GRADUATE AND POSTDOCTORAL STUDIES

McGILL UNIVERSITY

FINAL ORAL EXAMINATION
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

OF

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DEPARTMENT OF BIORESOURCE ENGINEERING

DEEP-FAT FRYING CHARACTERISTICS OF BLENDS OF PALM AND CANOLA OILS

DATE: January 4, 2017
TIME: 10:15 a.m.

MACDONALD-STEWART, ROOM MS2-022
McGill University, Macdonald Campus

COMMITTEE:
Dr. D. Zadworny (Pro-Dean) (Animal Science Department)
Dr. V. Orsat (Chair) (Bioresource Engineering Department)
Dr. M. O. Ngadi (Co-Supervisor) (Bioresource Engineering Department)
Dr. M-J. Dumont (Co-Supervisor) (Bioresource Engineering Department)
Dr. V. Yaylayan (Internal Member) (Food Science & Agricultural Chemistry)
Dr. A. Ismail (External Member) (Food Science & Agricultural Chemistry)

Dr. Josephine Nalbantoglu, Dean of Graduate and Postdoctoral Studies
Members of the Faculty and Graduate Students
are invited to attend

ABSTRACT
Selecting an appropriate oil for commercial deep-fat frying can be challenging. Commercial frying began with animal fats. Next, partially hydrogenated vegetable oils were commonly used. Due to the high temperature, the presence of oxygen, water, and other compounds from the food being fried, the frying oil undergoes thermo-oxidation induced irreversible degradation reactions. The highly-saturated animal fats and *trans*-fatty acids that come with hydrogenation procedures have adverse public health consequences. Oils with higher unsaturation are more susceptible to thermo-oxidation reactions. On the other hand, omega-3 and omega-6 monounsaturated fatty acids have proven health benefits, demand for natural products has been rising, and emphasis on nutritional enrichment has been increasing. The food industry has been exploring alternatives that address both public health concerns and improves frying process and products. The use of minimally processed stable oils, blending different oils in a frying medium, and breeding oil seeds with altered fatty acid composition appear to be the most viable cost effective alternatives to animal fats and hydrogenated vegetable oils. Virgin palm oil (VPO) has a balanced composition of saturated and monounsaturated fatty acids. It is very rich in endogenous phytonutrients (such as carotenoids, tocopherols and tocotrienols) with biological activity and health-promoting functions. This study investigated the stability of these phytonutrients and the extent of the phytonutrients' migration into fried products when VPO is used either alone or as the major component in blends of oils in deep-fat frying operations. Refined canola oil (RCO) was used as the second oil sample in the binary blends.
Firstly, Fourier transform near-infrared (FTNIR) spectroscopy (a non-destructive technique) was used to characterize the palm oil, canola oil and different blend ratios of the two oils. Chemometric analysis by Partial Least Squares (PLS) regression was used to correlate spectral data with iodine value (IV), free fatty acid (FFA) and peroxide value (PV) data of the oil samples obtained by the reference AOCS wet methods. The effects of different spectra pre-processing methods were investigated to predict the reproducibility and robustness of the PLS-NIR model developed. The best models were first derivative and first derivative + straight line subtraction. The study achieved simultaneous characterization of the essential quality parameters of VPO, RCO and their blends using the FTNIR spectroscopy.
The VPO, RCO and blend samples were then used in deep-fat frying of ripe and unripe plantain crisps at 180 °C for different times. There was no significant difference ($p > 0.05$) in the moisture loss rate and the crispness of the crisps produced using VPO and RCO. Significant differences ($p < 0.05$) were observed in the oil uptake and color properties of the crisps. VPO fried crisps absorbed 14% less oil in the unripe crisps samples and 26% less oil in the ripened crisps than RCO. The browning index showed that the VPO crisps had greater color changes than the crisps fried using RCO. The qualities of the crisps fried in the blends were also statistically ($p < 0.05$) different. The 70:30 and 50:50 (VPO: RCO) blends improved the quality of the crisps better than RCO alone. The remarkable results obtained further show the applicability of crude palm oil and blends as frying media in deep-fat frying operations.

Knowledge on kinetics parameters of the quality changes occurring during frying makes process improvement and prediction of final quality changes possible. The deterioration of CPO, RCO and CPO: RCO (1:1 w/w) blend during 20 h of successive deep-fat frying at 170, 180 and 190 ^{o}C was investigated. Kinetics of changes in oil quality indices, namely, FFA, PV, anisidine value (*p*-AV), total polar compounds (TPC) and color index (CI) were monitored. The results showed that FFA and PV accumulation followed the first order reaction model, while *p*-AV, TPC and CI followed the zero-order reaction model. The concentration and deterioration rate constants increased with increasing temperatures and was modeled by the Arrhenius equation. The results showed that PV build-up was the fastest during thermo-oxidation. The overall activation energy (E_a) values showed that the stability of the blend was superior and not just the mean of CPO and RCO results.

To test the migration and retention of the endogenous phytonutrients, CPO, RCO and blend (CPO: RCO 1:1 w/w) were used to fry potato slices at 170 ^{o}C for different times. The French fries produced using CPO and the blend were significantly enriched with phytonutrients, absorbed less oil and had more pronounced color changes. Over 50% of the total carotenoids, 40 – 45% of tocotrienols and 3 – 16% of tocopherols were absorbed from the oils. The order of tocopherol and tocotrienol enrichment based on the oil used during frying was CPO: RCO > CPO > RCO. The biphasic first order model was valid and satisfactory as a predictor model of changes in the concentration of the phytonutrients in the French fries. The carotenoid level in French fries influenced the overall color change (ΔE).

The thermostability of tocopherols, tocotrienols and carotenoids in VPO, RCO and their blends used in deep-fat frying at 170 to 190 ^{o}C for 20 h was assessed. The results showed that the deterioration kinetic rate of each homolog followed a reaction order greater than 1. The rate was dependent on frying temperatures and was adequately modeled by the Arrhenius relationship. The rate of deterioration and the E_a showed that the least stable homologs were γ-tocopherol and γ-tocotrienol while δ-tocotrienol and carotenoids were the most stable. The stability rate in α-tocopherol, α-tocotrienol and δ-tocopherol were very similar and intermediate. While the tocopherol and tocotrienol homologs were less stable in VPO, carotenoids were more retained in this oil sample as shown by the relatively high activation energy (E_a of 71±5 kJ/mol) of carotenoids in VPO. The tocopherols and tocotrienols were more stable in the blended oil samples as shown by their comparatively higher E_a values. These behaviors are related to the initial composition of the oils and their calculated oxidizability (Cox) value.

The results obtained in this study further broadened the knowledge on the behavior of VPO alone or in blend with other less saturated oils during deep-fat frying. The blended oil sample performed best in terms of stability of oil and phytonutrients. The fries produced in the blend absorbed the most phytonutrients. The results also gave a better understanding of the reaction rates with respect to individual quality parameters, bioactive homologs and frying medium. VPO and blends offer great advantages as choice frying oils and can be adopted in domestic and commercial deep-fat frying protocols.

CURRICULUM VITAE

UNIVERSITY EDUCATION

McGill University, Canada
PhD. Bioresource Engineering 2012-Date

Michael Okpara University of Agriculture Umudike, Nigeria
MSc. Food Science and Technology 2002-2005
Specialization - Food Processing and Preservation

Abia State University Uturu, Nigeria
BSc. Food Science and Technology 1990-1995

EMPLOYMENT

Department of Food Science and Technology, 2000 - Date
Abia State University Uturu, Nigeria
Lecturer/Research Associate

Kan Biscuit Company Ltd., Nigeria 1997 - 2000
Quality Control Officer/ Assistant Production Manager

Government Secondary School Suleja, Nigeria 1995 - 1996
National Youth Service Corps (NYSC, Nigeria)
Teaching and Community Service

AWARDS

- Tertiary Education Development Scholarship (Nigeria) 2012 - 2014
- Graduate Excellence Award 2012 - 2015
- GREAT Award 2013 - 2015

SELECTED COMMUNICATION

A. Publication

1. **Ogan I. Mba,** Marie-Josée Dumont, and Michael Ngadi **(2016).** Deterioration kinetics of palm oil, canola oil and blend during repeated deep-fat frying. *Journal of the American Oil Chemists' Society*, 93 (9), 1243 – 1253; doi: 10.1007/s11746-016-2872-z.
2. **Ogan I. Mba,** Marie-Josée Dumont, and Michael Ngadi **(2016).** Migration and concentration of valuable phytonutrients in French fries during deep-fat frying in palm oil, canola oil and blend. (under revision).
3. **Ogan I. Mba,** Marie-Josée Dumont, and Michael Ngadi **(2016).** Thermostability and degradation kinetics of phytonutrients in palm and canola oil blends used in deep-fat frying. *LWT – Food Science & Technology* (under review).
4. **Ogan I. Mba,** Marie-Josée Dumont, and Michael Ngadi **(2015).** Influence of palm oil, canola oil, and blends on characteristics of fried plantain crisps. *British Food Journal*, 117 (6), 1793 – 1807; doi: 10.1108/BFJ-04-2014-0155.
5. **Ogan I. Mba,** Marie-Josée Dumont, and Michael Ngadi **(2015).** Palm oil: Processing, characterization, and utilization in the food industry – A review. *Food BioScience*, 10 (1), 26 – 41; doi: 10.1016/j.fbio.2015.01.003.
6. **Ogan I. Mba,** Peter Adewale, Marie-Josée Dumont, and Michael Ngadi **(2014).** Application of near-infrared spectroscopy to characterize binary blends of palm and canola oils. *Industrial Crops and Products*, 61, 472 – 478; doi: 10.1016/j.indcrop.2014.07.037.
7. Peter Adewale**, Ogan I. Mba,** Marie-Josée Dumont, Michael Ngadi, and Robert Cocciardi **(2014).** Determination of the Iodine Value and the Free Fatty Acid content of Waste Animal Fat Blends using FT-NIR. *Vibrational Spectroscopy*, 72, 72 – 78; doi: 10.1016/j.vibspec.2014.02.016
8. **Ogan I. Mba,** Jamshid Rahimi, and Michael Ngadi **(2013**). Effect of Ripening Stages on Basic Deep-Fat Frying Qualities of Plantain Chips. *Journal of Agricultural Science and Technology A*, 3 (5), 341 – 348.

B. Conference Papers

1. **Ogan I. Mba,** Marie-Josée Dumont, and Michael Ngadi **(2016).** Retention and stability of tocopherols, tocotrienols and carotenoids in French fries during deep-fat frying in palm oil and blends. Poster presented at the *18th IUFoST – World Congress of Food Science and Technology*, Dublin, Ireland August, 21 - 25.
2. **Ogan I. Mba,** Marie-Josée Dumont, and Michael Ngadi **(2016).** Absorption of vitamin E isomers during deep-fat frying of French fries in palm oil and blends. Paper presented at the *Northeast Agricultural and Biological Engineering Conference (NABEC) 2016*, Orono, Maine, USA; July 31 – August 3.
3. Feifei Tao, **Ogan I. Mba**, Laura Liu, and Michael Ngadi **(2016).** Use of near-infrared hyperspectral imaging to visualize saturated, monounsaturated, and polyunsaturated fatty acids distribution in Salmon fillets. Paper presented at the *American Society of Agricultural and Biological Engineers (ASABE) 2016 Annual International Meeting*, Orlando, Florida, USA; July 17 - 20.
4. **Ogan I. Mba**, Marie-Josée Dumont, and Michael Ngadi **(2015).** Deterioration kinetics of palm oil and blends during repeated deep-fat frying. Poster presented at the *12th International Congress on Engineering and Food (ICEF12)*, Québec City, Canada; June 14 – 18.
5. **Ogan I. Mba,** Marie-Josée Dumont, and Michael Ngadi **(2014).** Effects of blends of palm and canola oils on fried plantain chips. Poster presented at the *American Society of Agricultural and Biological Engineers (ASABE) 2014 Annual International Meeting*, Montréal, Canada; July 13 -16.
6. **Ogan I. Mba,** Michael Ngadi, and Marie-Josée Dumont **(2013).** Evaluation of palm oil quality using FT-NIR Spectroscopy. Paper presented at the *Northeast Agricultural and Biological Engineering Conference (NABEC) 2013*, Altoona, Pennsylvania, USA; June 16 – 19.
7. **Ogan I. Mba** and Michael Ngadi **(2012).** Effect of ripening stages on fat and moisture content of deep-fried plantain chips. Paper presented at the *7th Commission Internationale du Génie Rural (CIGR) International Technical Symposium*, Stellenbosch, South Africa; November 25 – 28.