International Food Research Journal 23(3): 1107-1114 (2016)
Journal homepage: *http://www.ifrj.upm.edu.my*

Improving omega-3 fatty acid content in deep-fat fried sweet potato

Pongsing, W. and *Chaoruangrit, A.

Department of Food Technology, Faculty of Technology, Khon Kaen University, Khon Kaen 40002, Thailand

Article history

Received: 1 June 2015
Received in revised form: 18 September 2015
Accepted: 6 October 2015

Keywords

Blended oil
Fatty acid profile
Rice bran oil
Sweet potato

Abstract

The fatty acid compositions of deep fat fried products depend on type of frying oil used. Improving the levels of essential fatty acids, principally omega-3 fatty acids (linolenic acid), can be effectively achieved by frying in blended oils instead of using a single oil. The aim of this research was to increase linolenic acid content in deep fat fried sweet potato by using blended oils (rice bran oil and canola oil). The fatty acid compositions, tocopherols and gamma-oryzanol contents of rice bran oil (RBO), canola oil (CNO) and blended oils (RBO:CNO-1=90:10v/v, RBO:CNO-2=80:20v/v) were determined using HPLC method. The physical properties of the oils were also determined. Thin sticks of sweet potato (8x8x80 mm) were blanched and dried to a moisture content of 67+2%. The dried-blanched sweet potatoes were deep fried in selected blended oil at 170°C for 3.5 min. The fatty acid compositions, tocopherols and gamma-oryzanol contents of the fried product were determined. The results show that the chemical and physical properties of the frying oils depended significantly on the type oils and the blending proportions. The blended oils, RBO:CNO-1 and RBO:CNO-2, had higher linolenic acid content than the rice bran oil ($p \leq 0.05$). RBO:CNO-2 contained significantly higher linolenic acid and tocopherols contents, and possessed a smoke point higher than RBO:CNO-1. The sweet potato fried in RBO:CNO-2 had moisture, oil and total solid contents as 29.82%, 7.47% and 92.20%, respectively. It retained proper nutrition values (i.e., linolenic acid 1.33g/100 $g_{extracted\ oil}$, linoleic acid 14.61g/100 $g_{extracted\ oil}$, δ-tocopherol 2.30 mg/$kg_{extracted\ oil}$, ϒ-tocopherol 64.94 mg/$kg_{extracted\ oil}$, α-tocopherol 145.21 mg/$kg_{extracted\ oil}$ and gamma-oryzanol 871.78 mg/$kge_{xtracted\ oil}$). This study shows the effectiveness of using the blended oils (RBO:CNO-2; 80:20 v/v) to improve omega-3 fatty acid level and natural antioxidants in fried sweet potato, which is considered to be a healthier snack.

© All Rights Reserved

Introduction

Frying is a process of cooking and drying through contact with hot oil and it involves simultaneous heat and mass transfer, wherein the heat is transferred from hot oil to the product, water is evaporated and oil is absorbed. Crust formation and browning take place giving the product an attractive golden appearance and crispy mouthfeel (Pahade and Sakhale, 2012). Deep fat frying is a process of immersing food in hot oil with a contact among oil, air and food at a high temperature of 150 to 190°C (Serjouie *et al.*, 2010). Oil uptake is one of the most important quality parameters of fried food, which is incompatible with recent consumer trends towards healthier food and low fat products (Dueik *et al.*, 2012). Fried food is extensively consumed worldwide because of its desirable flavor, golden color and crispy texture (Al-Khusaibi *et al.*, 2012). Fried foods are most widely available in the market as snacks such as French fries, chicken nuggets and patties to name a few. Fried products based on potato are major businesses globally; McDonald's alone serves about 3.5 MMT of French fries to approximately 33 million customers worldwide every day (Moreira *et al.*, 1999). French fries are a universally popular snack globally. They are appreciated for their taste and texture (van Loon *et al.*, 2007).

Previous studies have demonstrated that diets with high contents of oleic and linolenic acids were associated with low levels of low-density lipoprotein cholesterol in blood plasma and they may reduce the incidence of coronary heart diseases (Nestel *et al.*, 1994; Noakes *et al.*, 1996). Omega-3 fatty acid (linolenic acid) therapy continues to show great promise in primary and, particularly in secondary prevention of cardiovascular diseases (Lavie *et al.*, 2009). The quality of the products from deep fat frying depends not only on the frying conditions but also on the type of oils and foods (Debnath *et al.*, 2012). Rice bran oil (RBO) obtained from the rice milling process is used extensively in Asian countries

*Corresponding author.
Email: *arayaa@kku.ac.th*

(Orthoefer 1996) and in Thailand, RBO obtained from the brown outer layer of the rice kernel, have been used for generations (Sakunpak *et al*., 2014). RBO is one of the most nutritious and healthy edible oils because it contains an abundance natural bioactive phytoceuticals such as oryzanol and tocopherols which play important roles in preventing some diseases (Rajam *et al*., 2005), and also extending the shelf - life of fried foods. Oryzanol is an antioxidant compound and is associated with decreasing plasma cholesterol, lowering serum cholesterol and decreasing cholesterol absorption (Patel and Naik, 2004). Tocopherols have been reported to increase the oxidative stability of vegetable oils rich in polyunsaturated fatty acid (PUFA) during frying (Al-Khusaibi *et al*., 2012). The high oxidative stability of RBO makes it preferred oil for frying and baking applications (Gunstone, 2004; Choudhary and Grover, 2013). Canola oil (CNO) is frying oil with low erucic acid content (<2%) and high smoking point. An important feature of this oil is high content of linolenic acid (18:3n-3) and linoleic acid (18:2n-6), which are essential dietary fatty acids (Al-Khusaibi *et al.*, 2012). Therefore, CNO oil can potentially be used to blend with RBO to increase the linolenic acid content of fried foods, especially fruit and vegetable which contain less omega-3 fatty acid.

Thai vegetable and fruit chips are snack products generally processed during peak season to add value. These snacks form good alternatives to French fried and nuts, particularly in the Thai diet (Ahromrit and Nema, 2010). Sweet potato is a nutritious food, low in fat and protein, but rich in carbohydrate. It is consumed as boiled roots and has traditionally been fried in Thailand. The sweet potato is easy to grow and cheaper than other crops but it is still poorly utilized. Sweet potato flour is used as a minor ingredient in products such as cakes, breads and noodles. Furthermore, sweet potato noodle is not much preferred by customers because of high cooking loss and moderately elastic qualities (Thao and Noomhorm, 2011). Potato, nut and sesame allergies in children have been reported (Dreborg *et al*., 1983; Castells *et al*., 1986; Scott *et al*., 2010). Cooked potato can be an allergenic food in a selected group of infants with atopic dermatitis reported by Majamaa *et al.* (2001) and Liliane *et al.* (2002). A number of foods are responsible for the majority of food-induced allergic reactions in children, namely wheat, soybean, cow's milk, egg, peanut, and fish (Sampson *et al*., 1999). Cases of allergy to cooked and fried sweet potatoes have not been reported. Sweet potato is potential as allergy-friendly sweet potato fries. French fries made from sweet potato is an interesting alternative snack to the traditional potato fries. The aim of this research was to increase linolenic acid content and natural antioxidants in deep fat fried sweet potato by using blended oils (RBO and CNO) which is considered as a healthier snack.

Materials and Methods

Materials

The sweet potato tubers (*Ipomea batatas* Lam) were obtained from a local market in Khon Kaen Province, Thailand. Chemical compositions of the sweet potatoes were analyzed following the methods of AOAC (2000), Nelson (1944) and Somogyi (1952). Color measurements (L^*, a^* and b^* values) was measured by UltraScan XE (Hunter LAB., USA) and the browning index (BI) was calculated (Saricoban and Yilmaz, 2010). Differential scanning calorimetry data (gelatinization temperature and enthalpy) were determined following the methods of Ahromrit *et al.* (2007).

Canola oil (CNO) and rice bran oil (RBO) were purchased from Tesco Lotus, in Khon Kaen Province, Thailand. Two vegetable oils, namely CNO and RBO were blended to prepare two different oil blends, i.e. RBO:CNO-1=90:10v/v and RBO:CNO-2=80:20v/v.

Preparation of sweet potato strips

The sweet potato tubers were washed, peeled and cut manually into 8 x 8 x 80 mm strips. The strips were blanched in 0.5% aqueous solution of $CaCl_2$ at 80+3°C for 5 min, drained and dried in a convection oven at 150+3°C for 12 min to reduce the surface moisture (Initial moisture=67±2%wb) for frying.

Frying conditions

A commercial deep fat fryer (model TEF-8DL, ETON STANDARD CO., LTD, Guangdong China) with temperature control of ±1°C was used. The fryer was filled with 4 L of oil and equipped with a 2-kW electric heater. The dried-blanched sweet potato strips to oil ratio was kept at 1:20 w/v and fried at a temperature of 170±2°C for 210 s. The frying started 15 min after the oil temperature reached 185±2°C and stabilized. The strips were removed from the oil and drained for 10 min over a wire screen; when most of the surface oil had been drained off, the chips were transferred to an absorbent towel and .

Physicochemical analyses of fresh oils

The four oil types (CNO, RBO, RBO:CNO-1 and RBO:CNO-2) were analysed for acid (Kardash and Turyan, 2005), iodine and peroxide values using

Table 1. Physical and chemical properties of fresh oils

Type of oils	Browning Index	Viscosity (mPas)	Smoke point (°C)	Iodine value (g I_2/100 g_{oil})	Peroxide value (meq O_2/kg_{oil})	Acid value (mg $_{KOH}$/g_{oil})
CNO	13.19 ± 0.04 [d*]	63.33 ± 0.06 [d]	256.20 ± 1.59 [a]	113.83 ± 2.27 [a]	5.88 ± 0.30 [a]	0.17 ± 0.01 [d]
RBO	22.39 ± 0.00 [a]	68.30 ± 0.00 [a]	237.20 ± 2.49 [b]	94.53 ± 1.31 [c]	2.48 ± 0.79 [b]	0.27 ± 0.00 [c]
RBO:CNO-1	20.61 ± 0.02 [b]	67.77 ± 0.06 [b]	221.17 ± 0.76 [c]	99.05 ± 1.10 [b]	2.95 ± 0.30 [b]	0.29 ± 0.01 [a]
RBO:CNO-2	19.80 ± 0.05 [c]	67.37 ± 0.06 [c]	233.93 ± 4.31 [b]	99.57 ± 0.60 [b]	3.31 ± 0.65 [b]	0.28 ± 0.01 [bc]

[*]Different letters (a-d) in the same column are significantly different ($p \leq 0.05$)

AOAC (2000) methods. Viscosity was measured by using a Brookfield DV-II+ viscometer with spindle S-1 maintained at 30±1°C (Ali *et al.*, 2014) and smoke was determined according to the Method No. Cc 9a-48 (AOCS 1998). Color was measured by UltraScan XE (Hunter LAB., USA) and browning index (BI) was calculated (Saricoban and Yilmaz, 2010). The fatty acids was measured by HPLC (Bodoprost and Rosemeyer, 2007), tocopherols and gramma-oryzanol (Chen and Bergman, 2005; Imsanguan *et al.*, 2008) was measured by HPLC (Waters 2690 Alliance, USA).

Physicochemical analyses of fried sweet potatoes

The moisture, oil, and total solid content were measured by AOAC 2000. The oils in fried samples were extracted following the methods of Wasti and Refique (2013). The fatty acids (Bodoprost and Rosemeyer, 2007), tocopherols and gramma-oryzanol (Chen and Bergman, 2005; Imsanguan *et al.*, 2008) of extracted oil from fried sweet potato were measured by HPLC. Color of the fried products was measured by a UltraScan XE (Hunter LAB., USA) and browning index was calculated (Saricoban and Yilmaz, 2010). The maximum cutting force (Ftmax) needed to cut each sample was determined from the maximum peak force expressed as hardness (N) (Tajner-Czopek *et al.*, 2008).

Statistical analysis

Statistical analyses were performed using SPSS statistical software (version 19 for windows) and are presented as mean values with standard deviations. Differences between mean values were established using Duncan's multiple range tests at a confidence level of 95%.

Results and Discussion

Physicochemical properties of sweet potato

The sweet potato used in this study contained 10.82+0.53%db reducing sugar, 0.31+0.01%db fat content, 3.11+0.02%db crude fiber, 71.13+0.34%wb moisture content, 28.87+0.01%wb total solid content, and 45.46 BI. The gelatinization enthalpy, onset temperature and peak temperature of samples were 3.18+0.19 J/gdb, 85.40+0.02°C and 88.02+0.02°C, respectively.

Physicochemical properties of fresh oils

The colors of oils were different depending on the pigment contained in the materials that it may affect on the appearance and color of fried products. Pigment in rice bran oil is brownish which influenced on the color of blended oil. The results show that the blended oils had lower BI than the RBO ($p \leq 0.05$) because CNO was added to blended oil that had lowest BI (Table 1).

Viscosity: RBO:CNO-2 (67.37+0.06 mPas) had a marginally lower viscosity than RBO:CNO-1 (67.77+0.06 mPas), because CNO (63.33+0.06 mPas) had a lower viscosity than RBO (68.30+0.00 mPas). This marginal lowering of viscosity was not significant in the context of this research. Although decreased oil viscosity is known to lower oil retention in the food (Dana and Saguy, 2006). It should be noted that present of CNO, approximately 10-20% may not influence on oil viscosity.

The smoke point of the oil, which is the temperature at which a fat or oil produces a continuous wisp of smoke when heated, is related to the amount of free fatty acids in the oil. The standard requirement for frying oils is that the smoke point must exceed 200°C (Choudhary and Grover, 2013). The results of this study indicates that CNO had highest smoke point, followed by RBO, RBO:CNO-2

Table 2. Initial fatty acid compositions (% of oil) of fresh oils

Type of oils	PUFA		MUFA	SFA	
	Linolenic acid (r^2 = 0.965)	Linoleic acid (r^2 = 0.941)	Oleic acid (r^2 = 0.975)	Palmitic acid (r^2 = 0.968)	Stearic acid [ns] (r^2 = 0.930)
CNO	4.62 ± 0.03 [a*]	12.20 ± 0.06 [c]	4.62 ± 0.03 [c]	ND	0.93 ± 0.01
RBO	0.77 ± 0.03 [d]	21.61 ± 0.39 [b]	27.05 ± 0.50 [b]	12.82 ± 0.08 [ab]	1.08 ± 0.03
RBO:CNO-1	1.33 ± 0.03 [c]	24.22 ± 0.08 [a]	31.64 ± 0.84 [a]	13.51 ± 0.45 [a]	1.34 ± 0.02
RBO:CNO-2	1.63 ± 0.14 [b]	21.57 ± 1.29 [b]	31.78 ± 2.09 [a]	12.26 ± 0.67 [b]	1.43 ± 0.47

*Different letters (a-c) in the same column are significantly different ($p \leq 0.05$) , ns = not significantly different ($p > 0.05$)
ND = Not detected
PUFA=Polyunsaturated fatty acid; MUFA=Monounsaturated fatty acid; SFA=Polyunsaturated fatty acid

and RBO:CNO-1. There was no significant difference between the smoke point of RBO:CNO-2 and that of RBO ($p > 0.05$). Smoke point decreases with increase in free fatty acid content thus addition of 10-20% CNO decreased the smoke point of the blended oil.

Iodine value (IV) is an index of the unsaturation, which is the most important analytical characteristic of oil (Choudhary and Grover, 2013) caused by the extent of oxidation and degree of heat treatment received during oil processing (Mandloi *et al*., 2014). Decrease in the IV is consistent with the decrease in double bonds when oil becomes oxidized. As shown in Table 1, CNO (113.83 $gI_2/100g_{oil}$) had highest IV and blended oils (99.05-99.57 $gI_2/100g_{oil}$) had higher IV than RBO (94.53 $gI_2/100g_{oil}$) ($p \leq 0.05$), the more rapid the oil tends to be oxidized, particularly during deep-fat frying.

Peroxide value (PV) is a measurement of oxidation during storage and the freshness of lipid matrix. In addition, it is a useful indicator of the early stages of rancidity occurring under mild condition and it is a measured of the primary lipid oxidation products. Thus, greater PV indicates greater oxidation of the oil (Choudhary and Grover, 2013). Acceptable levels for all oil samples should be below 10 $meqO_2/kg_{oil}$ following Notification of Ministry of Public Health, No.205/2000 (Ministry of Public Health, 2000). The PV values of all fresh oils in this study are below 10 $meqO_2/kg_{oil}$ (Table 1).

Acid value (AV) is a measurement of the free fatty acids in the oil. Normally, fatty acids are found in the triglyceride form, however, during processing the fatty acids may hydrolyze into free fatty acid. The higher the AV, the lower the oil quality is. Acceptable AV levels for all oil are below 0.6 $mgKOH/g_{oil}$ (Ministry of Public Health, Notification of Ministry of Public Health No.205/2000; Choudhary and Grover, 2013). All fresh oils used in this study had AV below 0.6 $mgKOH/g_{oil}$ (Table 1).

The results show that addition of CNO improved linolenic acid and oleic acid contents, but reduced gramma-oryzanol content ($p \leq 0.05$). RBO:CNO-1 (1.33%) and RBO:CNO-2 (1.63%), had higher linolenic acid content than that of RBO (0.77%) ($p \leq 0.05$). Furthermore, RBO:CNO-2 contained significantly higher linolenic acid than RBO:CNO-1 but oleic acid content was not significantly different (Table 2). It was observed slightly high SFA values occurred in blended oils but there was not significantly comparing with RBO ($p > 0.05$). Improving the levels of essential fatty acids, particularly omega-3 fatty acids (linolenic acid), can be effectively achieved by frying in blended oils instead of using a single oil. An important feature of the blended oil is its high content of linolenic and linoleic acids, which are essential dietary fatty acid and also have positive health impact (Chu and Kung, 1998; Lavie *et al*., 2009; Al-Khusaibi *et al*., 2012). The trouble of high PUFA content is the low thermal stability at frying temperatures, which reduces the useful life of the oil for deep fat frying (Warner, 2009). The results revealed that PUFA of RBO:CNO-1 and RBO:CNO-2 were 25.55 and 23.20%, respectively. Thus, RBO:CNO-2 containing less PUFA is chemically more stable, and hence, such this oil is considered to be more suitable for frying of sweet potato.

In the case of tocopherols content, addition of CNO (10-20%) enhanced tocopherols content (Table 3). CNO was a rich source of tocopherols. The antioxidant activity of α-tocopherol, γ-tocopherol has also been reported to be a strong antioxidant for vegetable oil products (KamalEldin and Appelqvist,

Table 3. Concentrations of tocopherols and gramma-oryzanol in the fresh oils

Type of oils	Tocopherols (mg/kg_{oil})			gamma-oryzanol (mg/kg_{oil})
	δ (r^2 = 0.998)	γ (r^2 = 0.986)	α (r^2 = 0.971)	(r^2 = 0.998)
CNO	11.23 ± 1.35 [a*]	301.05 ± 2.40 [a]	265.23 ± 3.70 [a]	ND
RBO	3.75 ± 0.26 [b]	67.96 ± 0.74 [d]	147.73 ± 6.34 [d]	1,399 ± 33.40 [a]
RBO:CNO-1	3.98 ± 0.69 [b]	90.48 ± 0.75 [c]	157.13 ± 5.79 [c]	1,172.55 ± 6.79 [b]
RBO:CNO-2	4.91 ± 0.20 [b]	115.58 ± 2.53 [b]	177.49 ± 6.35 [b]	1,048.23 ± 21.74 [c]

* Different letters (a-d) in the same column are significantly different ($p \leq 0.05$)
ND = Not detected

Table 4. Relevant nutritional constituents of oils extracted from fried sweet potato, deep fried in the fresh oils at 170°C for 3.5 min

Chemical composition	CNO	RBO	RBO:CNO-1	RBO:CNO-2
Linolenic acid**	5.02 ± 0.12 [a*]	0.64 ± 0.08 [d]	1.03 ± 0.06 [c]	1.33 ± 0.05 [b]
Linoleic acid**	5.75 ± 0.18 [d]	15.60 ± 1.23 [a]	13.45 ± 0.45 [c]	14.61 ± 1.07 [b]
Oleic acid**	18.73 ± 0.64 [b]	18.08 ± 0.08 [c]	17.56 ± 0.06 [d]	21.81 ± 1.13 [a]
Palmitic acid**	1.32 ± 0.03 [c]	7.92 ± 0.06 [b]	11.11 ± 0.83 [a]	7.70 ± 0.36 [b]
Stearic acid**	0.45 ± 0.05 [d]	2.56 ± 0.02 [a]	2.23 ± 0.14 [b]	1.57 ± 0.14 [c]
δ-tocopherol***	5.96 ± 0.04 [a]	1.13 ± 0.00 [c]	1.31 ± 0.18 [c]	2.30 ± 0.31b [b]
γ-tocopherol	227.77 ± 0.43 [a]	46.62 ± 0.13 [c]	43.15 ± 1.22 [c]	64.94 ± 0.24 [b]
α-tocopherol***	187.71 ± 2.43 [a]	128.39 ± 0.41 [c]	145.56 ± 3.82 [b]	145.21 ± 1.92 [b]
gramma-oryzanol***	ND	1,261.00 ± 0.13 [a]	849.98 ± 0.39 [b]	871.78 ± 28.53 [b]

*Different letters (a-d) in the same row are significantly different ($p \leq 0.05$)
ND = Not detected
** unit = $g/100g_{extracted\ oil}$, *** unit $mg/kg_{extracted\ oil}$

1996). The result of tocopherols content was revealed that a significant increase was observed with an extension of 15% in the case of RBO:CNO-1 and 36% in RBO:CNO-2 comparing with RBO ($p<0.05$). This give the RBO:CNO-2 an oxidation stability advantage as a positive effect of tocopherols on qualities of frying oil and fried products is claimed. Warner (2009) showed an effect of tocopherols on the stability of tortilla chips fried with different oils. The blended oils suffered minimal reductions in gramma-oryzanol. The RBO was a good source of gramma-oryzanol (1,399.35+33.40 mg/kg); however, the blended oils still maintained high gramma-oryzanol (1,048.23-1,172.55 mg/kg). This study shows that RBO:CNO-2 can combine good oxidative stability and nutritional quality. Consequently, RBO:CNO-2 contains significantly higher linolenic acid and tocopherol contents, and possesses a smoke point higher than those of RBO:CNO-1. Therefore, RBO:CNO-2 was selected as the frying medium.

Effect of frying oil types on changes of fatty acid compositions in fried sweet potato

The nutrition of oils extracted from fried sweet potato deep fried in four oils at 170°C for 3.5 min are shown in Table 4. The fatty acid compositions, tocopherols and gramma-oryzanol of deep fat fried products depend on type of frying oil used. Improving the levels of linolenic acid, δ-tocopherol, γ-tocopherol and α-tocopherol can be effectively achieved by frying in blended oil: RBO:CNO-2 instead of using a single oil: RBO. Several researchers

Table 5. Selected attributes of commercial French fries and sweet potato fries

Attributes	Commercial French fries	Sweet potato fries
Moisture (%wb)	30.48 ± 0.26 [ns]	29.82 ± 0.43 [ns]
Fat (%db)	23.32 ± 0.27 [a*]	7.47 ± 1.00 [b]
Total solid content (%db)	75.91 ± 1.37 [b]	92.20 ± 0.71 [a]
Browning index	46.82 ± 9.16 [b]	132.13 ± 19.22 [a]
Hardness (N)	42.93 ± 7.52 [b]	88.05 ± 16.63 [a]

[*] Different letters (a-b) in the same row are significantly different ($p \leq 0.05$)
ns = not significantly different ($p > 0.05$)

have investigated the possibility of using canola oil blended with other vegetable oils (Al-Khusaibi *et al*., 2012; Farhoosh and Kenari, 2009). Increase in the CNO ratio of blended frying oil is consistent with the increase in linolenic acid and tocopherols contents of the fried sweet potatoes. The present of CNO (10-20%) in frying medium did not influence on gramma-oryzanol content of the fried product ($p > 0.05$). Sweet potatoes fried in RBO:CNO-2 had higher essential fatty acids and tocopherols contents than those of sweet potatoes fried in RBO:CNO-1. This is in agreement with Sebedio *et al.* (1990) who reported that the bulk oil and oil absorbed by French fries were similar in fatty acid composition. Moreover, Sweet potatoes fried in RBO:CNO-2 remained a rich of gramma-oryzanol content (871.78 ± 28.53 mg/kg) which is considered as a healthier snack.

Comparison of selected quality attributes of sweet potato fries in RBO:CNO-2 and commercial French fries

Selected attributes of commercial French fries and fried sweet potatoes (RBO:CNO-2 at 170°C for 3.5 min) are shown in Table 5. There was no significant difference between moisture content of the fried sweet potato and that of the commercial French fries ($p > 0.05$) but it showed significantly lower oil content ($p < 0.05$). Available fried sweet potatoes in the market (Thailand) are the batter-coated products which contained higher oil contents than that of fried sweet potato and commercial French fries (data not shown). Color and texture characteristics of local products (data not shown) also varied due to frying process, oil quality and coating method. Many studies have been reported in relation to types of raw material, frying oil, coating and frying conditions with oil absorption, quality characteristics of fried products (van Loon *et al*.,2007; Tajner-Czopek *et al*.,2008; Ahromrit and Nema, 2010; Pahade and Sakhale, 2012). Crust of the fried sweet potatoes was also developed, which reduce oil uptake. Crust formation is a result of several changes (i.e. physical changes, gelatinization and protein denaturation) (Dana and Saguy, 2006). The fried sweet potato had higher hardness value and browning index than the commercial French fries because the nature of sweet potatoes and potatoes was different (i.e. color, reducing sugar, starch content, crude fibre) and frying conditions.

Conclusion

This study examined the compositions of blended frying oils and changes occurring in oil extracted from sweet potato deep fried in the oils at 170°C for 3.5 min. The blended oil RBO:CNO-2 contained significantly higher linolenic acid and tocopherols contents, which is considered to be very desirable from a health point of view. Moreover, this oil contained less PUFA than that of RBO:CNO-1 that RBO:CNO-2 can be considered as value-added oils for sweet potato fries. The smoke point of RBO:CNO-2 was higher than that of RBO:CNO-1; indicating frying stability and the useful life of the oil for deep fat frying. Thus, blended frying oils can combine good stability with significant nutritional benefits over individual oils. Sweet potatoes deep fried in RBO:CNO-2 had higher linolenic acid (omega-3 fatty acid), oleic acid, tocopherols contents than those of products fried in RBO:CNO-1 and RBO. Higher level of tocopherols in the fried product with RBO:CNO-2 gives the benefit by minimizing the formation of degradation of products. Moreover, it was also rich in gamma-oryzanol content which made the fried product a healthier snack. It was noted omega-3 fatty acid content in fried sweet potatoes can be improved by using the blended frying oil: RBO:CNO-2.

Acknowledgements

This work was supported by Research Fund for Supporting Lecturer to Admit High Potential Student to Study and Research on Lecturer's Expert Program Year 2012, Graduate School, Khon Kaen University and the Royal Thai Government. The authors acknowledge Professor Keshavan Niranjan for his guidance on experimental designs.

References

Ahromrit, A., Ledward, D.A. and Niranjan, K. 2007. Kinetics of high pressure facilitated starch gelatinization in Thai glutinous rice. Journal of Food Engineering 79: 834-841.

Ahromrit, A. and Nema, P.K. 2010. Heat and mass transfer in deep-frying of pumpkin, sweet potato and taro. Journal of Food Science and Technology-Mysore 47(6): 632-637.

Ali, M.A., Daud, A.S. M., Latip, R.A., Othman, N.H. and Islam, M.A. 2014. Impact of chicken nugget presence on the degradation of canola oil during frying. International Food Research Journal 21(2): 1083-1088.

Al-Khusaibi, M., Gordon, M.H., Lovegrove, J.A. and Niranjan, K. 2012. Frying of potato chips in a blend of canola oil and palm olein: changes in levels of individual fatty acids and tocols. International Journal of Food Science and Technology 47: 1701–1709.

American Oil Chemists' Society (AOCS). 2002. Official Methods and Recommended Practices of the American Oil Chemists' Society, 4th Edn., Ca 5a-40, Cd 8-53, Champaign, USA.

AOAC. 2000. Oils and Fats. In Official Methods of Analysis of AOAC International. (Ed. William, H), AOAC International, Maryland, USA. 1 - 69.

Bodoprost, J. and Rosemeyer, H. 2007. Analysis of phenacylester derivatives of fatty acids from human skin surface sebum by reversed-phase HPLC: Chromatographic mobility as a function of physico-chemical properties. International Journal of Molecular Sciences 8: 1111-1124.

Castells, M.C., Pascual, C., Martin, E.M. and Ojeda, J.A. 1986. Allergy to white potato. Journal of Allergy and Clinical Immunology 78: 1110-1114.

Chen, M.H. and Bergman, C.J. 2005. A rapid procedure for analysing rice brantocopherol, tocotrienol and ϒ-oryzanol contents. Journal of Computational Analysis and Applications 18: 139-151.

Chen, Z. 2003. Physicochemical properties of sweet potato starches and their applications in noodle products. Netherlands: Wageningen University, Ph.D dissertation.

Choudhary, M. and Grover, K. 2013. Effect of deep-fat frying on physicochemical properties of rice bran oil blends. Journal of Nursing and Health Science 1(4): 1–10.

Chu, Y.H. and Kung, Y.L. 1998. A study on vegetable oil blends. Food Chemistry 62: 191–195.

Dana, D. and Saguy, I.S. 2006. Review: Mechanism of oil uptake during deep-fat frying and the surfactant effect-theory and myth. Advances in Colloid and Interface Science 128(130): 267–272.

Debnath, S., Rastogi, N.K., Krishna, A.G.G. and Lokesh, B.R. 2012. Effect of frying cycles on physical, chemical and heat transfer quality of rice bran oil during deep-fat frying of poori: An Indian traditional fried food. Food and Bioproducts Processing 90: 249–256.

Dreborg, S. and Foucard, T. 1983. Allergy to apple, carrot and potato in children with birch pollen allergy. Allergy 38(3): 167-172.

Dueik, V., Moreno, M.C. and Bouchon, P. 2012. Microstructural approach to understand oil absorption during vacuum and atmospheric frying. Journal of Food Engineering 111: 528–536.

Farhoosh, R. and Kenari, R.E. 2009. Anti-rancidity effects of sesame and rice bran oils on canola oil during deep frying. Journal of the American Oil Chemists Society 86: 539–544.

Gunstone, F.D. 2004. The Chemistry of Oils and Fats. Sources, Composition, Properties and Uses. CRC Press: Blackwell Publishing Ltd.

Imsanguan, P., Roaysubtawee, A., Borirak, R., Pongamphai, S., Douglas, S. and Douglas, P.L. 2008. Extraction of alpha-tocopherol and gamma-oryzanol from rice bran. LWT - Food Science and Technology 41(8): 1417-1424.

Kardash, E. and Tur'yan, Y. I. 2005. Acid value determination in vegetable oils by indirect titration in aqueous-alcohol media. Croatica Chemica Acta 78(1): 99-103.

Kamal-Eldin, A. and Appelqvist, L. 1996. The chemistry and anti-oxidant properties of tocopherols and tocotrienols. Lipids 3(7): 671–701.

Lavie, C.J., Milani, R.V., Mehra, M.R. and Ventura, H.O. 2009. Journal of the American College of Cardiology 54(7): 585-594.

Lilliane, F.A., Pascal, C. and Jan, L.C. 2002. Allergy to cooked white potatoes in infants and young children: A cause of severe, chronic allergic disease. Journal of Allergy and Clinical Immunology 110(3): 524-529.

Majamaa, H., Seppälä, U., Paluoso, T., Turjanmaa, K., Klakkinen, N. and Reunala, T. 2001. Positive skin and oral challenges to potato and occurrence of immunoglobulin E antibodies to patatin (Solt1) in infants with atopic dermatitis. Pediatric Allergy and Immunology 12: 281-288.

Mandloi, S., Radadia, B.B., Visavadia, M. and Vaghela, A. 2014. A Review of chemical characteristics (acid value and iodine value) of Peanut oil. Weekly Science Research Journal 1(30): 1-4.

Ministry of Public Health. 2000. Oil and Fat. Notification of the Ministry of Public Health (No. 205) B.E. 2543 (2000) Re: Oil and Fat. Approved by Mr. Korn Thupparuagsri: Minister of Public Health (Published in the Government Gazette Vol. 118 Special Part 6 Ngor, dated 24th January 2001). Bangkok, Thailand.

Moreira, R. G., Castell-Perez, M. E. and Barrufet, M. A. 1999. Deep-Fat Frying: Fundamentals and Applications. Aspen Publication, Inc., Gaithersburg, MD.

Nelson, N. 1994. A photometric adaption of the Somogyi method for the determination of glucose. Journal of Biological Chemistry 153: 375-380.

Nestel, P., Clifton, P. and Noakes, M. 1994. Effects of increasing dietary palmoleic acid compared with palmitic and oleic acids on plasma lipids of hypercholesterolemic men. Journal of Lipid Research 35: 656–662.

Noakes, M., Nestel, P.J., and Clifton, P.M. 1996. Commercial frying fats and plasma lipid-lowering potential. Australian Journal of Nutrition and Dietics 53(1): 25–30.

Orthoefer, F.T. 1996. Rice bran oil: healthy lipid source.

Food Technology 50(12): 62-64.
Pahade, P.K. and Sakhale, B.K. 2012. Effect of blanching and coating with hydrocolloids on reduction of oil uptake in French fries. International Food Research Journal 19(2): 697-699.
Patel, M. and Naik, S.N. 2004. Gamma-oryzanol from rice bran oil – A review. Journal of Scientific & Industrial Research 63: 569-578.
Rajam, L., Kumar, D.R.S., Sundaresan, A. and Arumughan, C. 2005. A novel process for physically refining rice bran oil through simultaneous degumming and dewaxing. Journal of American Oil Chemists'Society 82(3): 213 - 220.
Sakunpak, A., Suksaeree, J., Pathompak, P., Charoonratana, T. and Sermkaew, N. 2014. Antioxidant individual ϒ-oryzanol screening in cold pressed rice bran oil of different Thai rice varieties by HPLC-DPPH method. International Journal of Pharmacy and Pharmaceutical Sciences 6(6): 592-597.
Sampson, H. A. 1999. Food allergy Part 1: Immmunopathogenesis and clinical disorders. Journal of Allergy and Clinical Immunology 103: 717-28.
Saricoban, C. and Yilmaz, M.T. 2010. Modelling the effects of processing factors on the changes in colour parameters of cooked meatballs using response surface methodology. World Applied Sciences Journal 9(1): 14-22.
Scott, H., Sicherer, M.D., Anne Munoz-Furlong, B.A., Godbold, J.H. and Sampson, H.A. 2010. US prevalence of self-reported peanut, tree nut, and sesame allergy: 11-year follow-up. Journal of Allergy and Clinical Immunology 125(6): 1322-1326
Sebedio, J. L., Bonpunt, A., Grandgirard, A. and Prevost, J. 1990. Deep fat frying of frozen prefried french fries: influence of the amount of linolenic acid in the frying medium. Journal of Agricultural and Food Chemistry 38: 1862–1867.
Serjouie, A., Tan, C.P., Mirhosseini, H. and Man, Y.B.C. 2010. Effect of vegetable-based oil blends on physicochemical properties of oils during deep-fat frying. American Journal of Food Technology 5(5): 310-323.
Somogyi, M. 1952. Note on sugar determination. Journal of Biological Chemistry 195: 19-25.
Tajner-Czopek, A., Figiel, A. and Carbonell-Barrachina, A.A. 2008. Effects of potato strip size and pre-drying method on French fries quality. European Food Research and Technology 227: 757–766.
Thao, H.M. and Noomhorm, A. 2011. Physiochemical properties of
sweet potato and mung bean starch and their blends for noodle production. Journal of Food Processing and Technology 2(1): 1-9.
van Loon, W.A.M., Visser, J.E., Linseed, J.P.H., Somsen, D. J. and Klok, J.H. 2007. Effect of pre-drying and par-frying conditions on the crispness of French fries. European Food Research Technology 225: 929-935.
Warner, K. 2009. Oxidative and flavor stability of tortilla chips fried in expeller pressed low linolenic acid soybean oil. Journal of Food Lipids 16: 133–147.
Wasti, A. and Refique, U. 2013. Extraction, methylation and quantification of fatty acids in fast food items and its health implications. Advances in Chemical Engineering and Science 3: 1-5.