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# Kinetics of Quality Changes during Vacuum Frying of Germinated Soybean Seeds

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**ABSTRACT**

The effect of vacuum frying process on the quality of germinated soybean seeds was evaluated to develop the empirical models for description of the water loss, oil uptake and bioactive compounds degradation during frying. Germinated soybean seeds were subjected to the frying at vacuum pressure of 660 mmHg and the temperatures of 130, 140, and 150°C up to 12 minutes with 1 minute intervals. The plots of the water and oil contents versus the frying time were recorded. They showed first-order exponential kinetic models adequately predicted the water loss and oil uptake and there was a strong relationship between oil uptake and moisture loss during frying of germinated soybean seeds. The degradation kinetics of total polyphenol content (TPC) and vitamin C during frying were well represented by first-order reactions. The temperature dependence of the kinetic constants was described by an Arrhenius type equation. The activation energies for moisture loss, oil uptake, TPC and vitamin C degradation were 24.15, 18.74, 21.37 and 60.59 kJ $mol^{-1}$, respectively.

**Keywords:** kinetic, moisture loss, oil uptake, soybeans, total polyphenol content, vitamin C

## I. INTRODUCTION

Soybeans (*Glycine max* L. *Merr.*) are widely consumed for centuries because of their beneficial nutritional and functional effects from protein, oil and other bioactive compounds. However, soybeans contain antinutritional factors such as oligosaccharides, phytic acid and trypsin inhibitors resulted in the limited acceptance by consumers (Kim *et al.* 2013; Warle *et al.* 2015). Germination has been identified as a simple, inexpensive and effective process for improving the bioavailability and nutritional properties of soybeans (Cho *et al.* 2009). In addition, soybean germination overcomes the disadvantages in soybean seeds, for example, undesirable flavor and texture as well as the antinutritional factors (Bau *et al.* 1997; Kim *et al.* 2013) and this technique have be used for the development of various food products (Warle *et al.* 2015).

Frying is one of the commonly used methods in food processing (Gazmuri and Bouchon 2009). In which, the food pieces are immersed into vegetable oil used as a heat transfer medium at the temperature above the boiling point of the water (Chen *et al.* 2009). The purpose of frying is to produce pleasant characteristics for food such as aromas, color, taste and texture (Dana and Saguy 2006). During frying process the simultaneous transport of heat and mass between the oil and food occur which results in the degradation of the bioactive compounds in food (Barakat 2014; Akdaş and Bakkalbaşı 2017). Therefore, it is important to evaluate degradation pattern of bioactive compounds during food frying.

Kinetic studies of mass transferring as well as the bioactivity changes during frying of food materials containing bioactive compounds are very important. Since, the kinetic parameters during the frying process are useful for prediction of nutritional and functional qualities changes as well as for improving the value of final product through correct frying conditions (Pedreschi and Zúñiga 2009). This study was conducted to examine the kinetic of moisture and oil transferring as well as the degradation of bioactive compounds during the vacuum frying of germinated soybeans.

## II. MATERIALS AND METHODS

### 2.1 Soybeans and germination process

Soybean variety MTD 760 (*Glycine max* L. *Merr.*) was supplied from Department of Genetics and Plant breeding, College of Agricultural, Cantho University. Soybeans were cleaned and rinsed with clean water before soaking for 12 hours to reach the equilibrium moisture content at ambient temperature (30±2°C). The soaked beans were drained, rinsed and placed in a germination chamber in dark condition. Watering automatically the seeds was set up two minutes for every 4 hours with cleaned water. Germination of soybean seeds was processed at 25°C for 36 hours (Duong 2017). Germinated soybeans were frozen for 3 hours at –40°C, subsequently the frozen samples were stored in deep freezer at −20°C until the frying trials (Maity *et al.* 2012).

**2.2 Frying process and samples preparation for analysis**

Frying process was set up at 130, 140 and 150°C and the vacuum pressure of 660 mmHg (Suwanchongsatit *et al.* 2004). The ratio of the product/oil was 1:10 weight/volume (Correa *et al.* 2018; Gallo-García *et al.* 2018). The frying time of the samples was 12 minutes with 1 minute intervals, after frying samples were centrifuged at 500 rpm for 8 minutes to remove the frying oil (Maity *et al.* 2014) and frozen 1 day for freeze drying until moisture contents of samples lower than 5% (Duong 2017). Moisture and oil contents, TPC and vitamin C content of samples were then determined. The extraction procedure for analysis of the antioxidant compounds followed the studied results of Duong *et al*. (2015).

**2.3 Determination of the TPC and vitamin C contents**

The TPC was estimated by Folin-Ciocalteu method (Jiang *et al.* 2013). The TPC of samples was expressed as milligrams garlic acid equivalents per gram of dry matter (mg GAE $g^{-1}$).

Ascorbic acid (vitamin C) content was determined by redox titration with iodine (Mussa and Sharaa 2014).

**2.4 Kinetic studies of mass transferring and bioactivity degradation**

*Rate constants for moisture loss and oil uptake*

The experimental data of moisture loss and oil uptake with respect to frying time was fitted into a first order exponential kinetics model as equations of (1) and (2) (Moreira *et al.* 1995; Krokida *et al.* 2001; Gupta *et al.* 2006; Moyano and Pedreschi 2006).

$$MR = \frac{W_t - W_e}{W_i - W_e} = e^{-k_w t} \quad (1)$$

$$OR = \frac{O_e - O_t}{O_e - O_i} = e^{-k_o t} \quad (2)$$

Where MR and OR are moisture ratio and oil ratio, $W_i$, $W_t$, $W_e$ are the moisture contents (%, db) of initial, at time t and at equilibrium respectively and $O_e$, $O_t$ and $O_i$ are the oil contents (%, db) at equilibrium at time t and at initial respectively; $k_{w,}$ $k_o$ are rate constants for moisture loss and oil uptake ($min^{-1}$) and t is time of frying (min).

*Rate constants for bioactive compounds degradation*

The degradation kinetics of many compounds in foods at constant temperature follows the first-order kinetics model (Taoukis *et al.* 1997), which can be expressed as equation (3).

$$C = C_o \exp(-kt) \quad (3)$$

Where C and $C_o$ are the TPC and vitamin C contents after frying time t and t=0 min, respectively, and the k is the kinetic constant ($min^{-1}$).

***Temperature dependency of rate constants***

The temperature dependence of rate constants of moisture loss, oil uptake and bioactive compounds degradation in deep fat frying process was determined using the Arrhenius equation as equation (4) (Yıldız *et al.* 2007; Bravo *et al.* 2009; Moreira *et al.* 2009).

$$k = k_{co}\exp(Ea\,(RT)^{-1}) \quad (4)$$

Where, $k$ is rate constant at temperature T, $k_{co}$ is the frequency factor/pre-exponential coefficient, Ea is the activation energy J $mol^{-1}$, R is the universal gas constant (8.314 J $mol^{-1}$) and T is absolute temperature in Kelvin. The activation energy was determined for each treatment by the graphic representation between ln(k) versus $T^{-1}$ (K).

**2.5 Statistical analysis**

From the modeling data values, Regression analysis was used to determine the correlation coefficient ($R^2$) using Microsoft Excel 2007.

## III. RESULTS AND DISCUSSION

**3.1 Moisture loss and oil uptake**

The moisture contents and oil contents of germinated soybeans during frying at different temperatures ranging from 130 to 150°C for time intervals of 1 min were shown in Figure 1 and 2. The figures showed typical drying curves of germinated soybeans during frying which are similar to the previous studies on vacuum frying of jackfruit chip (Garayo and Moreira 2002; Maity *et al.* 2014). As the frying time increased the moisture content decreased and oil uptake increased exponentially and reached a constant value (which is termed as equilibrium value) after 10 min of frying time. The rates of moisture loss and oil uptake were higher at elevated frying temperatures corresponding to same time of frying. As the frying temperature increased from 130°C to 150°C the equilibrium moisture content decreased from 2.88 to 1.04 (%, db) and oil content increased from 28.46 to 33.18 (%, db).

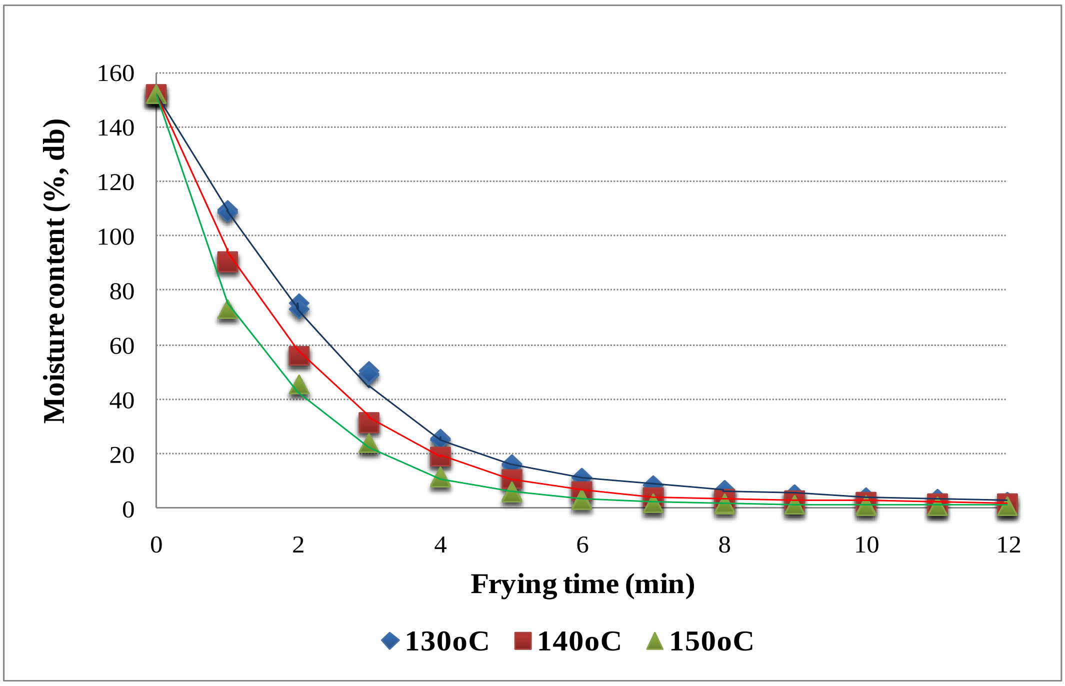


**Figure 1: Changes in moisture content during frying of germinated soybean seeds**

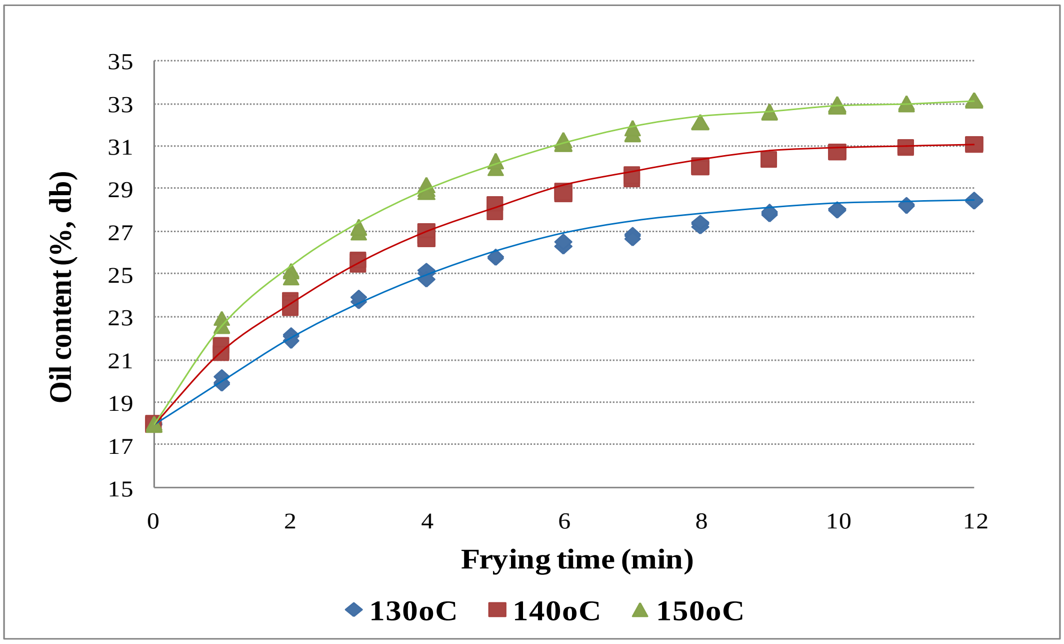


**Figure 2: Changes in oil content (%, db) during frying of germinated soybean seeds**

**Table I.** Kinetic rate constants for moisture loss and oil uptake of germinated soybean seed at different frying temperatures

| Parameters | Frying temperature (°C) | | |
|---|---|---|---|
| | 130 | 140 | 150 |
| Moisture loss rate constant $k_w$ ($min^{-1}$) | $0.481^a \pm 0.003$ | $0.567^b \pm 0.004$ | $0.677^c \pm 0.008$ |
| Oil uptake rate constant $k_o$ ($min^{-1}$) | $0.338^a \pm 0.004$ | $0.401^b \pm 0.005$ | $0.440^c \pm 0.006$ |

*Data Are Expressed as Mean±Standard Deviation (SD). Values in a Row With Different Superscripts Were Significantly Different ($p < 0.05$)*

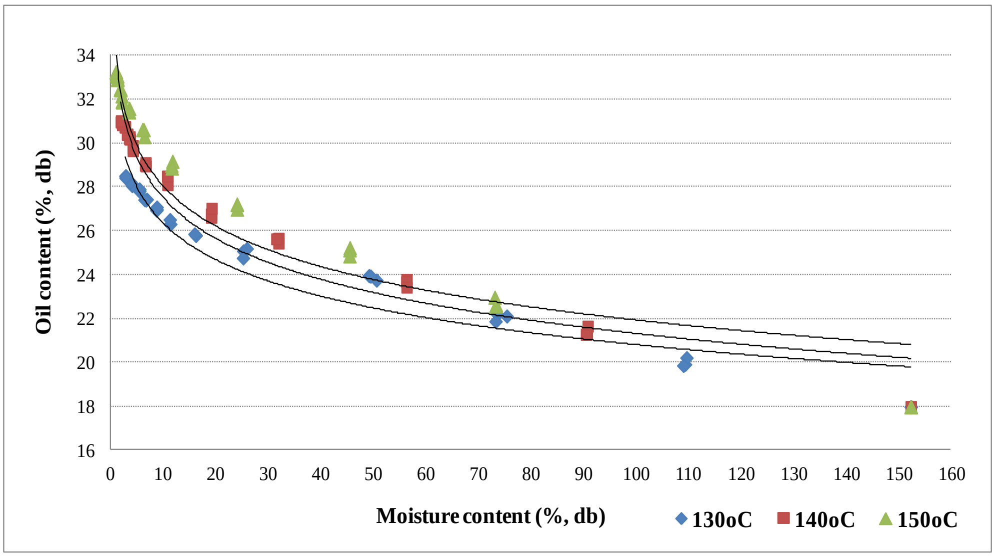


**Figure 3: Relationship between moisture and oil contents (%, db) during frying of germinated soybean seeds**

**Table II.** Parameters of different models relating to ratio of equilibrium oil content to equilibrium moisture content with temperature of frying during deep fat frying of germinated soybean seeds

| Models | $R^2$ |
|---|---|
| $O_{eq}/M_{eq} = 1.105 \times T - 437.5$ | 0.925 |
| $O_{eq}/M_{eq} = 5 \times 10^{-10} \times e^{(0.058 \times T)}$ | 0.982 |
| $O_{eq}/M_{eq} = 7 \times 10^{-63} \times T^{24.24}$ | 0.980 |

Kinetic coefficients for moisture loss and oil uptake were obtained as per equations 1 and 2 and were shown in Table I. Kinetic coefficients for moisture loss and oil uptake increased from 0.481 to 0.677 $min^{-1}$ and from 0.338 to 0.440 $min^{-1}$, respectively, with the increase in frying temperature. The increase in kinetic coefficients may be attributed to the increase in amount of heat energy transferred to the soybean seeds when increasing in the frying temperature. However, the rate of uptake of fat is far less than the rate of moisture removal. According to Rahman and Uddin (2008), since the water molecules are much smaller than the fat molecules and thus diffusion coefficient for water removal is much higher than that of fat uptake at a constant temperature.

Because moisture loss and oil uptake both were functions of the frying time, the correlation between these two variables was investigated. The results demonstrated a strong correlation between moisture content and oil content for different frying temperature (Figure 3). Gamble *et al*. (1987) hypothesized that oil entering the materials would lie in the voids left by the escaping water. Hence, in addition to quantitative aspects, water loss can become an explanatory variable for transformation and especially oil uptake (Vitrac *et al.* 2000). Similar analysis was given by Rahman and Uddin (2008) for papas frying.

The strong correlation between moisture content and oil content led to increase in the ratio of equilibrium oil content to moisture content with respect to frying temperature. Several model equations relating to ratio of equilibrium oil content to moisture content and frying temperature were tested and the parameters of the models as well as determination coefficient ($R^2$) were reported in Table II. With the highest value of $R^2$ (0.982), the relation between ratios of equilibrium oil content to moisture content was increased exponentially with frying temperature.

The temperature dependence of kinetic constants were described by the Arrhenius type equation (equation 4). The activation energy was calculated by the method of least square approximation. The activation energies of moisture loss and oil uptake were calculated to be 24.15 and 18.74 (kJ $mol^{-1}$) respectively. The activation energy for moisture loss was high compared to that of oil uptake, which indicated that moisture loss was highly temperature sensitive than that of oil uptake. According to Bhat and Bhattacharya (2001), the rate of moisture loss was much higher than that of oil uptake at same temperature of frying. Similar result was reported in deep fat frying of gethi strips (Manjunatha *et al.* 2014). In which, the activation energy for moisture loss and oil uptake were 41.53 and 27.12 kJ $mol^{-1}$.

**3.2 Degradation of antioxidant compounds**

Antioxidant compounds such as phenolics and vitamin C play an important role in increasing health benefits. These components was lost by the frying process (Barakat 2014). In this study, Total phenolic and vitamin C contents of germinated soybean seeds were found to degrade during frying (Figure 4 and 5). Sahlin et al. (2004) found that the TPC and ascorbic acid content of tomatoes had significantly reduced during frying.

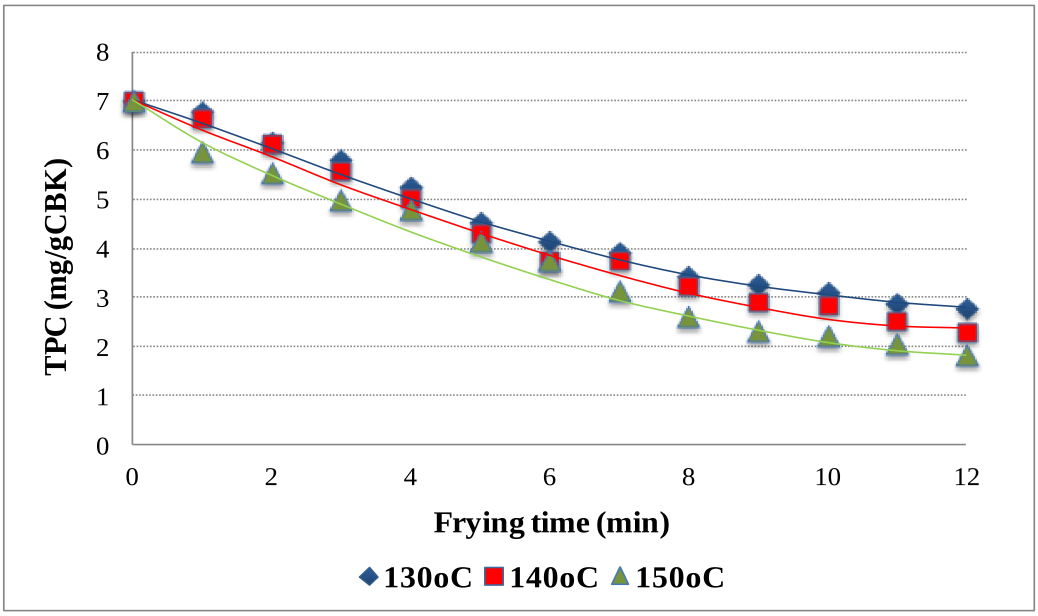


**Figure 4: Changes in TPC during frying of germinated soybean seeds**

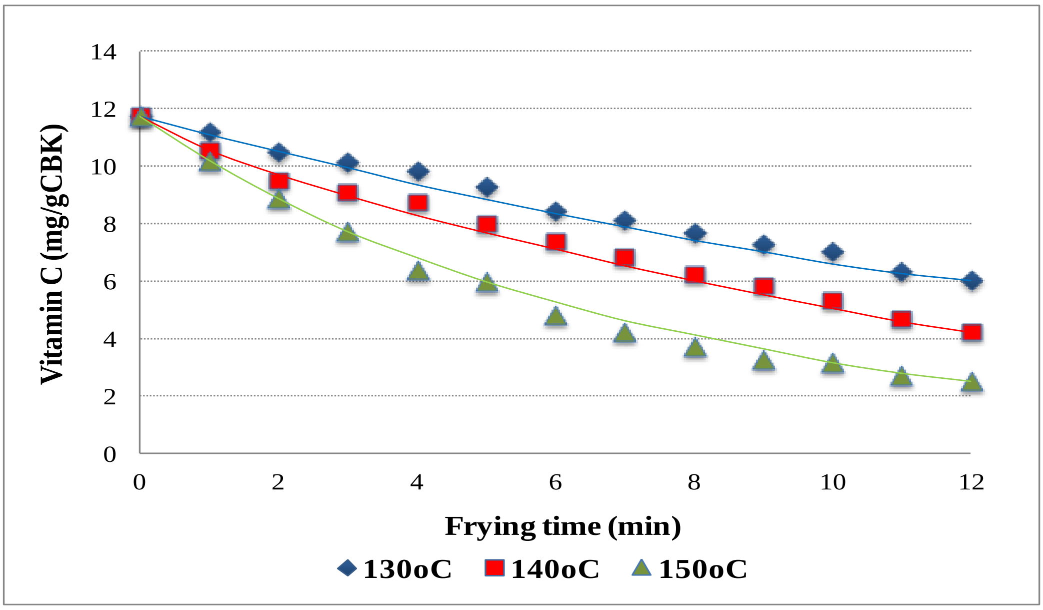


**Figure 5: Changes in vitamin C during frying of germinated soybean seeds**

**Table III.** Kinetic rate constants for antioxidant compounds degradation of germinated soybean seed at different frying temperatures

| Parameters | Frying temperature ($^{o}$C) | | |
|---|---|---|---|
| | 130 | 140 | 150 |
| TPC degradation constant $k_{TPC}$ (min$^{-1}$) | 0.055$^{a}$ ± 0.004 | 0.082$^{b}$ ± 0.004 | 0.114$^{c}$ ± 0.006 |
| Vitamin C degradation constant $k_{VtC}$ (min$^{-1}$) | 0.098$^{a}$ ± 0.010 | 0.094$^{b}$ ± 0.006 | 0.130$^{c}$ ± 0.005 |

*Data Are Expressed as Mean±Standard Deviation (SD). Values in a Row With Different Superscripts Were Significantly Different ($p < 0.05$)*

Stability of the most unstable group of polyphenols mostly depends on processing conditions such as pressure, temperature, process duration, pH, light, oxygen, metal ions, enzymes and sugars. Thermal treatments has the most important influence on polyphenol stability. Thermal degradation during processing results in the production of different degradation products which vary according to the heating temperature (Ifie and Marshall 2018). According to Alam and Parveen (2017), the decrease of TPC of fried materials may be due to the degradation of phenolic compounds as well as leaching to the frying medium. Loss of vitamins C resulted from high temperatures or enzymatic oxidation during the preparation process or long periods of frying (Somsub *et al.* 2008). Adams and Erdman (1988) stated that using high temperature for even a short time during frying was sufficient to cause reduction in the heat-labile vitamin concentration such as vitamin C.

The frying process of germinated soybean seeds showed a first order degradation for TPC and vitamin C. Some authors have shown that phenolic compounds and ascorbic acid degradation in general, follows first order reaction kinetic during heat treatment process (Vikram *et al.* 2005; Lima *et al.* 2010; Ling *et al.* 2015; Nikolić *et al.* 2018). The rate constants k were determined as the slope of Newton empirical kinetic models and were displayed in Table III. The activation energies of TPC and vitamin C degradation were calculated basing on the relation of the rate constants (k) and inverse absolute temperature and activation energy by an Arrhenius type relationship, to be 21.37 and 60.59 (kJ $mol^{-1}$) respectively. Lima *et al.* (2010) showed that the reaction kinetics during 100–180$^{o}$C heat treatments of cashew apples in oil bath was well represented by first-order reactions and the activation energy for vitamin C degradation was 94±3 kJ $mol^{-1}$. Zoric et al. (2014) has carried out heat treatment of Marasca cherries at the temperature from 80 to 120°C and has found out the degradation of anthocyanins and phenolic acids at all temperatures followed the first order reaction kinetics. The activation energy for the anthocyanin compounds degradation in Marasca cherries were in range of 42–55 kJ $mol^{-1}$ and the activation energies for phenolic acids degradation were from 8.1 to 27.1 kJ $mol^{-1}$.

## IV. CONCLUSION

The present study confirms that frying process had a major effect on moisture and oil contents as well as polyphenol and vitamin C levels of germinated soybean seeds. The kinetics of moisture loss and oil uptake showed that data is following first order exponential model and there was a strong relationship between oil uptake and moisture loss during frying which is an important phenomenon in the context of characterizing the physical properties of fried product. The degradation kinetics for the polyphenol and vitamin C contents followed first-order reaction and kinetic coefficients for these changes were found to increase with the temperature. The modeling of the kinetics would be useful for the process standardization in the operation of food frying.

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