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Effect on physico-thermal properties of *Pantoa* during sub-baric frying

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Abstract
Pantoa is traditional dairy product of the Indian subcontinent. The physico-thermal properties of *Pantoa* during sub-baric frying were evaluated at varying temperatures. The *Pantoa* balls were fried at 115, 125 and 135 °C for 4, 6 and 8 min at 200 mm Hg vacuum. The average sphericity values of sub-baric fried *Pantoa* at 115, 125 and 135 ºC were 0.921, 0.943 and 0.968, respectively. The rate of expansion of *Pantoa* increased with increase in sub-baric frying temperature. The Apparent density values decreased with increase in the frying temperatures. The thermal conductivity of *Pantoa* decreased as frying time and temperature increased from 0.354±0.015 W/mK to 0.169±0.020, 0.158±0.025 and 0.146±0.031 W/mK at 115, 125 and 135 ºC, respectively. The thermal diffusivity had an increasing trend up to 270 s of sub-baric frying at 135 and 125 ºC and reached higher value of 0.196±0.064 mm^2/s and 0.186±0.067 mm^2/s, respectively from the initial value of 0.105 mm^2/s. The volumetric specific heat of *Pantoa* was decreased as its function of sub-baric frying temperature and time.

Keywords: *Pantoa*, sphericity, expansion ratio, apparent density, thermal conductivity, thermal diffusivity, volumetric specific heat

Introduction
India leads the world in milk production with annual 155.5 million tonnes of milk (NDDB, 2016) [10], which accounting for more than 18.5 per cent of world milk production. The per capita availability of milk in India is increased from 176 g per day in 1990-91 to 322 g per day in 2014-15. It is more than the world average of 294 g per day during 2013. This represents a sustained growth in availability of milk and milk products for the growing population. Production and consumption of milk products is rapidly changing in all over the country (Pal, 2008) [13].

Pantoa is a traditional *chhana* based sweet, originated from the Eastern parts of the country. It is similar to *Gulabjamun* in flavour and appearance but differ in its chemical composition and textural attributes. *Pantoa* is manufactured by blending *chhana*, sometimes mixed with *khoa*, *maida*, baking powder and other optional ingredients followed by deep fat frying (DFF) in *ghee* or vegetable oil and soaking in sugar syrup. *Pantoa* is typically characterized by a light brown to deep brown crust and creamish white spongy core. The final product has optimum sweetness and caramelized flavour with a hard and firm body and slightly chewy texture (Nath, 1992) [9].

Vacuum frying is a novel frying process that is carried out under pressures well below atmospheric levels, preferably below 50 torr (6.65 kPa) (Andres-Bello *et al.*, 2011). Due to the reduced pressure, the boiling points both of the oil and the moisture in the foods are lowered. Vacuum frying has some advantages that include: (1) can reduce oil content in the fried product, (2) can preserve natural colour and flavour of the product due to the low temperature and oxygen content during the process and (3) has less adverse effects on oil quality (Shyu *et al.*, 1998) [16].

Measurements of thermal properties are very important in the determination of heart transfer parameters. Knowledge of accurate heat and mass transfer parameters is important for modeling processes during which simultaneous heat and mass transfer take place. The heat and mass transfer during deep fat frying is thus simultaneous and complex because of the temperature and concentration gradients developed in the product. The physico-thermal properties of the food material change continuously because of moisture depletion and temperature change. The changes in product properties provide an interesting engineering problem to analyse and quantify the dynamics of heat and mass transfer during sub-baric frying. An understanding of the heat and mass transfer mechanism could aid in the design and development of energy efficient and optimal processes for sub-baric process.

Materials and methods

Preparation of *Pantoa*

Pantoa was prepared according to the procedure outlined by Neethu (2013) [11] with slight modifications and sub-frying and soaking were carried out in sub-baric thermal processor (Kumar, 2016) [5]. The detailed procedure was given in the following paragraphs.

Preparation of *khoa*

For the *khoa* preparation, the method described by Rajorhia (1976) [15] was adopted with slight modifications. Fresh milk having 3.8-4.0% fat and 8.5% SNF was transferred to a steam-jacketed kettle where the steam pressure was maintained at 2 kg/cm^2. The milk was then allowed to boil vigorously with continuous stirring-cum-scraping. It was concentrated to a semi-solid consistency till the moisture content reached 25 to 30% on wet basis (w.b.).

Preparation of *chhana*

Chhana was prepared following the method suggested by Verma (1989) [20] with slight modifications. Fresh milk having 3.8-4.0% fat and 8.5% SNF was heated to 90 °C in a stainless steel vessel with continuous stirring. Then it was cooled to 85 °C. Citric acid solution (Brand: Finar Chemicals Ltd., Ahmedabad, India) at 2% concentration (70-75 °C) was added slowly to the milk (85±2 ºC) until the pH of milk reached 5.4. Constant stirring was done without breaking the coagulum until the clear greenish whey separated from it. It was left undisturbed for 15-20 min and then filtered through a muslin cloth to get the coagulated mass separated from whey. The coagulum was tied in muslin cloth and hung for 40-45 min to drain off whey. Thus *chhana* with 55-60% moisture (w.b.) content was obtained.

Preparation of dough

Dough was prepared by blending *khoa* and *chhana* in the ratio of 4:5. Other non-dairy ingredients such as *maida*, *semolina* and arrowroot powder were added to the blend, each at the rate of 3% on w/w basis of dough. Ground sugar was added at the rate of 0.7%, on w/w basis. The dry ingredients were mixed and added to the *khoa-chhana* blend. The blend containing all the ingredients was kneaded in a dough blender (Lalith Industries, Bangalore, India) for 5-7 min to obtain dough.

Sub-baric (vacuum) frying of *Pantoa*

Frying was the main unit operation involved in the manufacture of *Pantoa*. The dough was rolled into balls of each having 12 g weight and sub-baric fried in refined sunflower oil at three different temperatures namely, 115, 125 and 135 °C for 4, 6 and 8 min at 200 mm Hg vacuum. Sub-baric frying process was carried out in sub-baric thermal processor as shown in Fig (Kumar, 2016) [5] with ten balls in each batch. The experiment was initiated once the oil temperature reached the required frying temperature without any temperature gradients. Initially, rolled balls were loaded to perforated trays of sub-baric fryer. Then trays immersed into frying oil chamber. Frying chamber was depressurized and product was fried for required time at particular temperature and pressure. During sub-baric frying, basket was rotated clockwise or anti-clockwise in order to eliminate temperature gradients and also ensure uniform frying. After complete frying, frying basket was lifted and suspend in vacuum for 5 min @ 600 mm Hg vacuum in order to remove oil from the surface of the fried product. Finally, chamber was pressurized and fried *Pantoa* balls was taken out and cooled to room temperature. After cooling, the samples were transferred to labeled plastic containers for further analysis.

Measurement of Thermal Properties

For the measurement of core temperature during sub-baric frying of *Pantoa*, the thermocouple probe of the data logger thermometer (Model: CENTER® 374, HTA Instrumentation Pvt. LTD., Bangalore, India) was pierced into the geometric centre of *Pantoa (*dough ball) and then immersed in oil for sub-baric frying. The core temperature of the sample was recorded every 10 s time interval during sub-baric frying. The temperature measurement was repeated 6 times for each time-temperature combination.

The thermal properties of *Pantoa* such as thermal conductivity, thermal diffusivity and volumetric specific heat were monitored and recorded using KD2 Pro thermal properties analyzer (Decagon Devices, Pullman, WA) with SH-1, dual needle type probes (30 mm) at 30 s frying time interval. The properties were measured after cooling the samples to ambient temperature. The probe was inserted into the geometric centre of the product and kept undisturbed then the measurement was taken. Thermal properties measurement was carried 3 times for each time-temperature combination.

Determination of Dimensional Changes

The weight and dimensional changes of *Pantoa* were measured using weighing balance (Model: CP323S, Sartorius Mechatronics India Pvt. Ltd.) and digital caliper (Model: CD-6" CSX, Mitutoyo Corp. Kawasaki, Japan), respectively. The dimensions of *Pantoa* were measured as 'a', 'b' and 'c' in 'x', 'y' and 'z' directions of the geometry, respectively. From the 'a', 'b' and 'c' values obtained, sphericity, apparent density and expansion ratio were calculated.

Sphericity (φ)

The geometry of foods was essential to model the heat and mass transport phenomena in the product. *Pantoa* at every 30 s of frying were evaluated for their ability to retain the shape at all the three temperatures at constant vacuum pressure. Sphericity of *Pantoa* was calculated using the Eq. (1) (Mohsenin, 1970) [6].

$$\phi = \frac{\text{Geometric mean diameter}}{\text{major diameter}} \qquad (1)$$

Geometric mean diameter = (abc)^{⅓}

Where 'a', 'b' and 'c' are the dimensions of *Pantoa*

Expansion ratio (ε)

The expansion ratio of a product can be defined as the ratio of final cross sectional area to initial cross sectional area. It was determined using the Eq. (2)

$$\varepsilon = \frac{A_t}{A_0} \qquad (2)$$

Where, A_t was the cross sectional area of *Pantoa* at time't' and A_0 was the cross sectional area of *Pantoa* at zero time.

Apparent density (ρ_{app})

Apparent density of the product can be defined as the ratio of weight of *Pantoa* ball to volume of *Pantoa* ball. It was calculated using the Eq. (3)

$$\rho_{app} = \frac{\text{weight of pantoa ball}}{\text{volume of pantoa ball}} = \frac{w}{\frac{4}{3}\pi r^3} \qquad (3)$$

Where, *'w'* was the weight of *Pantoa* and 'r' was the radius of *Pantoa*

Results and Discussions

The physico-thermal properties of *Pantoa* as it transitioned at various times during sub-baric frying were determined and the results are discussed below.

Thermal properties of *Pantoa* fried in sub-baric fryer at different temperature and time

Changes in the thermal properties such as thermal profile of *Pantoa*, thermal conductivity, thermal diffusivity and volumetric specific heat occurred during sub-baric frying of *Pantoa* at 115, 125 and 135 ºC for 480 s (30 s intervals) at 200 mm Hg vacuum are discussed below.

Thermal profile

The Fig.1 represents the temperature profiles of sub-baric fried *Pantoa*. The graph dawn between sub-baric core temperatures of *Pantoa* and sub-baric frying time resembles sigmoid in shape for all experiments (Fig. 1). The sub-baric core temperatures of *Pantoa* recorded at every 10 s frying time interval for all sub-baric frying temperatures 115, 125 and 135 ºC during 480 s of sub-baric frying. At all the sub-baric frying temperatures tried, there was an initial lag period for about 30 s because the temperature did not change much until the heat from the oil was transferred to core of the *Pantoa* ball. After the initial lag period, the core temperature increased drastically till about 180 s, which showed the rapid heating of product before finally approaching the boiling point of water (88±0.5 °C). Since, the *Pantoa* was fried under reduced pressure in a closed system, which lowered the boiling point of water in the product.

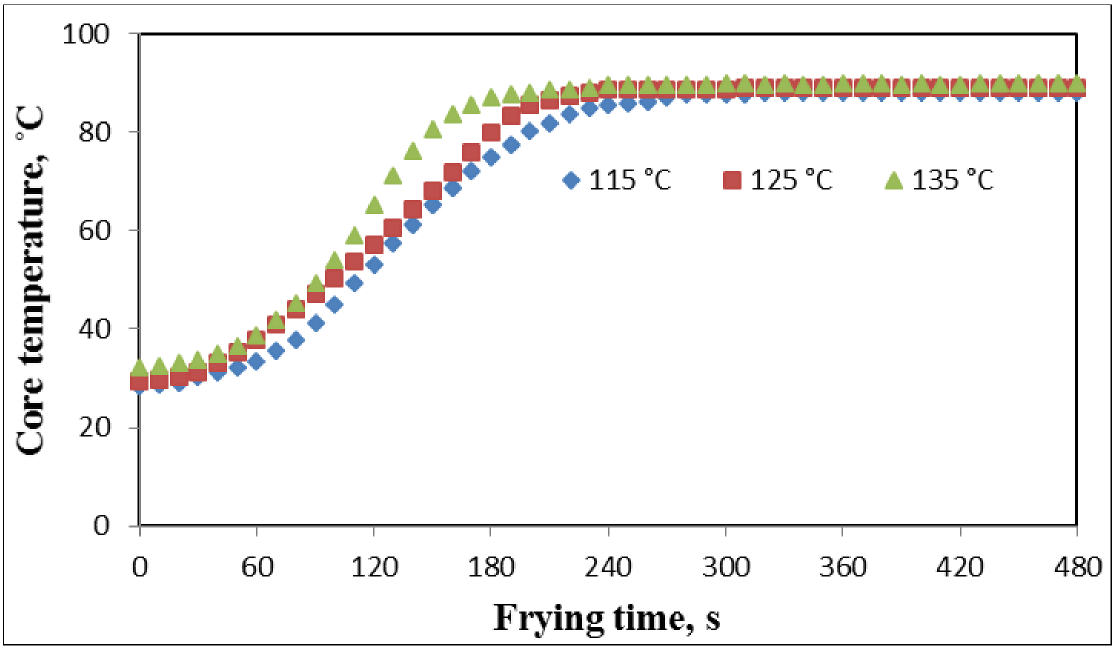

Fig 1: Thermal history of *Pantoa* during sub-baric frying at different temperature and time

It was found to be more core temperature at higher sub-baric frying temperature which is in agreement with the results of *Pantoa* fried in conventional fryer at different temperatures (Neethu, 2013); *Gulabjamun* (Franklin *et al.*, 2013) [13]; vacuum frying of potato strips (Yamsaengsung *et al.*, 2008) [22]. Sub-baric frying of *Pantoa* took 280, 220 and 180 s of frying time at 115, 125 and 135 °C, respectively to attain the boiling point of water. Elevation of the boiling point of water inside the product due to presence of solutes inside the product which got concentrated during the frying process (Yildiz *et al.*, 2007) [23]. The temperature inside the product reached a plateau towards the end of frying because the interior was not dry enough to allow for the internal energy to increase (Yildiz *et al.*, 2007) [23].

Thermal conductivity (k)

The thermal conductivity of *Pantoa* samples measured every 30 s frying time interval during sub-baric frying at different temperature is shown in the Fig. 2. It was found that the thermal conductivity of *Pantoa* decreased as sub-baric frying time and temperature increased. The thermal conductivity of *Pantoa* decreased from the initial value of 0.354±0.015 W/mK to 0.169±0.020, 0.158±0.025 and 0.146±0.031 W/mK at 115, 125 and 135 ºC, respectively during sub-baring frying. Decreased moisture content and increased fat uptake in the product during sub-baric frying resulted decrease in thermal conductivity value with respect to time.

Higher thermal conductivity was observed in the *Pantoa* having more moisture and less fat content in the initial stages of frying. Moisture was replaced by fat inside the product as frying progressed and increase in fat content which acted as insulation resulted in reduced heat conduction, thereby lowering the thermal conductivity values (Radhakrishnan, 1997) [14]. Similar trend observed for *Pantoa* (Neethu, 2013) [11] and the 'k' values of *Pantoa* decreased from 0.351±0.024 W/mK to 0.232±0.030, 0.231±0.010 and 0.199±0.028 W/mK at 125, 135 and 145 ºC, respectively during sub-baric frying of *Pantoa*. Moreira *et al.*, (1995) [9] observed that 'k' values of tortilla chips decreased from 0.230 to 0.090 W/mK when fried at 190 ºC in soy bean oil.

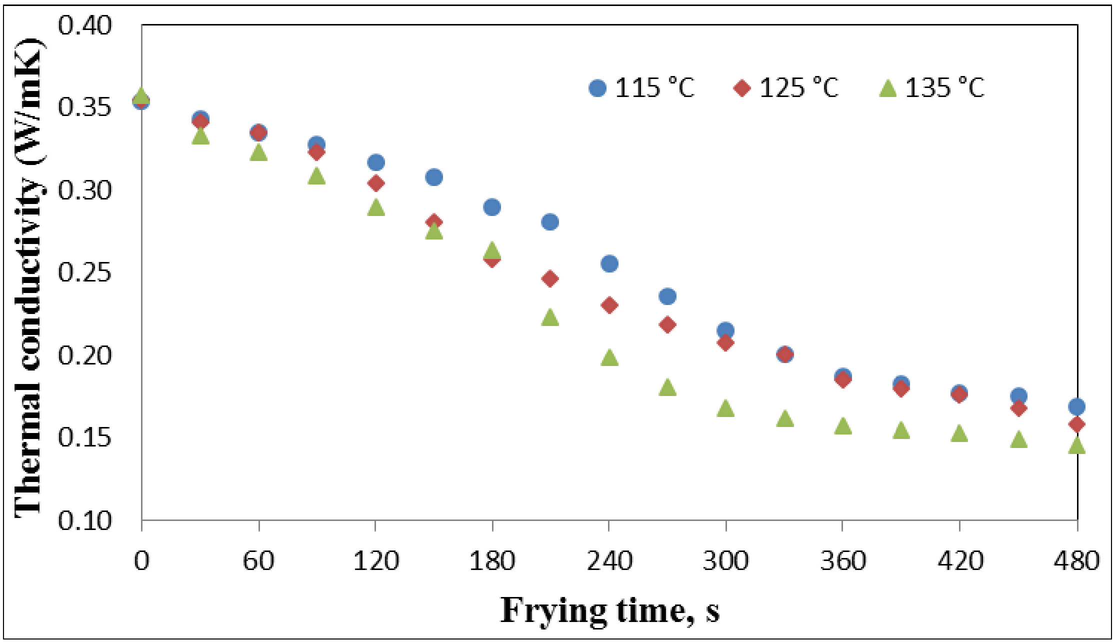

Fig 2: Thermal conductivity (k) of *Pantoa* during sub-baric frying at different temperature and time

Thermal diffusivity (α)

The thermal diffusivity of *Pantoa* samples measured at every 30 s interval sub-baric frying time at different temperature is presented in the Fig.3. Thermal diffusivity of *Pantoa* was increased as function of frying temperature and time during sub-baric frying. The results showed that thermal diffusivity has increasing trend up to 270 s of sub-baric frying at 135 and 125 °C and reached higher value of 0.196±0.064 mm^2/s and 0.186±0.067 mm^2/s, respectively from the initial value of 0.105 mm^2/s.

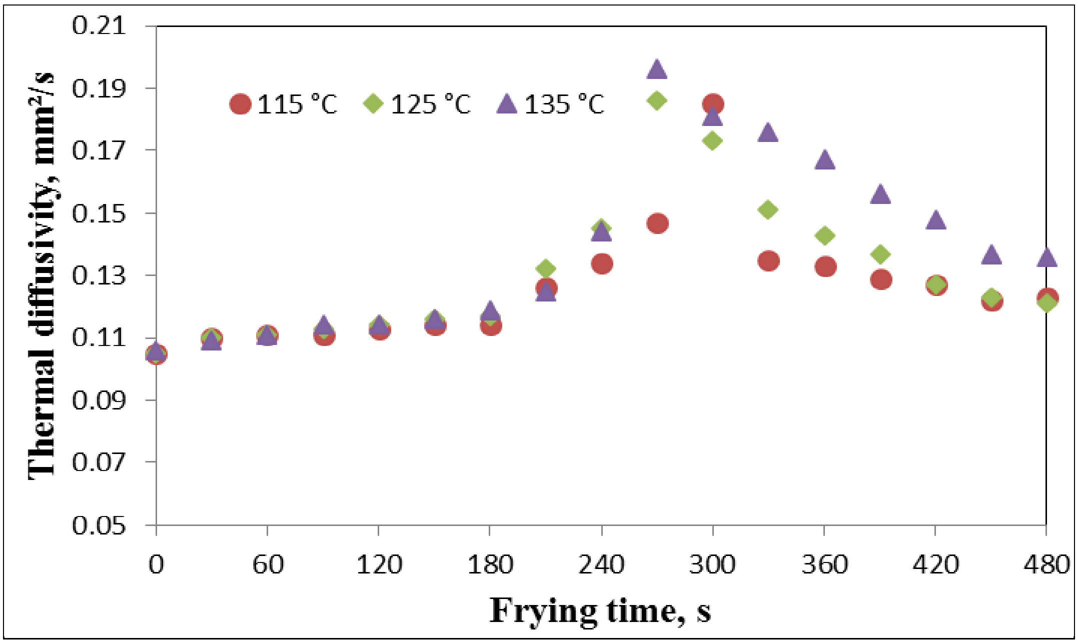

Fig 3: Thermal diffusivity (mm^2/s) of *Pantoa* during sub-baric frying at different temperature and time

However, at 115 ºC the thermal diffusivity continued to increase till 300 s of frying and attained 0.185±0.011 mm^2/s. Thereafter, it decreased gradually till the end of frying irrespective of the sub-baric frying temperature. Similar results were observed for *Pantoa* fried in conventional fryer (Neethu, 2013) [11] and chicken slabs (Velez-Ruiz *et al.*, 2002). The results showed that thermal diffusivity increased with increase in frying temperature and attained higher values, then decreased gradually till the end of frying.

Volumetric specific heat (C_p)

The volumetric specific heat of *Pantoa* samples measured at every 30 s interval at different temperature combinations as shown in the Fig. 4. The volumetric specific heat of *Pantoa* was decreased as it functions of sub-baric frying temperature and time. It has been found that specific heat was decreased from initial value of 3.334 MJ/m^3K to 1.264, 1.182 and 1.143 MJ/m^3K at 115, 125 and 135 ºC, respectively during sub-baric frying.

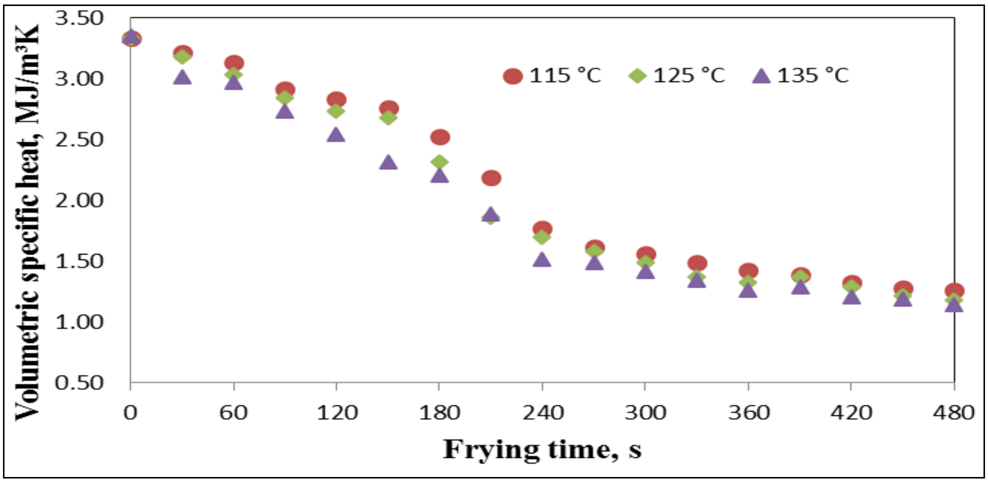

Fig 4: Volumetric specific heat (MJ/m^{3}K) of *Pantoa* during sub-baric frying at different temperature and time

The decrease in C_p value with frying time was attributed to the decrease in moisture content and increase in oil content of the product. In general, C_p showed a similar trend as that of thermal conductivity of the sub-baric fried product. A similar trend was reported for *Pantoa* fried in conventional fryer (Neethu, 2013) [11] and tortilla chips (Moreira *et al.*, 1995) [8] while contrary to the frying temperature effect on Cp, Baik and Mittal (2003) reported that the specific heat of tofu increased with increase in frying temperature.

Effect on dimensional changes in *Pantoa* during sub-baric frying at different temperature and time

Changes in product dimensions such as sphericity, expansion ratio and apparent density occurred during sub-baric frying of Pantoa at 115, 125 and 135 °C for 480 s (30 s intervals) at 200 mm Hg vacuum are discussed below.

Sphericity

The sphericity of *Pantoa* samples measured every 30 s interval at different time temperature combinations. The average sphericity values of sub-baric *Pantoa* at 115, 125 and 135 °C were 0.921, 0.943 and 0.968, respectively. The sphericity of *Pantoa* was increased with increase in sub-baric frying temperature. At lower sub-baric frying temperature, intermediate stages of frying the product had a soft crust, which could not retain the desired shape. Sphericity of sub-baric fried *Pantoa* observed to be higher as compare to DFF *Pantoa* because rate of evaporation water in sub-baric frying was at faster rate. Since the sphericity values were closer to 1, the product was considered as a sphere for modeling of heat and mass transfer phenomena during sub-baric frying.

Expansion ratio (ε)

The effects of sub-baric frying temperature and time on expansion ratio of Pantoa are depicted in the Fig. 5. The rate of expansion of *Pantoa* increased with increase in sub-baric frying temperature. The maximum expansion ratios of 1.195, 1.206 and 1.231 were attained after 270, 240 and 210 s of sub-baric frying at 115, 125 and 135 °C, respectively. No baking powder was used for *Pantoa* during sub-baric frying as it reported to influence expansion of the product (Kumar, 2016) [5]. The expansion ratios decreased marginally as sub-baric frying time progressed. The expansion of the product was attributed to the formation of void spaces and pores in the product, formed by flash evaporation of moisture.

Volumetric expansion found to be higher at higher sub-baric frying temperature, because of rapid flash evaporation of moisture from the product at higher temperature produces larger pores in the product, which leading to increased expansion. Thus in the beginning of frying, the moisture loss was rapid and the balls expanded quickly (Tan and Mittal, 2005). At the end of frying, the shrinkage was highest and expansion ratio was lowest at 135 °C. This could be due to the faster formation of crust at higher temperature, producing increased resistance to expansion (Yagua and Moreira, 2011) [21]. Similar trend was observed for *Pantoa* (Neethu, 2013) [11] and donuts (Velez-Ruiz and Sosa-Morales, 2003).

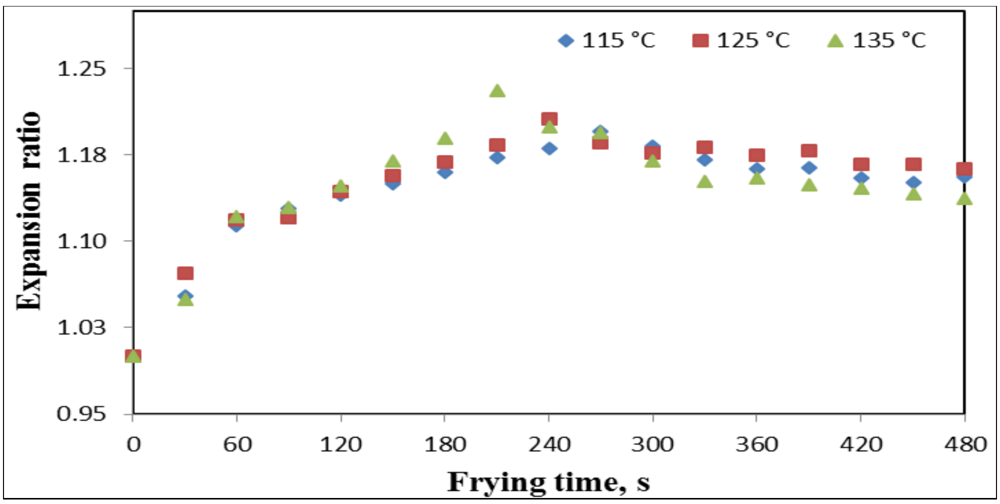

Fig 5: Effect of sub-baric frying on expansion ratio of *Pantoa* at different temperature and time

Apparent density

The Fig. 6 represents that the apparent density of *Pantoa* decreased as increase in sub-baric frying time and temperature. Apparent density of *Pantoa* decreased from initial value of 1112.24 kg/m^3 to 536.01, 482.12 and 412.25 kg/m^3 at 115, 125 and 135 ºC during sub-baric frying. The average apparent density of *Pantoa* was found to be 740.62, 715.94 and 675.91 kg/m^3 at 115, 125 and 135 ºC, respectively. The change in apparent density of the product was highly influenced by moisture loss and oil uptake during frying (Krokida *et al.*, 2000) [4].

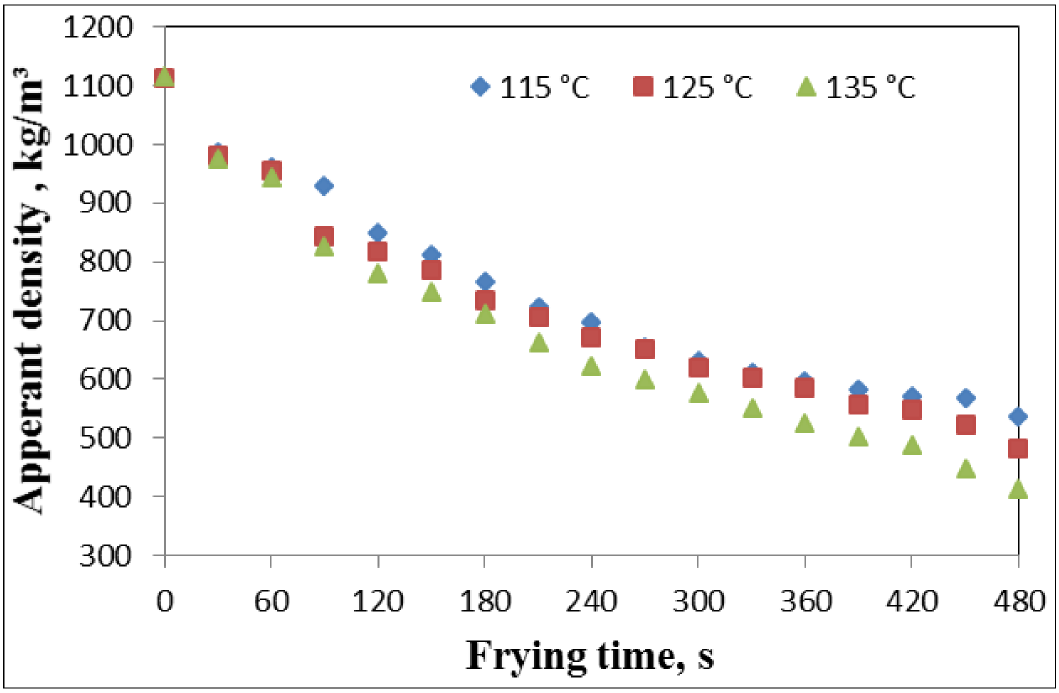

Fig 6: Effect of sub-baric frying on apparent density of *Pantoa* at different temperature and time

At 135 °C of sub-baric frying temperature, the highest decrease in density of the product could be due to the rapid evaporation of moisture from the product. Initially, after 30-60 s of sub-baric frying time most of the changes in apparent density of product at all the sub-baric frying temperatures. The apparent density during frying decreased with increase in frying time and temperature in food products such as *Pantoa* (Neethu, 2013) [11], sweet potatoes (Taiwo and Baik, 2007) [17], potato chips (Moreira *et al.*, 2009; Yagua and Moreira, 2011) [21, 7], donuts (Velez-Ruiz and Sosa-Morales, 2003) and mango chips (Nunes and Moreira, 2009) [7].

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Conclusion

The study estimated the physico-thermal properties of *Pantoa* during sub-baric frying. Sphericity was closer to unity and the expansion ratio of sub-baric fried *Pantoa* was relatively more than the conventional one. The reduction in thermal conductivity values with increase in frying time could be attributed to decreased moisture content and increased fat uptake in the product during frying. The effect of crust formation leads to changes in the thermal diffusivity values. The decrease in the volumetric specific heat value with increase in frying time could be due to the decrease in moisture content of the product.

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