 100±2 g of potato strips was fried in oils regularly. Frying time (4 min) and waiting time (26 min) were set in each frying batch. The overall time was 3 days (8 h/ day). Frying oils (SO, RO, PO, and SuO) at different frying time of 0.06, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24 h were used for French fries frying. Extraction of oil from the French fries was performed according to the method described by Li et al., (2017). Those samples were stored at -20 °C until analysis.

2.3 The physicochemical properties of French fries

The fatty acid composition was analyzed by a gas chromatography (Agilent 7820, USA) (Table S1). The conditions were performed according to our previous research (Li, Wu, Liu, Jin, Wang, 2015). AV and PV of samples were measured according to the AOCS official method 3a-63 (AOCS, 2003a), and AOCS Cd 8b-90 (AOCS, 2003b) respectively. The determination of TPC was based on the AOCS official method Cd 20-91 (AOCS,1993). The compositions of TPC (e.g., TGP, OTG, THP) in oils extracted from French fries were obtained by a high-performance size-exclusion chromatography method described by Dobarganes, *et al.*, (2000).

2.4 FTIR analyses

A Bruker FTIR spectrometer (VERTEX 70 series) was employed to obtain the FTIR spectra. Each recorded spectrum was obtained by averaging 16 scans at a resolution of 4 cm^{-1}. Each sample was measured three times. The average of the three spectra obtained from each same sample was used in subsequent analysis. The spectra file of samples was pretreated through normalization to reduce measurement error. Each spectrum was aligned to the baseline using instrumentation software. 100 μL of oil extracted from the French fries was deposited onto PE film surface to form a uniform film. With PE film as background, the spectrum of oil was obtained. Using the calibration equation associating the effective path length with the absorbance of 4334 cm^{-1}, the effective path lengths of spectra were normalized to 0.15 mm (Dong, Li, Sun, Chen, Yu, 2015).

2.5 Artificial neural network Modeling and Partial least-squares model

The BP-ANN is a multi-layer feedforward neural network trained based on the error back propagation algorithm (Sun, Zhang, Mujumdar, & Yang, 2019). It is composed of input layer, hidden layer, and output layer. In general, the three-layer network can approach the target value with arbitrary precision if the number of hidden layers is sufficient. Through parameter optimization in the pre-experiment, the best BP-ANN model was obtained with the neuron number of 10 in hidden layer, the training function of trainlm, and the transfer functions of tansig and purelin in hidden layer and output layer, respectively. Therefore, a three-layer network was selected for all neural network models in this study, and 156 sets of data were obtained and divided into training data (70%, 110 samples), and validation data (15%, 23 samples), and testing data (15%, 23 samples). Based on our preliminary experiment and previous study (Xu, Yu, Liu, Li, & Zhang, 2016), the FTIR absorbance peak at 1696 cm^{-1}, 3471 cm^{-1} and 968 cm^{-1} related to oil oxidation were used as inputs of BP-ANN model to predict the conventional indexes (output) (TPC, TGP, THP, OTG, AV and PV). The partial least-squares (PLS) model was also validated using the FTIR absorbance peak height at 1696 cm^{-1}, 3471 cm^{-1} and 968 cm^{-1} and these relevant conventional indexes. Root Mean square error (RMSE), coefficient of determination (R^2) of the predicted conventional indexes were computed to evaluate the performance of fitting and predicting. Furthermore, in order to compare the quality of BP-ANN model and PLS, root mean square error of calibration (RMSEC) and root mean square error of prediction (RMREP) were calculated for the evaluation. Besides 10 external validation French fries samples were collected to

2.6 Statistical analyses

The reference values and the spectra collected of the samples were conducted in triplicate. The relevant results were denoted as mean ± standard deviation (SD). BP-ANN was performed using MATLAB R2014a (The MathWorks Inc., Natick, MA, USA). The PLS model was performed using SIMCA-P (version 13.0, Umea, Sweden). Spectral data analyses were conducted with the use of OMNIC 7.3 (Thermo Electron Inc., Madison, WI).

3. Results and discussion

3.1 Results of chemical analysis

Before FTIR analysis, the TPC, TGP, THP, OTG, AV and PV of oil samples from French fries were determined. Here, the degree of thermal oxidative decomposition in French fries fried in frying oils at 0.06, 4, 8, 12, 16, 20 h are displayed in Fig. 1.

With a longer period of frying process, the TPC in French fries kept increasing but the increase rates declined gradually in general. For TPC, the content of polar compounds in F-SO was consistently higher than that in F-RO, F-SuO, and F-PO, the polar compounds in F-SuO and F-PO was the lowest during frying. The F-SO reached 26.64% at 20 h frying compared with F-PO with TPC of 19.61%. (Fig. 1A). The TGP contents in F-SO, F-RO, F-SuO and F-PO reached to 13.24%, 10.59%, 10.14% and 9.83% in the three days of frying, and the order of growth rate was F-SO (0.43%) >F-RO (0.34%) > F-SuO (0.32%) > F-PO (0.31%) (Fig. 1B). The OTG contents in F-SO and F-RO increased rapidly at the first 8 h and then increased slowly. While, the OTG contents greatly fluctuated in F-SuO and F-PO and their contents were lower than F-SO and F-RO at the primary frying period (before 15 h) (Fig. 1C). The THP contents in French fries increased with the frying time at slower pace. The order of THP average growth rates were F-SO (0.22%) > F-RO (0.17%)> F-SuO (0.15%)> F-PO (0.12%) (Fig. 1D). Fig. 1(F) showed that PV increased slowly from 4 h to 20 h after a quick increase at the first 4 h. The reason may be that hydroperoxide is an intermediate of primary oxidation, which is susceptible to be cleaved into aldehydes and other volatile compounds (Xu, Yu, Liu, Zhang, 2016). The AV increased with the frying time as presented in Fig. 1(E), and F-SO presented a higher value compared to other samples.

3.2 FTIR Analysis

FTIR spectroscopy is a rapid method for the food detection, which is an alternative to traditional methods in the food industries. The complete FTIR spectra of oil samples extracted from French fries were exhibited in Fig. 2(A). For lipid oxidation analysis, the most essential spectral regions correspond to ROOH, FFA (C=O bond), and -HC=CH- (trans) functional groups (Xu, Yu, Liu, Li, & Zhang, 2016). More specifically, the corresponding regions were the following wavenumbers: the -HC=CH- (trans) bond occurred at nearly 980–960 cm^{-1}; the FFA (C=O bond) occurred between 1720–1680 cm^{-1} and the ROOH corresponded to the regions of 3650-3300 cm^{-1} (Guillen and Cabo, 2000; Sow, Tan, & Yang, 2019; Sow, Yu Toh, Wong, & Yang, 2019). The change in intensity of these spectral regions of oil samples could reflect the chemicals transformation during frying, consequently denoting the degree of lipid oxidation.

Functional group spectra's variation for samples in the course of frying was shown in Figure 2(A). The FFA (C=O bond) absorbance at about 1696 cm^{-1}, –HC=CH-(trans) bond absorbance at about 968 cm^{-1} and ROOH characteristic absorption peak height at about 3471 cm^{-1} of oils extracted from French fries showed the growth trend during frying. The starting adjacent spectral gaps at the height of these absorption peaks were small, whereas the adjacent spectral gaps increased with time, suggesting that hydrogen peroxide, free fatty acids and isolated trans fatty acids increased with time (Fig. S1(A-C)). Fig. 2(B-D) showed that F-PO and F-SuO displayed the lower characteristic absorption peak height at 3471, 1696 and 968 cm^{-1} compared with F-SO and F-RO by comparing the FTIR absorbance intensity of the ROOH, FFA (C=O bond), and –HC=CH-(trans) bond in French fries samples, the results revealed that the degree of oxidative stability was F-PO > F-SuO > F-RO> F-

SO.

3.3 Model establishment and verification by BP-ANN

In order to establish the BP-ANN model for the change of quality in French fries during deep-frying, the FTIR absorbance peak at 1696, 3471 and 968 cm^{-1}, were set as variable X. Meanwhile, the conventional indexes (TPC, TGP, THP, OTG, PV, AV) were set as variables Y. Through parameter optimization, the BP-ANN model with the topology of 3-10-1(the neuron number of input layer, hidden layer, and output layer was 3, 10, and 1, respectively), performing algorithm of Levenberg-Marquardt, transfer function of tansig and purelin in hidden layer and output layer, respectively, and training function of trainlm (Levenberg-Marquardt) outperformed the fitting performance and accuracy. Training set included 70% of the samples, and the prediction models of TPC, TGP, THP, OTG, PV and AV established by BP-ANN method are shown in Figure 3. The predicted values were well correlated with the actual values, and the R^2 of the training set were all>0.915. 15% of the samples were used as validation set and 15% as test set. The results showed that the R^2 of the validation set and testing set of TPC, TGP, THP, AV, PV were >0.930 and >0.940, respectively, indicating that the prediction ability of the model was available (table 1), numerous studies revealed that the R^2 higher than 0.9 in the model indicated excellent classification performance as well as prediction ability (Cavanna, Righetti, Elliott, & Suman, 2018). However, R^2 of the testing set of OTG was only 0.863, which is not good owing to the fluctuation of OTG with frying time. From Table 1, the MSE of the TPC, TGP, THP, OTG, AV and PV training models were 0.539, 0.302, 0.121, 0.252, 0.133, and 0.287, respectively, and the MSE of validation and testing models were <0.639 and <0.753, respectively, which indicated that BP-ANN models had excellent predictive ability for oxidation indexes in French fries during deep-frying. Furthermore, in order to evaluate the performance of the model, the results of BP-ANN models were compared with PLS models (Table 2). Compared with PLS model, the RMSEC and RMSEP of the BP-ANN model was reduced by 46.32%-79.02% and 47.35%-82.61%, and the R^2 value was increased by 4.14%-10.16%, respectively. In our study, the lower RMSEC, RMSEP and higher R^2 of the calibration (training) equations for TPC, TGP, THP, OTG, PV, AV were obtained compared with PLS models. The BP-ANN had achieved excellent predictive performance ($R^2 > 0.9$) for the TPC, TGP, THP, AV, PV conventional indexes during frying process.

3.4 Sample external validation

After calibrating the models, external validation procedure was carried out to provide an estimate of the overall accuracy of the predictions. Blind samples from 10 different French fries samples prepared in different oxidation degree of oils were used to validate the performance of the proposed method. The TPC, TGP, THP, OTG, AV and PV of the oils were initially analyzed using AOCS standard method before the proposed FTIR analysis. The results obtained are presented in Fig. 4.

Fig.4 confirms that the two methods agreed with each other well, with $R^2 > 0.975$ for TPC, TGP, THP, AV and PV prediction, except for OTG ($R^2 = 0.656$). FTIR methods combined with ANN could measure efficiently the TPC, TGP, THP, AV and PV of various French fries. Therefore, the proposed method can be used as an alternative

TPC, TGP, THP, AV and PV determination method.

4. Conclusions

This study aimed to simplify oxidation parameters determination in French fries using a rapid and convenient PE film-based FTIR procedure, which are considered practical for routine implementation. Furthermore, compared with PLS model, the BP-ANN model showed good performance and excellent prediction for the changes of quality (TPC, TGP, THP, AV and PV) in French fries during frying based on FTIR spectroscopy. FTIR spectral regions correspond to ROOH, FFA (C=O bond), and –HC=CH- (trans) functional groups were selected for the model establishment. With the increase of the FTIR absorbance intensity in these regions, deeper degree of thermal oxidative decomposition was presented in French fries during frying. The proposed method indicated that the quality of F-PO was better than F-SuO and F-RO, followed by F-SO. This investigation opens new opportunities for developing FTIR spectroscopy combined with BP-ANN as a promising method for the quality detection of fried food in a wide range of applications.

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References

American Oil Chemists' Society. (2003a). AOCS official method Cd 3a-63 acid value method. Official methods and recommended practices of the AOCS. Champaign, IL.

American Oil Chemists' Society. (2003b). AOCS official method Cd 8b -90 peroxide value acetic acid-isooctane method. Official methods and recommended practices of the AOCS. Champaign, IL.

American Oil Chemists' Society. (1993). AOCS official method Cd 20–91. Official methods and recommended practices of the AOCS. Champaign, IL.

Cavanna, D., Righetti, L., Elliott, C., & Suman, M. (2018). The scientific challenges in moving from targeted to non-targeted mass spectrometric methods for food fraud analysis: A proposed validation workflow to bring about a harmonized approach. *Trends in Food Science & Technology*, 80, 223-241.

Chen, J. Y., Zhang, H., Ma, J. K., Tuchiya, T., Miao Y. L. (2015). Determination of the Degree of Degradation of Frying Rapeseed Oil Using Fourier-Transform Infrared Spectroscopy Combined with Partial Least-Squares Regression, *International Journal of Analytical Chemistry*, 1-6.

Chen, J., Zhang, L., Geng, Q., Jing, B., & Yu, X. (2018). Determination of Total Polar Compounds in Frying Oils by PE−Film−Based FTIR and ATR−FTIR Spectroscopy. *European Journal of Lipid Science and Technology*, 120, 1800250.

Choe, E., & Min, D. B. (2007). Chemistry of deep-fat frying oils. *Journal of Food Science*, 72, R77-R86.

Dobarganes, M. C., Velasco, J., & Dieffenbacher, A. (2000). Determination of polar compounds, polymerized and oxidized triacylglycerols, and diacylglycerols in oils and fats - Results of collaborative studies and the standardized method (Technical Report). *Pure and Applied Chemistry*, 72, 1563-1575.

Dong, X., Li, Q., Sun, D., Chen, X., Yu, X.(2015).Direct FTIR analysis of free fatty a cids in edible oils using disposable polyethylene films. *Food Analyitcal Methods*, 8, 857-863.

Erickson, M. D. (2007). Deep frying: Deep frying chemistry, nutrition, and practical application, 2nd, Champagne, IL: AOCS Press.

Esteki, M., Simal-Gandara, J., Shahsavari, Z., Zandbaaf, S., Dashtaki, E., & Vander Heyden, Y. (2018). A review on the application of chromatographic methods, coupled to chemometrics, for food authentication. *Food Control*, 93, 165-182.

Frankel, E. N. (1984). Chemistry of free radical and singlet oxidation of lipids. *Progress in Lipid Research*, 23, 197−221.

Goyal, S. (2013). Artificial neural networks (ANNs) in food science–A review. *International Journal of Scientific World*, 1(2), 19-28.

Guillén, M. D., Cabo, N. (2000). Some of the most significant changes in the Fourier Transform Infrared Spectra of edible oils under oxidative conditions. *Journal of* *the Science of Food and Agriculture*, 80, 2028–2036.

Gupta, M. K., Warner, K., White, P. J., Gupta, M. K., Warner, K., & White, P. J. (2004). Frying technology and practices. Urbana: AOCS press, (chapters 2, 12).

Huang, J. Y., Guo, X. P., Qiu, Y. B., & Chen, Z. Y. (2007). Cluster and discriminant analysis of electrochemical noise data. *Electrochimica Acta*, 53, 680-687.

Karaman, S., Ozturk, I., Yalcin, H., Kayacier, A., & Sagdic, O. (2012). Comparison of adaptive neuro-fuzzy inference system and artificial neural networks for estimation of oxidation parameters of sunflower oil added with some natural byproduct extracts. *Journal of the Science of Food and Agriculture*, 92(1), 49-58.

Li, J., Cai, W., Sun, D., & Liu, Y. (2016). A quick method for determining total polar compounds of frying oils using electric conductivity. *Food Analytical Methods*, 9, 1444-1450.

Li, Q., Chen, J., Huyan, Z., Kou, Y., Xu, L., Yu, X., & Gao, J. M. (2018). Application of Fourier transform infrared spectroscopy for the quality and safety analysis of fats and oils: A review. *Critical reviews in food science and nutrition*, 1-15.

Li, X., Wu, X., Liu, R., Jin, Q., Wang, X. (2015). Effect of frying conditions on fatty acid profile and total polar materials via viscosity. *Journal of Food Engineering*, 166, 349-355.

Li, X., Yu, X., Sun, D., Li, J., Wang, Y., Cao, P., Liu, Y., (2016). Effects of polar compounds generated from the deep-frying process of palm oil on lipid metabolism and glucose tolerance in Kunming mice. *Journal of Agricultural and Food Chemistry*, 65, 208-215.

Li, X., Li, J., Wang, Y., Cao, P., & Liu, Y. (2017). Effects of frying oils' fatty acids profile on the formation of polar lipids components and their retention in French fries over deep-frying process. *Food Chemistry*, 237, 98-105.

Liu, Y., Wang, Y., Cao, P., & Liu, Y. (2018) Degradation of Edible Oil During Deep-Frying Process by Electron Spin Resonance Spectroscopy and Physicochemical Appreciation. *European Journal of Lipid Science and Technology*, 120(2), 1700376.

Nenadis, N., Tsimidou, M. Z. (2017). Perspective of Vibrational Spectroscopy Analytical Methods in on-Field/official Control of Olives and Virgin Olive Oil. *European Journal of Lipid Science and Technology*, 119, 1–18.

Ordukaya, E., & Karlik, B. (2016). Fruit juice-alcohol mixture analysis using machine learning and electronic nose. *IEEJ Transactions on Electrical and Electronic Engineering*, 11, S171–S176.

Sow, L. C., Kong, K., & Yang, H. (2018). Structural modification of fish gelatin by the addition of gellan, κ−carrageenan, and salts mimics the critical physicochemical properties of pork gelatin. *Journal of food science*, 83(5), 1280-1291.

Sow, L. C., Chong, J. M. N., Liao, Q. X., & Yang, H. (2018). Effects of κ-carrageenan on the structure and rheological properties of fish gelatin. *Journal of Food Engineering*, 239, 92-103.

Sow, L. C., Tan, S. J., & Yang, H. (2019). Rheological properties and structure modification in liquid and gel of tilapia skin gelatin by the addition of low acyl gellan. *Food Hydrocolloids*, 90, 9-18.

Sow, L. C., Yu Toh, N. Z., Wong, C. W., & Yang, H. (2019). Combination of sodium alginate with tilapia fish gelatin for improved texture properties and nanostructure modification. *Food Hydrocolloids*, 94, 459-467.

Sumnu, S. G., Sahin, S. (2008). Advances in deep-fat frying of foods. CRC Press.

Sun, Q., Zhang, M., & Mujumdar, A. S. (2019). Recent developments of artificial intelligence in drying of fresh food: A review. *Critical reviews in food science and nutrition*, 59(14), 2258-2275.

Sun, Q., Zhang, M., Mujumdar, A. S., & Yang, P. (2019). Combined LF-NMR and Artificial Intelligence for Continuous Real-Time Monitoring of Carrot in Microwave Vacuum Drying. *Food and Bioprocess Technology*, 1-12.

Talpur, M. Y., Hassan, S. S., Sherazi, S. T. H., Mahesar, S. A., Kara, H., & Kandhro, A. A. (2015). A simplified FTIR chemometric method for simultaneous determination of four oxidation parameters of frying canola oil. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 149, 656-661.

Tabee, E., Jägerstad, M., & Dutta, P. C. (2009). Frying quality characteristics of French fries prepared in refined olive oil and palm olein. *Journal of the American Oil Chemists' Society*, 86(9), 885-893.

Winiczenko, R., Górnicki, K., Kaleta, A., Martynenko, A., Janaszek-Mańkowska, M., & Trajer, J. (2018). Multi-objective optimization of convective drying of apple cubes. C*omputers and Electronics in Agriculture*, 145, 341–348.

Xu, L., Yu, X., Liu, L., Zhang, R. (2016). A novel method for qualitative analysis of edible oil oxidation using an electronic nose. *Food Chemistry*, 202, 229-235.

Xu, L., Yu, X., Liu, L., Li, M., & Zhang, R. (2016). A rapid method for evaluating the edible oil oxidative stability during ambient storage by FTIR spectroscopy using a mesh cell. *Analytical Methods*, 8(25), 5117-5122.