Status of the bioactive phytochemicals during deep-fat frying of snack food using *nutra-coconut oil*

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Revised: 5 July 2017 / Accepted: 23 August 2017 / Published online: 7 September 2017
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Abstract The present study was carried out to study the physico-chemical changes that take place in both product and oil during the deep fat frying of a traditional savoury snack ‘kodubale’, at 120–160 °C for 120–600 s using coconut oil (CO) and nutra-coconut oil (NCO). Further, kinetic studies on moisture loss, oil uptake, color and degradation of β -carotene, total polyphenol content and antioxidant activity for kodubale was carried out during frying as a function of temperature and time. The study showed that the kinetic coefficients for above parameters increased with temperature and time and the data obtained were well fitted with first order kinetic model. The results also revealed that NCO fried product retained major phenolic acids due to the presence of antioxidants in the NCO which was enriched with flaxseed oil concentrate. The fatty acids profile of oil extracted from products obtained by frying using NCO was characterized with higher ω -3 and ω -6 fatty acids content as compared to same obtained using CO. However, the breaking strength and sensory characteristics of CO and NCO fried kodubale was found to have no significant difference ($p < 0.05$).

Keywords Frying · Nutra-coconut oil · Kodubale · Physico-chemical changes · Kinetics

Introduction

Recent consumer trends towards healthier fried foods had a substantial impact on snack food consumption which bestowed a massive growth of snack food market in the world. Deep-fat frying is one of the oldest processes of food processing (Stier 2004). Deep-fat frying not only fastens the food preparation by engrossing it into the hot oil but also delivers all the desirable characteristics such as flavors and texture in the fried product (Moreira et al. 1999). Frying involves simultaneous heat and mass transfer diffusion process in which oil provides an effective frying medium resulting in physico-chemical changes (Choe and Min 2007). During frying moisture is converted into vapour and its subsequent condensation during post frying stage results in entry of oil into the product with the development of negative pressure in the evacuated pores of the product (Krokida et al. 2000; Moreira et al. 1997). The *kodubale* is a popular traditional spicy fried snack food in India (Kumar et al. 1993) that compliments with tea or coffee. The coconut oil, containing 92% of saturated fatty acids is used as edible oil in South India especially in the state of Kerala and southern part of Karnataka (Gopala Krishna et al. 2010). The suitability of coconut oil as frying medium is well explored. However, coconut oil lacks in ω -3 and ω -6 fatty acids and oil soluble vitamins, which needs to be supplemented through blending or other means, such as enzymatic interesterification. On the other hand, the flaxseed oil contains significantly higher amount of ω -3 and ω -6 fatty acids and has several health benefits (Aliani et al. 2011). The oil seeds cake, a by-product of vegetable oil industry has anti-oxidative phytochemicals and anti-cancerous molecule (secoisolaricresinol). Therefore, it is required to elevate ω -3 and ω -6 fatty acids in coconut oil and incorporate anti-oxidative phytochemicals by utilizing the by-product, extract of oil cake.

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The key characteristics of any fried product is its quality and acceptability which is mainly governed by chemical, physical and biological reactions during processing. Kinetic models can be employed to describe the influence of processing on essential quality parameters. These models are helpful in predicting the kinetic parameters as a function of frying time and temperature. During frying, the bioactive compounds get absorbed into the product. The condensed vapours in the presence of oxygen initiate complex chemical reactions resulting in deterioration of fried oil quality and higher oil uptake by the fried product. Despite yielding desirable flavor and color, frying can also impart adverse effects, such as degradation of bioactive components (polyphenols and β -carotene) in the oil/product at higher temperatures (Andrikopoulos et al. 2002; Paulo et al. 2008). Many studies have been reported towards the changes in frying oil, during heating of oil and frying (Stier 2004; Debnath et al. 2012a, b; Alireza et al. 2010). However, reports on the nutritional availability and status of phytochemicals absorbed in the fried product are scanty. Hence, it is worth investigating the status of health promoting phytochemicals in the fried foods. In view of the above discourse, the objective of the present investigation is designed to explore the physico-chemical changes and degradation kinetics of bioactive phytochemicals during frying of snack food using coconut oil and *nutra*-coconut oil as frying medium.

Materials and methods

Procurement of raw materials and sample preparation

Bengal gram flour, coconut oil (CO), rice flour, flaxseed, spices and salt were procured from the local supermarket. The *nutra*-coconut oil (NCO) was prepared by blending CO and solvent extracted flaxseed oil in 70:30 ratio with addition of solvent extracted flaxseed oil cake concentrate (3000 ppm) using homogenizer (Heidoiph, RZR 2020, Germany) (30 min, 1500 rpm) at room temperature (Faiza et al. 2016). The dough was prepared by blending Bengal gram flour (750 g), rice flour (150 g), salt (50 g), chilli powder (50 g) and spices (20 g), adding water (400 ml) followed by mixing. The dough was made into thick cylindrical threads using low-pressure pasta making machine (La Prestigiosa, Italy), cut with the help of a sharp edged blade and made into toroidal shape (raw *kodubale*). Outer and inner diameter of *kodubale* varied between 1.7–2.2 and 1.2–1.6 cm, respectively.

Deep fat frying

The *kodubale* was prepared by frying using CO or NCO (sample: oil ratio: 1:20) in an electrical table top deep fat fryer (Mini master fryer, Continental India, Bangalore, capacity 5 l) at (120–160 °C) for (120–600 s). The oil was preheated at the set temperature to ensure uniform and constant frying temperature. Oil temperature was controlled using thermostat fixed to the fryer and monitored with digital temperature indicator. The sampling was done by taking products at different time interval and allowed to cool at room temperature (25 ± 1 °C) before packing it in air tight opaque blow molded HDPE containers of 200 g capacity and stored at refrigerated temperature. The CO and NCO fried *kodubale* were dissolved in hexane for the extraction of oil which was recovered by evaporating the hexane using Rota-vapor (Buchi, Switzerland). The hexane extracted oil obtained from product was stored in air tight HDPE containers at refrigerated temperature and further used for quality analysis (Debnath et al. 2012a, b).

Modeling of kinetic parameters

First order kinetic rate equation was employed to calculate moisture loss (k_m), oil uptake (k_o). The kinetics of degradation for β -carotene (k_β), total polyphenol contents (k_{tpc}) and anti-oxidant property (k_{AO}) were evaluated using first order reaction (Eq. 1). The change of color of *kodubale*, during frying, was described by using first order rate equation (Eq. 1) (for L^* , b^* and ΔE) and zero order rate equation (Eq. 2) (for a^*) as furnished below:

$$\ln C = \ln C_o - kt \quad (1)$$

$$C = C_o - kt \quad (2)$$

where C_o is the initial concentration of reactants, C is the concentration of reactants at time t , and k is the reaction rate constants for first order (Eq. 1) and zero order rate of reactions.

For the approximation of the mass transfer of moisture and oil flow, first order mass transfer equation Eqs. (3) and (4) were adopted, respectively (Krokida et al. 2001a, b; Manjunatha et al. 2014).

$$\ln(m_t - m_\infty)/(m_o - m_\infty) = \ln(M_r) = -K_m t. \quad (3)$$

$$\ln(o_t - o_\infty)/(o_o - o_\infty) = \ln(O_r) = K_o t \quad (4)$$

where K_m and K_o are the kinetic coefficients for moisture and oil transfer, respectively. The m_∞ and o_∞ are the pseudo-equilibrium moisture and oil content. The consideration of pseudo-coefficients was due to the nonexistence of equilibrium during frying process although the system

conducts in an equilibrium state because of mass transfer alterations occurring in the product during frying which hinders the rate of flow of moisture and oil. The moisture (M_r) and oil (O_r) ratios were calculated using initial and equilibrium moisture and oil contents. The K_m and K_o are predicted from the slopes of plot of $-\ln(M_r)$ and $\ln(O_r)$ against time (t). The temperature dependency for β -carotene, total polyphenol content, antioxidant activity degradation and color parameters were quantified by the following Arrhenius equation (Eq. 5):

$$k = k_o \cdot \exp(-E_a/RT) \quad (5)$$

where k is the reaction rate constant (s^{-1}), k_o is the pre-exponential constant (s^{-1}), E_a is the activation energy (kJ/mol), R is the universal gas constant (kJ/mol K) and T is the absolute temperature (K). Degradation coefficients are calculated by plotting the natural logarithm of particular parameter against frying time for each temperature.

Quality analysis

Physico-chemical properties

Saponification value, iodine value, acid value, free fatty acids and peroxide value were determined using the International Union of Pure and Applied Chemistry (IUPAC) method (2.202, IUPAC 1979).

Apparent viscosity of oil

The apparent viscosity of CO and NCO was measured using controlled shear-stress viscometer (Rheolab, Anton-paar, Austria) consisting of coaxial cylinder at a shear rate of $80 s^{-1}$ at $25 \pm 1^\circ C$. The temperature of the oil was maintained by thermostatically controlled water bath.

β -carotene of oil

Analysis was carried out by dissolving 5 mg of β -carotene in 50 ml of acetone. Different concentrations were prepared from this stock solution and volume made up to 10 ml with acetone. Similarly, equal amount of oil and acetone were added for sample preparation and absorbance of the solution was read using spectrophotometer (UV-1800, Shimadzu Corporation, Kyoto, Japan) at 446 nm (Myer 1966).

Total polyphenol content of the oil

The total polyphenol content in extracted oil sample was estimated by colorimetric assay based on procedures described by Jayaprakash et al. (2001).

Anti-oxidant activity using DPPH

Antioxidant activity of oil sample extract was determined according to antioxidant assay method using DPPH* (William et al. 1995). For a typical assay DPPH* reagent was prepared by dissolving 2.4 mg DPPH* in 100 ml methanol. Stock solution of sample (50 mg/15 ml MeOH) was prepared. About 3.9 ml of DPPH* reagent was pipetted into test tube containing 0.1 ml of sample stock. Absorbance of the solutions was recorded at 515 nm using spectrophotometer (UV-1800, Shimadzu Corporation, Kyoto, Japan) by taking measurements at 0, 5, 10, 20, 25, 30, 40, 50, 60 and 90 min until the absorbance value reaches plateau. Methanol was used as control. The % antiradical activity is calculated as follows:

$$\text{Antiradical activity (\%)} = \frac{(\text{Control absorbance} - \text{Sample absorbance}) * 100}{\text{Control absorbance}} \quad (6)$$

Phenolic acids

Phenolic acids and lignans were isolated from the deep fat fried *kodubale* by solvent extraction using Soxhlet apparatus. These samples were dissolved in methanol, followed by acid hydrolysis to release aglycon and filtered through $0.2 \mu m$ inorganic membrane filter. Phenolic acids standards such as ferulic acid, sinapic acid, coumaric acid, chlorogenic acid and secoisolariciresinol were injected and peak areas were compared relative to known concentration for each phenolic acid that matched the retention time of the concentrates.

The separation of phenolic acids was carried out using 20 D HPLC system with a microorb instrument, C18 reverse phase column ($25 \text{ cm} \times 10 \text{ mm i.d.}$ $5 \mu m$ particles), protected with a guard cartridge. Detection set at 280 nm to monitor lignans and phenolic peaks were scanned. Elution was done with a flow rate of 0.6 ml/min using following solvent systems: solvent A = water/glacial acetic acid (99.8:0.2 v/v) and solvent B = acetonitrile. An initial ratio of 70A:30B was followed by a linear gradient to 50A:50B, over 55 min, then back to 70A:30B, to reach equilibration of the system over 5 min. Phenolic acids were expressed as $\mu g/100 \text{ mg}$ (Meagher et al. 1999).

Fatty acids

The *kodubale* obtained during frying using CO and NCO were dissolved in hexane for the extraction of oil. The oil was recovered by evaporating the hexane using Rota-vapor (Buchi, Switzerland). About 100 mg of oil sample was

collected and dissolved in 2 ml of hexane. To this 2 ml of 0.1 M methanolic KOH is added followed by swirling for 30 s. The mixture was heated on water bath at 50–60 °C for 10 min, allowed to cool and added with 2 ml of hexane. Top layer was collected and injected into GC (IUPAC 1987). Fatty acids were analysed using GC (model GC-15A, FID, data processor, model CR-4A, SS column, 3 m length $\times$ 0.5 mm i.d., 15% DEGS, 60–80 mesh Chromosorb WAW, Shimadzu Corporation, Kyoto, Japan). The GC was run at column temperature 180 °C, injector temperature 220 °C, detector temperature 230 °C, N₂ flow of 40 ml/min, H₂ flow of 40 ml/min, air flow of 300 ml/min. The fatty acids were detected by comparing retention times of standard fatty acid methyl esters.

Moisture content of product

Moisture content of deep fried *kodubale* was determined (AOAC 2005) by drying the samples in a hot air oven at 105 °C for 6 h until they reach to a constant weight.

Oil content of product

Oil present in the fried product was estimated using AOAC (1995) method. Soxhlet fat extraction apparatus was used for the extraction of fat at 80 °C for 6 h using hexane. After extraction of oil evaporation of the solvent was performed using hot air oven at 105 °C for 1 h. The oil content was determined by weight difference.

Colour characteristics of the product

Colour parameters (L^* , a^* , b^*) were measured with a colorimeter (CR-310, Minolta Co., Ramsey, NJ, USA). The illuminant used was D65 and standard observer was set at 10°. The instrument was standardized with a white and black ceramic plate prior to measurement of *kodubale* samples. Samples were placed in the transmission compartment using transparent petri dish and evaluated at different locations to determine the L^* , a^* , b^* values. Average of ten trials is reported. Colour changes during frying were calculated using standard first order (Eq. 1) and Zero order (Eq. 2) equations. Temperature dependency of colour parameters were determined by Arrhenius equation.

Texture of product

The texture of *kodubale* were analyzed by means of the Texture analyzer (Model TA-HDi, Stable Micro System, Surrey, U.K.) using a load cell of 1KN. Breaking strength was measured for the annulus shaped fried sample mounted on a 3-point support. The cross-head speed was 50 mm/

min, respectively. The values reported were average of 10 replicates.

Sensory evaluation of product

The acceptability of the product was evaluated using hedonic scale test (Meligarrd et al. 1999). Panels were selected from the institute (CSIR-CFTRI, Mysore, India) consisting of 10 members from different departments not having any kind of relationship with the present study, in order to avoid psychological bias. The quality attributes such as color, texture, appearance, flavor and overall acceptability were tested. The 7-point hedonic scale test was used (Ram et al. 2011) to ascertain the likeness of the products by the Panellists.

Statistical analysis

All the experiments were conducted in triplicates and the mean values with standard deviations were reported. Experimental data obtained were analyzed using Microsoft EXCEL and Statistica (Statistica, StatSoft v5.5, Statsoft Inc., Tulsa, USA). Coefficient of determination, R^2 was used as the primary criteria for adequacy to fit the kinetic models. The sensory attributes of *kodubale* obtained using frying with CO and CNO and variation among the groups are interpreted with Duncan multiple range test using SPSS software (Version 16 for windows, SPSS, Inc, Chicago, IL). Statistical significance was estimated at 0.05 probability level.

Results and discussion

Physico-chemical parameters of oil

Deep fat frying leads to formation of primary oxidation products (hydroperoxides) and subsequently decomposes to yield secondary oxidation products (carbonyl, alcoholic compounds and acids) (Shyu et al. 1998). The free fatty acids formed are monitored by acid value (AV) and peroxide value (PV) indicate the production of primary oxidation products which act as index for ascertaining the early stages of oxidation of fats and oils during frying (Amany et al. 2012). The acid values of CO and NCO increased with temperatures and time and the variation was not significant ($p < 0.05$). In NCO, the peroxide value was found to increase with temperature and time whereas in CO it remained unchanged. The mean values of AV and PV for NCO were found to be 0.42 (%) and 0.48 meqv. of O₂/kg oil, respectively. Free fatty acids (FFA) are the reliable indicator for the oil quality (Debnath et al. 2012a). FFA was found to increase in both CO and NCO with

temperature and time but there was no significant ($p < 0.05$) variation observed. The mean FFA values were found to be 0.23 and 0.19 mg KOH/g of oil for CO and NCO, respectively. Iodine value (IV) is used to determine the degree of unsaturation present in the fatty acids and to characterize the fats and oils (Alireza et al. 2010). Mean iodine values were found to be 7.22 and 59.27 g I₂/100 g of oil for CO and NCO, respectively. Saponification value (SV) indicated the average molecular weight of all the fatty acids. Higher values of SV for CO (253.7 mg KOH/g of oil) and NCO (232.29 mg KOH/g of oil) can be attributed to the presence of high quantity of low molecular weight triacylglycerols (Nehdi et al. 2011).

The apparent viscosity of fresh CO and NCO were observed 0.0394 and 0.0405 Pa s, respectively. The slight change in flow behavior was strongly influenced by the unsaturated fatty acids in NCO (Kim et al. 2010). Further as the frying proceeds, oils are exposed to oxygen at higher frying temperatures leading to increase in viscosity due to the formation and accumulation of undesirable components (suspension of food elements or thermal and oxidative degraded products) (Li et al. 2015). A significant variation in viscosity of oils (Table 1) and higher oil uptake by the product (Table 4) (Kim et al. 2010) was observed.

Changes in color of the product

The frying temperature of oil has negative effect on L* value of both CO and NCO fried *kodubale*, as the

temperature of frying increases lightness decreases with time due to commencement of maillard reaction during frying. Kinetic reaction in *kodubale* obtained during frying using both CO and NCO followed the first-order equation showing desirable higher R² values indicating the best fit (Table 2). The rate constant of lightness is found to increase with increase in frying temperature (Table 2). The activation energy was found to be lower than the gulab jamun (43.52 kJ/mol) (Kumar et al. 2006) but higher than wheat-flour-based donuts (18.2 kJ/mol, (Velez-Ruiz and Sosa-Morales 2003). It was reported (Villota and Hawkes 1992) that the activation energy for non-enzymatic browning varies between (37–167 kJ/mol) and the values in this study were found within the range.

The a* values were found to increase significantly with temperature and frying time during frying, indicating the increase in redness of the savoury snack food. Zero order kinetic model was followed by a* value showing decreasing trend in the rate constant with increase in frying temperature. The accounted value of E_a in the range of values (Table 2) as specified by Villota and Hawkes (1992) was found to close to the value 62.3 kJ/mol for hazelnut roasting (Ozdemir and Devres 2000) and higher than 16.9 kJ/mol for meatball frying (Ateba and Mittal 1994).

The b* values were observed to decrease for the products obtained during frying using CO and NCO, indicating the decrease in yellowness of the snack product with increase in frying temperature (120–160 °C) and positive effect on rate constant. The ΔE values also followed the

Table 1 Changes in apparent viscosity of CO and NCO during frying

Frying temperature (°C)	Frying time (s)	Apparent viscosity* (Pa s)	
		CO	NCO
120	120	0.0397 ± 0.04 ^c	0.0408 ± 0.03 ^c
	240	0.0401 ± 0.09 ^{de}	0.0414 ± 0.08 ^{bc}
	360	0.0405 ± 0.04 ^{cde}	0.0418 ± 0.01 ^{bc}
	480	0.0409 ± 0.06 ^{bcde}	0.042 ± 0.04 ^{abc}
	600	0.0411 ± 0.05 ^{bcde}	0.0425 ± 0.02 ^{abc}
140	120	0.0414 ± 0.07 ^{bcde}	0.0427 ± 0.07 ^{abc}
	240	0.0419 ± 0.02 ^{abcde}	0.0431 ± 0.03 ^{abc}
	360	0.0423 ± 0.08 ^{abcde}	0.0435 ± 0.08 ^{abc}
	480	0.0429 ± 0.03 ^{abcde}	0.044 ± 0.01 ^{abc}
	600	0.0434 ± 0.05 ^{abcde}	0.0446 ± 0.03 ^{abc}
160	120	0.0435 ± 0.02 ^{abcde}	0.0448 ± 0.05 ^{abc}
	240	0.0437 ± 0.08 ^{abcd}	0.0453 ± 0.09 ^{ab}
	360	0.0441 ± 0.04 ^{abc}	0.0458 ± 0.01 ^{ab}
	480	0.0444 ± 0.01 ^{ab}	0.0462 ± 0.02 ^{ab}
	600	0.0452 ± 0.06 ^a	0.0465 ± 0.08 ^a

Each column containing mean values followed by different superscripts are significantly different ($p < 0.05$)

* Mean values ± SD

Table 2 CIE color kinetic model parameters for CO and NCO fried *kodubale* at frying temperature (120–160 °C) and time (120–600 s)

CO fried <i>kodubale</i>				NCO fried <i>kodubale</i>		
Color parameters	E _a (kJ/mol)	K (s ⁻¹)	R ²	E _a (kJ/mol)	K (s ⁻¹)	R ²
L*	41.85	−0.057 to −0.017	0.99	37.76	−0.054 to −0.018	0.97
a*	67.57	0.107 to 0.623	0.97	59.49	0.122 to 0.649	0.96
b*	32.54	−0.058 to 0.023	0.95	27.91	−0.060 to −0.027	0.97
ΔE	30.86	−0.553 to −0.023	0.99	26.70	−0.053 to −0.027	0.98

same trend as that of b* values with increase in temperature. Activation energy of all the color parameters for both the CO and NCO fried products showed a close values. The E_a value (Table 2) for decrease of ΔE was found to close to E_a of decrease in b* and rather lower than that of decline in L* and increase in a* (Table 2). The increase in total color change of the product may be attributed to the higher frying temperature and lower moisture content, ensuring the beginning of non-enzymatic browning (Baik and Mittal 2003).

Changes in fatty acids profile of CO and NCO during frying

The GC analysis was performed for the determination of fatty acid profile in the fried product using CO and NCO. About 91% of the total fatty acid is saturated in coconut oil and flaxseed oil contains 11% SFA and 70% of polyunsaturated fatty acids. The NCO fried *kodubale* was found to retain polyunsaturated fatty acids that were found lacking in CO fried product. The presence of ω-3 (9.39%) and ω-6 (18.09%) in NCO fried *kodubale* were ascertained (Table 3).

Changes in total polyphenol content and anti-oxidant activity

Anti-oxidant properties of oil are associated with the total polyphenol content (TPC) (Esposto et al. 2015). The polyphenol containing oils get absorbed accompanied by

moisture loss condensation during frying results in the elevation of polyphenols in the fried product. On the contrary, loss of polyphenols due to oxidative alterations directs to have the opposite end result. From the above mentioned changes, the net effect appears to be a significant reduction in the TPC in CO fried and NCO fried product (Table 4). This may be due to temperature sensitivity and oxidative loss of the polyphenols during frying and the conclusion is affirmed by Andrikopoulos et al. (2002). There was a severe loss of TPC observed for first 240 s. The TPC was found almost constant at the end of all the frying temperatures. Reduction of TPC was observed in the range of 50.36–78.50 and 17.99–74.45% for all the frying temperatures (120–160 °C) studied for CO and NCO fried product, respectively. First order kinetic model was found to be well fitted explaining the degradation kinetics of TPC and anti-oxidant activity with high R² values. The degradation rate constants (k) were found to increase with increase in temperatures and remaining kinetic parameters are shown in Table 4. The higher activation energy indicated its more temperature sensitivity of TPC and anti-oxidant activity. The loss of phytochemicals is observed may be due to increase in temperature and interaction of water present in the *kodubale* (Amit et al. 2012; Debnath et al. 2012b).

Changes in β-carotene

The β-carotene is the major carotenoid present in the oil which imparts color and stability. The effect of

Table 3 Fatty acid profile (% relative area) of oil extracted from *kodubale* obtained during frying with CO and NCO

Samples	140 °C/360 s	
	CO fried <i>kodubale</i>	NCO fried <i>kodubale</i>
Fatty acid profile (% wt)		
Capric acid (C10:0)	10.21 ± 0.1	3.06 ± 0.2
Lauric acid (C12:0)	44.60 ± 0.1	30.37 ± 0.1
Myristic acid (C14:0)	19.88 ± 0.5	11.12 ± 0.5
Palmitic acid (C16:0)	12.69 ± 0.3	9.87 ± 0.2
Stearic acid (C18:0)	7.64 ± 0.3	3.27 ± 0.3
Oleic acid (C18:1)	4.94 ± 0.1	14.81 ± 0.3
Linoleic acid (C-18:2) (ω-6)	–	18.09 ± 0.4
Linolenic acid (C-18:3) (ω-3)	–	9.39 ± 0.1

Table 4 Kinetic parameters for quality of *kodubale*

Parameters	<i>Kodubale</i> fried using CO				<i>Kodubale</i> fried using NCO			
	Ea (kJ/mol)	A (s ⁻¹)	K (s ⁻¹)	R ²	Ea (kJ/mol)	A (s ⁻¹)	K (s ⁻¹)	R ²
Moisture content (% kg/kg, db)	12.65 (14.5–0.34)*	0.572	0.023–0.034	0.970	13.49 (12.7–1.1)*	0.66	0.036–0.052	0.969
Oil uptake (% kg/kg, db)	1.38 (5.87–15.82)*	2.153	0.025–0.026	0.981	2.64 (6.05–14.24)*	2.62	0.024–0.031	0.992
β-Carotene (μg/100 g)	20.71 (2848.86–1899.24)*	0.0001	0.003–0.004	0.952	10.42 (4248.3–2998.8)*	4.84×10^{-6}	0.015–0.027	0.987
Total polyphenol content (%)	37.24 (0.653–0.253)*	0.039	0.05–0.011	0.977	28.03 (1.324–0.403)*	1.09×10^{-7}	0.011–0.041	0.945
Anti-oxidant activity (%)	10.579 (65.894–46.912)*	0.023	0.004–0.0047	0.947	5.741 (64.713–46.401)*	0.075	0.0029–0.0039	0.896

Ea, is Activation energy; A and K, are kinetic constants; R², is coefficient of determination

* The values within the parentheses indicate the interval of specific parameters

Table 5 Phenolic acids and lignan composition of oil extracted from *kodubale* obtained during frying with NCO

Frying condition		<i>Kodubale</i> fried using NCO					
Frying Temperature (°C)	Frying time (s)	Cholorogenic acid (mg/100 g)	Coumaric acid (mg/100 g)	Ferulic acid (mg/100 g)	Seco-isolariciresinol (mg/100 g)	Gallic acid (mg/100 g)	Sinapic acid (mg/100 g)
120	360	0.046 ± 0.01	0.016 ± 0.02	0.001 ± 0.06	1.970 ± 0.05	0.023 ± 0.09	0.018 ± 0.08
120	480	0.020 ± 0.12	0.005 ± 0.14	0.001 ± 0.02	0.917 ± 0.12	0.012 ± 0.07	0.011 ± 0.18
140	360	0.079 ± 0.21	0.16 ± 0.09	0.034 ± 0.16	5.478 ± 0.25	0.071 ± 0.13	0.014 ± 0.05
140	480	0.033 ± 0.03	0.029 ± 0.21	0.001 ± 0.14	3.140 ± 0.15	0.053 ± 0.06	0.013 ± 0.03
160	360	0.002 ± 0.04	0.012 ± 0.13	0.001 ± 0.04	2.914 ± 0.11	0.038 ± 0.01	0.012 ± 0.01
160	480	0.01 ± 0.17	0.001 ± 0.16	0.002 ± 0.03	0.199 ± 0.02	0.009 ± 0.02	0.011 ± 0.14

frying temperature on β-carotene loss is significant. The β-carotene was found to degrade as the frying temperature increased with time may be due to its heat-sensitiveness (Paulo et al. 2008). The reduction of β-carotene in CO and NCO fried *kodubale* was found in the range of 49–66 and 24–47%, respectively. The β-carotene showed a higher degradation in CO fried product than NCO fried product. This may be due to presence of antioxidants in the NCO which was enriched with flaxseed oil concentrate. For each temperature plot of natural logarithm of β-carotene with frying time is shown in Table 4 and confirming that the response of β-carotene degradation followed a first order equation (Engin et al. 2013). The kinetic parameters of β-carotene degradation in the product obtained by frying using both the oils are shown in Table 4. The activation energies for CO and NCO fried product are 20.71 and 10.42 kJ/mol K, respectively, indicating higher retention of β-carotene in NCO fried *kodubale*.

Changes in phenolic acids of CO and NCO during frying

The secoisolariciresinol was found to be present in highest proportion in NCO fried product than the phenolic acids (chlorogenic acid, coumaric acid, ferulic acid, gallic acid, sinapic acid) (Table 5). In CO fried product most of the phenolic acids were not detected, and hence not presented in the Table 5. At 140 °C, *kodubale* was prepared using frying for 360 s and acknowledged to have highest retention of phenolic acids and lignans (Table 5). These bioactive compounds showed a declining pattern with increase in time and temperature of frying. This may be due to the heat sensitivity of phytochemicals affected by frying temperature.

Moisture loss and oil uptake by the product

Oil uptake is considered as surface phenomenon resulting from the contest between drainage and suction into the

Fig. 1 Moisture loss and oil uptake during frying at 140 °C for 360 s

product after removal from the fried oil. Accordingly, oil absorption is related to moisture loss which is affected with frying temperature and time (Manjunatha et al. 2014). With increase in temperature moisture loss and fat uptake has been found to increase significantly (Fig. 1). The kinetic coefficients for moisture and oil transfer were yielded by plotting the negative logarithm of moisture and oil ratio against frying time. The mass transfer coefficients for moisture loss and oil uptake for fried product obtained during frying using CO and NCO were found to increase with increase in frying temperature. From the Table 4 it can be observed that activation energies for moisture loss and oil uptake are not significantly different. Higher values of activation energy for moisture loss in case of NCO fried product than CO fried product can be attributed by materials having low moisture contents having a strong water–substrate interaction (Saravacos and Maroulis 2001).

Changes in texture of the product

Oil absorption and moisture loss are associated with crust formation. Remarkable crust formation in the external zone of the product during frying leads to increase the breaking strength of fried products as observed with time and temperature. It is observed (Fig. 2) that the breaking strength for both the deep fried products obtained using two different oils (CO and NCO) at different temperatures (120–160 °C) and time (120–600 s) were found to have close values. Effect of fried oils on the hardness of the product was found to be not significant ($p < 0.05$).

Sensory evaluation

The results of sensory quality characteristics like color, texture, flavor, taste and overall acceptability were presented in the Fig. 3. The fried product obtained at each stage was subjected to panel members for sensory evaluation. The fried product obtained at 140 °C for 360 s was

Fig. 2 Breaking strength of CO and NCO fried *kodubale* at different frying temperatures (120, 140 and 160 °C) and frying intervals (120, 240, 360, 480 and 600 s)

Fig. 3 Sensory attributes of *kodubale* obtained during frying using CO and NCO

found to be superior and acceptable by the Panellists. The attributes of the fried products obtained by frying using CO and NCO were found to be not significantly different ($p > 0.05$).

Conclusion

In the present work, kinetics for the moisture loss, oil uptake and degradation of bioactive phytochemicals in the snack food (*kodubale*) during frying with *nutra*-coconut oil were studied. The *kodubale* obtained during frying using *nutra*-coconut oil was found to enrich with several health protective phytochemicals (e.g., secoisolariresinol, polyunsaturated fatty acids etc.) that are lacking in *kodubale* obtained using coconut oil. The degradation kinetics of β -carotene and polyphenols during frying were explicated well with the first order kinetic model. The physico-chemical analysis of fried oils clearly demonstrated the effect of frying temperature on the health protective constituents in fried oil and product. The mass transfer

coefficients of moisture loss and oil uptake for *kodubale* fried using CO and NCO increased with the frying temperature. However, no significant variation was observed in the texture of product fried in each oil. Based on kinetic and quality parameters, the best possible frying condition observed was 140 °C for 360 s, resulting low fat (10.3%) snack food rich in polyunsaturated fatty acids (27.48%) and phytochemicals. Therefore, the present work provides suitability to widen the scope for the use of *nutra*-coconut oil as frying medium for obtaining the healthy fried snack foods.

Acknowledgements The authors thank Prof. Ram Rajasekharan, Director, CSIR-CFTRI, Mysore, for his constant help, encouragement and providing facilities for carrying out experiment. Financial support for this work from Coconut Development Board, Kochi, is highly acknowledged.

References

- Aliani M, Donna R, Pierce GN (2011) Effect of flax addition on the flavor profile of muffins and snack bars. *Food Res Int* 44:2489–2496. doi:[10.1016/j.foodres.2011.01.044](https://doi.org/10.1016/j.foodres.2011.01.044)
- Alireza S, Tan CP, Hamed M, Che Man Y (2010) Effect of frying process on fatty acid composition and iodine value of selected vegetable oils and their blends. *Int Food Res J* 17(2):295–302. doi:[10.1007/s40011-014-0324-9](https://doi.org/10.1007/s40011-014-0324-9)
- Amany MB, Shaker MA, Azza AA (2012) Vacuum frying: an alternative to obtain high quality potato chips and fried oil. *Banats J Biotechnol* 3(5):22–30
- Amit KJ, Shilpi G, Abu-Ghannam N (2012) Kinetic evaluation of colour, texture, polyphenols and antioxidant capacity of Irish York cabbage after blanching treatment. *Food Chem* 131(1):63–72. doi:[10.1016/j.foodchem.2011.08.032](https://doi.org/10.1016/j.foodchem.2011.08.032)
- Andrikopoulos NK, Dedoussis GVZ, Faliarea A, Kalogeropoulos N, Hatzinikola HS (2002) Deterioration of natural antioxidant species of vegetable edible oils during the domestic deep-frying and pan-frying of potatoes. *Int J Food Sci Nutr* 53(4):351–363. doi:[10.1080/09637480220138098](https://doi.org/10.1080/09637480220138098)
- AOAC (1995) Official methods of analysis, 16th edn. Association of Official Analytical Chemists, Washington, DC
- AOAC (2005) Official methods of analysis, 18th edn. Association of Official Analytical Chemists, Washington, DC
- Ateba P, Mittal GS (1994) Dynamics of crust formation and kinetics of quality changes during frying of meatballs. *J Food Sci* 59(6):1275–1278. doi:[10.1111/j.1365-2621.1994.tb14694.x](https://doi.org/10.1111/j.1365-2621.1994.tb14694.x)
- Baik OD, Mittal GS (2003) Kinetics of tofu color changes during deep-fat frying. *Lebensm Wiss Technol* 36:43–48. doi:[10.1016/S0023-6438\(02\)00175-5](https://doi.org/10.1016/S0023-6438(02)00175-5)
- Choe E, Min DB (2007) Chemistry of deep-fat frying oils. *J Food Sci* 72:77–86. doi:[10.1111/j.1750-3841.2007.00352.x](https://doi.org/10.1111/j.1750-3841.2007.00352.x)
- Debnath S, Prakash M, Lokesh BR (2012a) Lipase-mediated inter-esterification of oils for improving rheological, heat transfer properties and stability during deep-fat frying. *Food Bioprocess Technol* 5:1630–1641. doi:[10.1007/s11947-010-0485-3](https://doi.org/10.1007/s11947-010-0485-3)
- Debnath S, Rastogi NK, Gopala Krishna AG, Lokesh BR (2012b) 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 Bioprod Process* 90:249–256. doi:[10.1016/j.fbp.2011.05.001](https://doi.org/10.1016/j.fbp.2011.05.001)
- Engin D, Yahya T, Yusuf Y (2013) Degradation kinetics of lycopene, β -carotene and ascorbic acid in tomatoes during hot air drying. *Lebensm Wiss Technol* 50:172–176. doi:[10.1016/j.lwt.2012.06.001](https://doi.org/10.1016/j.lwt.2012.06.001)
- Esposto S, Taticchi A, Maio DI, Urbani S, Veneziani G, Selvaggini R, Sordini B, Servili M (2015) Effect of an olive phenolic extract on the quality of vegetable oils during frying. *Food Chem* 176:184–192. doi:[10.1016/j.foodchem.2014.12.036](https://doi.org/10.1016/j.foodchem.2014.12.036)
- Faiza S, Nasirullah, Debnath S (2016) Molecular finger Printing of *nutra*-coconut oil with improved health protective phytochemicals and its efficacy as frying medium. *J Am Oil Chem Soc* 93:1301–1310. doi:[10.1007/s11746-016-2878-613](https://doi.org/10.1007/s11746-016-2878-613)
- Gopala Krishna AG, Raj Gaurav, Ajit SB, Prasanth KPK, Preeti C (2010) Coconut oil: chemistry, production and its applications—a review. *Indian Coconut J* 53(3):15–27
- IUPAC International Union of Pure and Applied Chemists (1987) Standard methods for analysis of oils, fats and derivatives, method number 2.301, 7th edn. Blackwell, Oxford, pp 174–182
- Jayaprakash GK, Singh RP, Sakariah KK (2001) Antioxidant activity of grape seed extracts on peroxidation models in vitro. *Food Chem* 73:285–290. doi:[10.1016/S0308-8146\(00\)00298-3](https://doi.org/10.1016/S0308-8146(00)00298-3)
- Kim J, Kim DN, Lee SH, Yoo SH, Lee S (2010) Correlation of fatty acid composition of vegetable oils with rheological behaviour and oil uptake. *Food Chem* 118(2):398–402. doi:[10.1016/j.foodchem.2009.05.011](https://doi.org/10.1016/j.foodchem.2009.05.011)
- Krokida MK, Oreopoulou V, Maroulis ZB (2000) Water loss and oil uptake as a function of frying time. *J Food Eng* 44:39–46. doi:[10.1016/S0260-8774\(99\)00163-6](https://doi.org/10.1016/S0260-8774(99)00163-6)
- Krokida MK, Oreopoulou V, Maroulis ZB, Marinos-Kouris D (2001a) Effects of osmotic dehydration pretreatment on quality of french fries. *J Food Eng* 49:339–345. doi:[10.1016/S0260-8774\(00\)00232-6](https://doi.org/10.1016/S0260-8774(00)00232-6)
- Krokida MK, Oreopoulou V, Maroulis ZB, Marinos-Kouris D (2001b) Effect of pre-drying on quality of French fries. *J Food Eng* 49:347–354. doi:[10.1016/S0260-8774\(00\)00233-8](https://doi.org/10.1016/S0260-8774(00)00233-8)
- Kumar KR, Subramanian BG, Indiramma AR (1993) Studies on the storage characteristics of *Kodabale*—a popular Indian spicy savoury. *J Food Sci Technol* 4:269–274
- Kumar AJ, Singh RRB, Patel AA, Patil GR (2006) Kinetics of colour and texture changes in Gulab jamun balls during deep-fat frying. *Lebensm Wiss Technol* 39:827–833. doi:[10.1016/j.lwt.2005.05.016](https://doi.org/10.1016/j.lwt.2005.05.016)
- 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. *J Food Eng* 166:349–355. doi:[10.1016/j.jfoodeng.2015.07.007](https://doi.org/10.1016/j.jfoodeng.2015.07.007)
- Manjunatha SS, Ravi N, Negi PS, Raju PS, Bawa AS (2014) Kinetics of moisture loss and oil uptake during deep fat frying of *Gethi* (*Dioscorea kamoensis Kunth*) strips. *J Food Sci Technol* 51(11):3061–3071. doi:[10.1007/s13197-012-0841-6](https://doi.org/10.1007/s13197-012-0841-6)
- Meagher LP, Gary RB, Vincent PF, Betty WL (1999) Isolation and characterization of the liganans, isolaricresinol and pinoresinol in flaxseed meal. *J Agric Food Chem* 48:3173–3180. doi:[10.1021/jf981359y](https://doi.org/10.1021/jf981359y)
- Meligarrd M, Civille GV, Carr BT (1999) Sensory evaluation techniques, 3rd edn. CRC Press LLC, Boca Raton
- Moreira RG, Sun X, Chen Y (1997) Factors affecting oil uptake in tortilla chips in deep-fat frying. *J Food Eng* 31(4):485–498. doi:[10.1016/S0260-8774\(96\)00088-x](https://doi.org/10.1016/S0260-8774(96)00088-x)
- Moreira RG, Castell-Perez ME, Barrufet MA (1999) Fried product processing and characteristics. In: Barbosa-Canovas GV (ed) Deep-fat frying: fundamentals and applications. Chapman & Hall, Food Science Book, Gaithersburg, pp 11–31
- Myer F (1966) Methods of vitamin assay, 3rd edn. The Association of Vitamin Chemists, Interscience, London, p 101
- Nehdi IA (2011) Characteristics and composition of Washingtonia filifera (Linden ex André) H. Wendl. seed and seed oil. *Food Chem* 126(1):197–202. doi:[10.1016/j.foodchem.2010.10.099](https://doi.org/10.1016/j.foodchem.2010.10.099)

- Ozdemir M, Devres O (2000) Kinetics of color changes of hazelnuts during roasting. *J Food Eng* 44:31–38. doi:[10.1016/S0260-8774\(99\)00162-4](https://doi.org/10.1016/S0260-8774(99)00162-4)
- Paulo F, Silva Da, Moreira RG (2008) Vacuum frying of high quality fruit and vegetable- based snack. *Lebensm Wiss Technol* 41:1758–1767. doi:[10.1016/j.lwt.2008.01.016](https://doi.org/10.1016/j.lwt.2008.01.016)
- Ram Y, Thaworn A, Kulchanat P (2011) Effects of vacuum frying on structural changes of bananas. *J Food Eng* 106:298–305. doi:[10.1016/j.jfoodeng.2011.05.016](https://doi.org/10.1016/j.jfoodeng.2011.05.016)
- Saravacos GD, Maroulis ZB (2001) Transport properties of foods. Marcel Dekker Inc, New York
- Shyu SL, Hau LB, Hwang LS (1998) Effect of vacuum frying on the oxidative stability of oils. *J Am Oil Chem Soc* 75(10):1393–1398
- Stier RF (2004) Tests to monitor quality of deep frying fats and oils. *Eur J Lipid Sci Technol* 106:76–771. doi:[10.1002/ejlt.200401049](https://doi.org/10.1002/ejlt.200401049)
- Velez-Ruiz JF, Sosa-Morales ME (2003) Evaluation of physical properties of dough of donuts during deep-fat frying at different temperatures. *Int J Food Prop* 6:341–353. doi:[10.1081/JFP-120017813](https://doi.org/10.1081/JFP-120017813)
- Villota R, Hawkes JG (1992) Reaction kinetics in food systems. In: Heldman DR, Lund DB (eds) *A handbook of food engineering*, Marcel Dekker, Inc., New York, pp 39–144
- William B, Cuveliar ME, Berset C (1995) Use of a free radical method to evaluate antioxidant activity, *Lebensm Wiss Technol* 28 (1):25–30 (pp 39–144). Marcel Dekker, Inc, New York