Food Research 5 (2) : 106 - 112 (April 2021)
Journal homepage: http://www.myfoodresearch.com

FULL PAPER

Drying kinetics and quality of tray dried peanut milk residue

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Article history:
Received: 3 August 2020
Received in revised form: 7 September 2020
Accepted: 9 November 2020
Available Online: 21 February 2021

Keywords:
Peanut milk residue,
Thin layer drying,
Drying kinetics,
Muffins,
Quality parameters

DOI:
https://doi.org/10.26656/fr.2017.5(2).424

Abstract

The research was aimed to prepare muffins using groundnut milk residue. Groundnut or Peanut (*Arachis hypogaea*) is one of the most consumed legumes in the world. Groundnut is also a prominent source of plant-based milk. The groundnut milk was prepared by the conventional method with 1:2 ratio of water. The residue was tray-dried at different temperatures (60, 70, 80°C) to study the drying kinetics. Physical and chemical properties of optimized groundnut milk residue powder were analysed. Muffins were developed using milk residue. Quality parameters and sensory analyses were also done for the product obtained from milk residue. The results indicated that groundnut milk residue dried at 70ºC had less water absorption capacity and more water solubility index. Also, the powder retained colour when dried at 70°C. The experimental data were fitted to five mathematical models. Wang and Singh's model was found to have the best fit with R^2 value of 0.9932. The increase in temperature promotes drying at a faster rate.

1. Introduction

Groundnut or Peanut (*Arachis hypogaea*) is known as an inexpensive source of plant protein. Peanuts are widely used in the roasted form as a supplement in many bakery products, desserts and soups. Now, peanuts are also used to prepare milk substitute and other beverages as plant-based milk. Peanut milk is widely popular in developing countries instead of mammalian milk. It can be converted into low-cost edible product with high nutritional value. It is extensively used in India and most developing countries by low-income starch diets, underweight people, vegetarians, and more recently, by children allergic to cow's milk proteins. The interest in peanut milk is influenced due to the growing awareness of the nutritional benefits of vegetable proteins in low fat and low cholesterol diets by health-conscious people. Peanut milk is easy to preserve in countries located in high temperature regions and best option for lactose-intolerant people (Rustom *et al*., 1990). The peanut milk is prepared by filtering the slurry of peanuts and water. The leftover peanut milk residue (PMR) is the main byproduct of plant-based milk industry which can be used in many values added products. Preservation of this residue for long shelf life is important to increase its use in various food products. Drying is the most common method used for food preservation due to water activity reduction, physical and chemical changes occurring during storage and microbial activity. Drying also reduces the weight and volume of product for easy transportation (Erbay and Icie, 2010). An understanding of drying kinetics is significant to design and control the drying process in order to get a quality product (Cheenkachorn *et al.* 2012). During the drying process, physical changes such as a change in weight and volume occur that lead to a reduction of transportation and storage cost (Kothakota *et al.* 2014; Saini, 2015).

There are many methods of drying like spray drying, thin layer drying, freeze-drying and more used in the food industry. The study of the drying behaviour of different fruits and vegetables is important to scale up in industries. (Akpinar *et al*., 2002)

The objective of this research is to determine the effect of different temperatures on drying kinetics and powder characteristics of peanut milk residue. Also, the PMR powder was used in the preparation of muffin by replacing 50% refined wheat flour, followed by which colour and textural studies were done.

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eISSN: 2550-2166

2. Materials and methods

2.1 Materials

Raw peanuts, refined wheat flour, sugar, salt, unsalted butter (Amul Co., India), milk and baking powder was procured from the supermarket in Guduvanchery, Chennai. Peanuts were peeled, cleaned and sorted.

2.2 Preparation of peanut milk residue powder

For the extraction of milk, peanuts were soaked in 1% sodium carbonate solution for 16 to 17 hrs. The soaked peanuts were drained and ground with water (1:2 w/v) to form slurry. The slurry was filtered using a muslin cloth to separate solid particles (Salunkhe and Kadam, 1989). The leftover residue was dried in tray drier at 60ºC, 70ºC and 80ºC to remove moisture. The dried residue was ground to fine powder. The drying temperature was optimized based on the quality characteristics of the PMR powder. The powder was then used for muffin preparation.

2.3 Preparation of muffins

The optimized PMR powder was used as flour base with refined wheat flour for the preparation of muffin. The ingredients used for muffin preparation were flour base 100 g, unsalted butter 50 g, 50 g sugar, 75 g milk, 3.33 g baking powder and 0.3 g salt. Sugar, butter and milk were blended for 2 mins. Refined wheat (formulation 1) and 30% PMR power with refined wheat flour (formulation 2) were prepared as flour base and baking soda was added in the base. The flour base was mixed slowly in a sugar-butter mixture using a wire whip. The prepared batter was poured in greased muffin cups and baked at 180^0C for 25 mins in the preheated oven.

2.4 Drying kinetics

The Tray drier was used to dry peanut milk residue. It consists of 5 trays of mesh sheets. The temperature was controlled manually ranging from 30 to 90ºC. The initial moisture content of the peanut milk residue is measured by the oven-dry method (Saini, 2015). Drying was done at three different temperatures (60ºC, 70ºC, 80ºC). The airflow rate of about 1m/s is maintained during drying. The sample weight was recorded for every 60 mins using a digital weighing balance with 0.001 g precision. The drying process is done until a constant weight is achieved. The moisture content of the product was also calculated during dehydration at different temperatures. The obtained data were further used to determine the moisture ratio (Lahsasni *et al*., 2004).

2.5 Thin-layer drying model

Mathematical modelling has been adopted to analyze the drying of peanut milk residue. Following thin layer drying models were used to study the drying behavior of peanut milk residue. Coefficient of determination R^2 and standard error values are used to evaluate the goodness of fit. The model with the highest R^2 value and the lowest standard error value is considered for the goodness of fit. In thin-layer drying, the moisture ratio during drying is calculated using,

$$Moisture\ Ratio\ (MR) = \frac{M_t - M_e}{M_i - M_e} \quad (1)$$

Where M_i is the initial moisture content, M_e is the equilibrium moisture content, and M_t is the moisture content at time ‘t’

The correlation coefficient R^2 is one of the primary criteria to select the best equation in the tray drying curves of the dried samples (Midilli and Kucuk, 2003). The relationship between the drying air temperature and the constants of the best fit for the drying of PMR was determined in this study. The dried samples were powdered using a mixer. Thus, the powders obtained from drying at different temperatures were stored for further analysis. The different mathematical models are mentioned in Table 1.

2.6 Bulk density, tap density and porosity

Peanut milk residue powder was taken in a measuring jar with a capacity of 25 mL. Bulk density was calculated in mass/volume (kg/m³). Tapping the measuring jar which provides the tap density is expressed as mass/volume (kg/m³). Porosity is the void space between particles, which is calculated using the following formula and is expressed in terms of

Table 1. Mathematical models applied to the drying curves

S.No	Model name	Equation	References
1	Newton	MR = exp $(-kt)$	Ayensu (1997)
2	Henderson and Pabis	MR = $a\ exp\ (-kt)$	Kashaninejad *et al.* (2007)
3	Logarithmic	MR = $a\ exp\ (-kt) + c$	Torgul *et al.* (2002)
4	Page model	MR = exp $(-kt^n)$	Page (1949)
5	Lewis	MR = exp (-kt)	Bruce (1985)
6	Midlli-kucuk	MR = $a\ exp\ (-kt^n) + bt$	Midlli and Kucuk (2003)
7	Wang and Singh	MR = $1 + at + bt^2$	Wang *et al.* (2007)

percentage (Caparino *et al.*, 2012).

$$Porosity = \frac{\rho t - \rho b}{\rho t} \times 100 \quad (2)$$

2.7 Flowability studies

Hausner's ratio (HR) was used to understand the flowability of the dried powders (Table 2). It was determined by calculating the ratio between tap density and bulk density (Kotaro *et al.*, 2001)

$$HR = {}^{\rho t}/_{\rho b} \quad (3)$$

Table 2. Specifications for Hausner's ratio and Carr's index

S.No	Flowability	Carr's index (%)	Hausner's ratio
1	Excellent	0-10	1-1.11
2	Good	10 - 15	1.12-1.18
3	Fair	16-20	1.19-1.25
4	Possible	21-25	1.26-1.34
5	Poor	26-31	1.35-1.45

2.8 Water activity and moisture content

The water activity of PMR powder was measured using a water activity meter (LAB touch LT NOVASINA) at 27ºC. The average of triplicate values was recorded.

The moisture content of the powder was measured by the oven dry method. The powder (5 g) is dried in the oven at 104ºC until it reaches constant weight (AOAC, 1990).

$$Moisture\ content = \frac{M1 - M0}{M1} \times 100 \quad (4)$$

Where M_1 is the initial weight of the sample and M_0 is the final weight of the sample

2.9 Colour analysis

Colour analysis was done using hunter colour lab (Colour Quest XE Hunter Colour Meter) on the basis of three variables viz. L, a and b. L signifies the lightness, a represents the redness or greenness and b represents the yellowness or blueness of the product. The instrument was calibrated with standard white tile (Trirattanapikul and Phoungchandang, 2014).

2.10 Texture analysis

The texture of muffins was analyzed by using Stable micro systems texture analyzer. (Stable Micro Systems, U.K) Force and height were calibrated. Texture profile analysis of the muffin was done using P/75 (a 75 mm aluminium plate) for compression. It is done for firmness, springiness and cohesiveness (Kumar *et al*, 2010). Muffin was compressed twice in order to obtain springiness, hardness, resilience and cohesiveness. The chewiness is the secondary texture parameter calculated using hardness, cohesiveness and springiness of the product (Jauharah *et al*, 2014).

2.11 Statistical analysis

A total of three replications of colour, water activity, bulk density, tap density, porosity and Hausner's ratio were used to determine each parameter. MINITAB Version 17 for Windows was used to compute analysis of variance (ANOVA). Duncan's multiple range test was performed to determine the significant temperature at a 95% confidence interval (Trirattanapikul and Phoungchandang, 2014).

3. Results and discussion

3.1 Effect of different drying time on moisture content

The change in the moisture content of PMR with respect to different drying temperature is shown in Figure 1. A nonlinear decrease in moisture with time was observed. The rate of removal of moisture increased with increase in drying temperature. The time taken to reach the equilibrium moisture content decreased with increase in temperature. When PMR is dried at 60ºC, it took 9 hrs to reach the constant weight. Whereas, at 70 and 80ºC, complete drying took place in 7 and 5 hrs, respectively. The equilibrium moisture content was obtained as 3.5±0.2%. As the temperature in dryer increased, the temperature of air also increased. The air with high temperature can absorb more moisture or liquid from the substance. In this case, relative humidity is decreased which promotes faster drying. The low relative humidity in the dryer caused drying of power in less time. The equilibrium moisture content of powders dried at different temperature was the same. The change in drying temperature did not affect the final moisture content of powders.

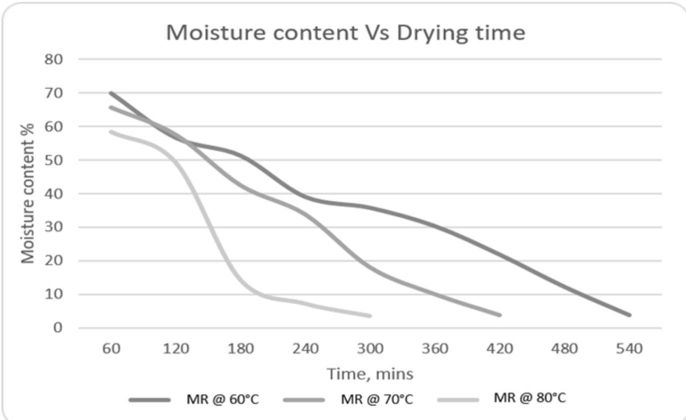

Figure 1. Change in moisture content with drying time

3.2 Effect of drying temperature on drying rate of peanut milk residue

Effect of different drying temperature on the drying rate of PMR is shown in Figure 2. The moisture loss was at a fast rate in PMR dried at 80ºC when compared to 60 and 70ºC. This could be due to an increase in the energy of water molecules with increased temperature causing quick evaporation of water from the sample. There was an initial stage where the PMR is getting adapted to the ambient to reach the defined temperature, followed by which drying rate increased. And so constant rate period was absent during the drying process. The falling rate period frequency showed that moisture movement in the sample is led by diffusion. During the drying process, with the decrease in moisture content and increase in drying time, the drying rate decreased. This is due to the fact that with decreasing moisture content the moisture migration to the surface slowed down. An increase in operational temperature in a specific time results to increase in evaporation rate. The high rate of evaporation leads to a decrease in moisture content at the same time. The results are in agreement with previous literature studies on drying (Kongdej, 2011).

3.3 Evaluation of mathematical models

The moisture ratio with respect to drying time at different temperature is plotted in Figure 3. The moisture ratio decreased with time indicating that the drying occurs in the falling rate period. Thin layer drying models such as the Lewis model, Henderson and Pabis model, Newton model, Wang and Singh model, Page model, Midilli Kucuk model were used to fit the experimental data. The statistical parameters (R^2 and standard error) and constants for peanut milk residue dried at 60ºC, 70ºC and 80ºC were listed in Table 3. The results showed that the relationship between moisture ratio and drying time. Wang and Singh's model was found to have maximum R^2 value and a minimum standard error value. For the peanut milk residue dried at 70ºC, the R^2 value was more than 0.95 for all the drying models studied. Whereas, for drying temperature 60ºC and 80ºC, the R^2 values ranged between 0.88 - 0.94. Wang and Singh's model is observed to have the goodness of fit with the maximum R^2 value of 0.9932 and minimum standard error value of 0.000135. Wang and Singh's model is the best fit for rough rice and grains (Madamba *et al*., 1996).

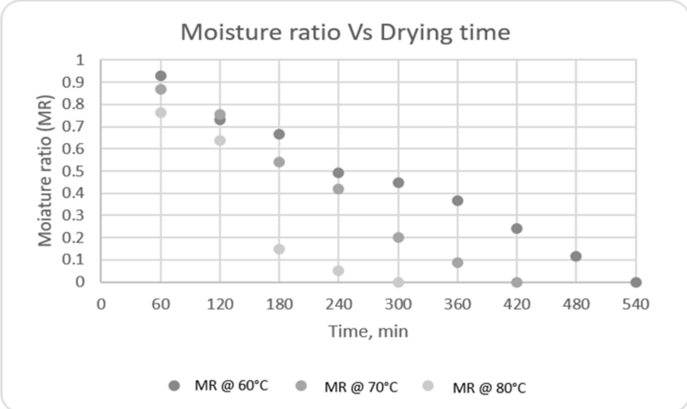

Figure 3. Change in moisture ratio at various temperatures

3.4 Effect of drying temperature on physical properties of PMR powder

PMR powder was analyzed for bulk density, tapped density, porosity, Hausner's ratio, water activity and colour by AOAC methods. The data is presented in Table 4. When PMR was dried at 70ºC the density was

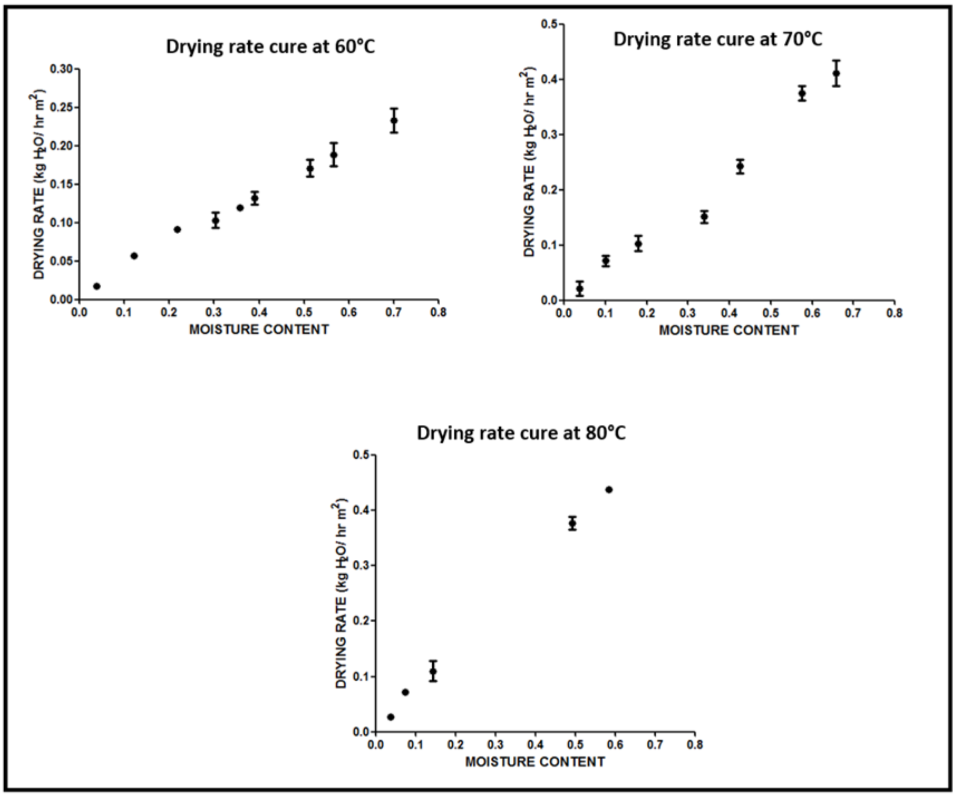

Figure 2. Drying rate curve of PMR dried at various temperature

eISSN: 2550-2166

Table 3. Curve fitting criteria and drying parameters for various models

Temperature, °C	Model	Model constants	R^2	Standard error
60	Lewis	k= 0.003132	0.899	0.000627
70		k= 0.004285	0.959	0.000311
80		k=0.007216	0.8928	0.001655
60	Henderson and Pabis model	a=1.21; k=0.003861	0.9402	0.000461
70		a=1.332; k= 0.0057	0.9585	0.0009451
80		a=1.551; k=0.01048	0.8819	0.00336
60	Newton	k=-0.00313	0.899	0.000627
70		k=-0.00429	0.9599	0.000311
80		k=-0.00722	0.8928	0.001655
60	Wang and Singh	a=-0.00195; b= 2.3E-07	0.919	0.00014
70		a=-0.0025; b= 7.283E-08	0.9932	0.0001356
80		a=-0.004704; b= 0.000003965	0.9928	0.001115
60	Page model	k=0.00015; n=1.531	0.9402	0.00015
70		k=3.3E-05; n=1.89	0.9285	3.40E-05
80		k=1.5E-05; n=2.219	0.8819	4.40E-05
60	Midilli Kucuk	a=0.9528; k=3.465; n=-9.922; b=-0.00173	0.899	0.00016
70		a=0.007577; k=-2.827; n= -0.02025; b=-0.00229	0.9599	0.0001
80		a=2.56E-06; k= -14.16; n=-0.02483; -0.00208	0.8928	0.00182

Table 4. Physical properties of peanut milk residue dried at 60, 70 and 80°C

Drying Temperature	Water activity	Moisture content (%)	Bulk density (g/mL)	Tapped density (g/mL)	Porosity	Hausner's ratio	Flowability
60°C	0.54±0.02[a]	3.75±0.01[a]	0.19±0.04[a]	0.22±0.03[a]	13.63±0.03[a]	1.15±0.02[a]	Good
70°C	0.53±0.01[b]	3.5±0.02[b]	0.17±0.02[b]	0.2±0.02 [a]	15±0.02[b]	1.17±0.01[b]	Good
80°C	0.53±0.02[b]	3.52±0.01[a]	0.3±0.03[c]	0.41±0.01[b]	26.82±0.0[c]	1.36±0.02[c]	Poor

less as compared to 60 and 80ºC. There was a significant difference in bulk density and tapped density with different drying temperatures. Bulk density is related to the moisture content of PMR. The decrease in bulk density could be due to less moisture content when PMR is dried at 70ºC. Hausner's ratio expresses the flow property of powder. Lesser the Hausner's ratio better is the flowability. After drying at 60 and 70ºC, the Hausner's ratio was in the range of 1.12-1.18 indicating good flowability. Whereas when peanut milk residue was dried at 80ºC, the powder flowability was poor. Another important physical parameter is porosity which represents the void volume of the dried powder. Porosity is calculated from the bulk and tapped density, which increased with an increase in drying temperature. The results were on par with literature where tomato is dried at different temperatures (Goula and Adamopoulos, 2005). Commercially, the volume of packaging material required for any food substance is designed based on the density. The shelf life of the dried product is evaluated based on water activity. Increased water activity indicates more growth of microorganisms. When peanut milk residue was dried at 70 ºC, it showed water activity of about 0.53 which is low when compared with 60ºC (0.54±0.02). There was no significant difference in water activity when PMR was dried at 70 and 80ºC. Colour is an important parameter for the acceptability of the product. Drying causes degradation of colour due to heat application leading to browning of the product (Ozgur *et al*., 2011). The lightness increased when PMR was dried at 70ºC, but with increasing temperature, the L value decreased as shown in Figure 4. In case of a value, indicating redness or greenness, there was no significant difference between the drying temperatures.

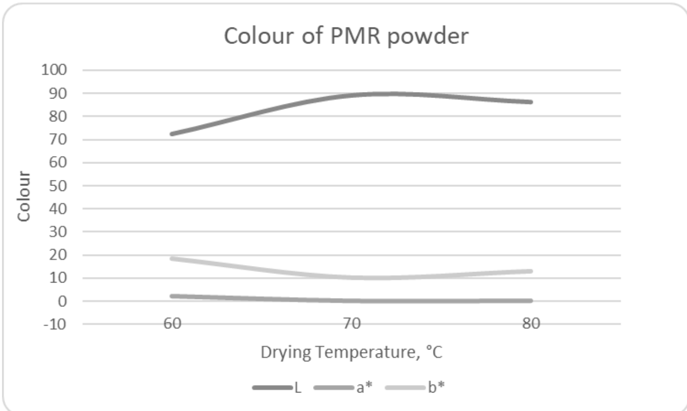

Figure 4. Change in colour with different drying temperatures

3.5 Colour and texture profile analysis of muffin obtained from peanut milk residue powder.

The colour of the muffin was affected by the replacement of refined wheat flour with 50% peanut milk residue powder. In general, the crust colour of the PMR muffin became darker than the control muffin as measured by the hunter colour lab. The crust of the control was lighter and more yellow than muffins obtained using peanut milk residue powder as in Figure 5.

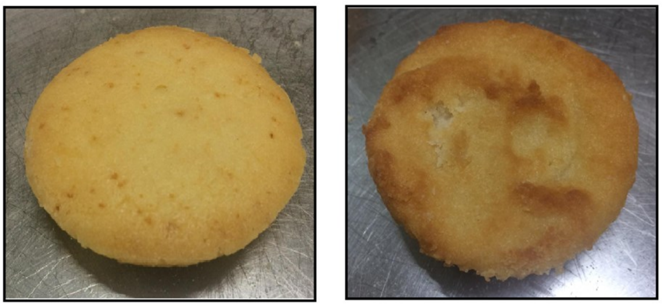

Figure 5. Representation of muffin obtained from peanut milk residue powder

In texture profile analysis, control muffin was harder than PMR muffin as in Figure 6. The firmness of the muffin depends on the density. Increase of hardness in the control muffin could be due to more volume of the product. Cohesiveness represents the internal resistance of the structure of the food. Springiness is about the elasticity of the material. It is determined based on the recovery between the first and second compression. It is linked with the amount of air bubbles incorporated into the muffins during the mixing process. Gumminess is determined by hardness and cohesiveness. The chewiness is determined by gumminess and springiness, and it denotes the amount of energy needed to disintegrate food for swallowing. The results indicated that the gumminess and chewiness of PMR muffin are on par with the control. Similar results were observed when wheatgrass powder was replaced for muffin flour (Rahman, *et al.,* 2015).

4. Conclusion

The present study focused on the optimization of best temperature for drying of peanut milk residue with improvement in the quality of the powder. The analysis of the experimental data shows that different drying temperature, time and their combined impact have a reasonable effect on moisture content. It was observed from the kinetics that drying occurs in the falling rate period. With the increase in drying temperature, the moisture content was removed at a faster rate. Six thin layer drying models were evaluated from which Wang and Singh's model is found to have the highest R^2 value (0.9932), indicating the best fit. Physical properties of the obtained powder are evaluated and compared at all temperatures. Results indicated that PMR powder obtained by drying at 70ºC is found to have water activity 0.53 which is appropriate for dried products. Also, the powder had good acceptability based on color and flowability. A muffin was successfully developed by substituting 50% of refined wheat flour with optimized peanut milk residue powder and compared with muffin prepared with 100% wheat flour. The developed muffin showed acceptable sensory properties.

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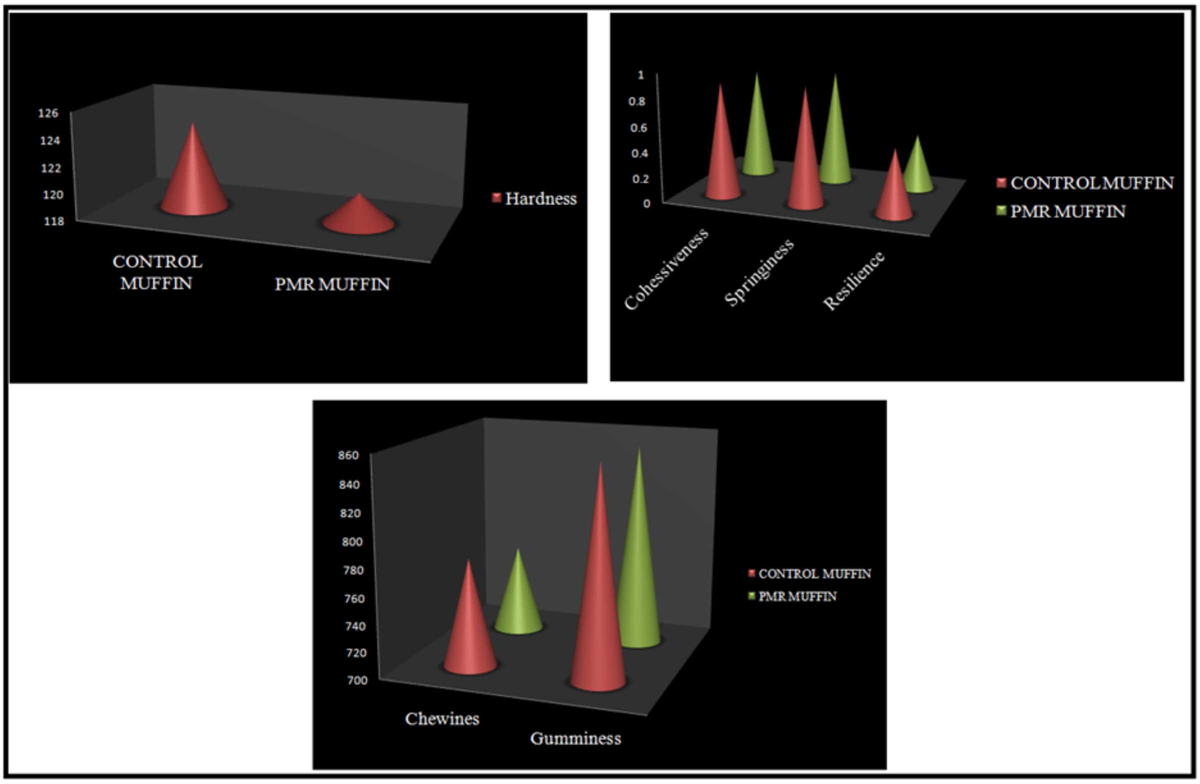

Figure 6. Representation of texture profile of muffin

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