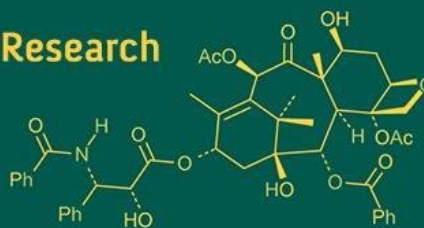


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(9): 951-955
www.biochemjournal.com
Received: 27-07-2025
Accepted: 30-08-2025

Sneha Sharad Jog
M.Sc. (PHT) in Food Grains
and Seeds Processing
Technology at Post Graduate
Institute of Post-Harvest
Technology and Management
Killa-Roha, Raigad,
Maharashtra, India

Ishwar Lakhichand Pardeshi
Professor and Head,
Department of Food Grains
and Seeds, Post Graduate
Institute of Post-Harvest
Technology and Management,
Killa-Roha, Raigad,
Maharashtra, India

Shrikant Baslingappa Swami
Professor and Head,
Department of Post-Harvest
Engineering, Post Graduate
Institute of Post-Harvest
Technology and Management,
Killa-Roha, Raigad,
Maharashtra, India

Dr. RC Ranveer
Professor (CAS), Department
of Post Harvest Management
of MPF, PGI-PHTM, Killa-
Roha, Raigad, Maharashtra,
India

Corresponding Author:
Sneha Sharad Jog
M.Sc. (PHT) in Food Grains
and Seeds Processing
Technology at Post Graduate
Institute of Post-Harvest
Technology and Management
Killa-Roha, Raigad,
Maharashtra, India

Study on shelf life of hot air puffed barnyard millet

Sneha Sharad Jog, Ishwar Lakhichand Pardeshi, Shrikant Baslingappa Swami and RC Ranveer

DOI: <https://www.doi.org/10.33545/26174693.2025.v9.i9SI.5624>

Abstract

Less expensive value-added products are more appealing and accepted by today's consumers. Producing Barnyard millet puff with a hot air puffing system offers users numerous advantages, as a continuous hot air puffing system typically has greater capacity, enhanced safety, and simpler operation. In this research, optimally puffed barnyard millet (puffed at 310 °C with a feed rate of 7500 g/h) was stored under accelerated storage conditions. Storage of puff Barnyard Millet grain in Metalized polyester (MP) and High-density polyethylene (HDPE) indicates that MP is superior for storing puff grain compared to HDPE. Storage research indicated that at extremely high humidity (95%) and temperature (40 °C), the hot air puffed barnyard millet retained its shelf life for only 21 days in HDPE and for 52 days in MP, respectively.

Keywords: Hot air puffing, barnyard millet, accelerated storage

1. Introduction

Millets are nutrient-dense and hold a significant role in the diets of individuals in various areas across the globe. Despite their nutritional advantages over cereals, millets are primarily consumed by traditional users and those from lower-income groups (Jaybhaye *et al.* 2014) [9]. Barnyard millet is the most ancient cultivated small millet. The primary species of Barnyard millet are *Echinochloa esculenta*, known as Japanese Barnyard millet or Japanese millet, and *Echinochloa frumentacea*, referred to as Indian Barnyard millet. The barnyard millet from India is referred to as Billion Dollar Grass (USDA NRCS. 2002) [24].

Echinochloa frumentacea belongs to the Poaceae family and is a self-pollinating plant. *Echinochloa frumentacea* is the toughest millet and is widely recognized by various names such as *Sanwa* and *Jhangora* (Hindi), *Shyama* (Sanskrit), *Oodalu* (Kannada), *Kuthiravaali* (Tamil), *Udalu* and *Kodisama* (Telugu), *Shamul* (Marathi), *Sama* (Gujarati), *Shamula* (Bengali), and *Swank* (Punjabi). It is grown in several nations, including India, China, Japan, Malaysia, the East Indies, Africa, and the United States (Anuradaha *et al.* 2014) [1]. In India, it is predominantly grown in Orissa, Maharashtra, Madhya Pradesh, Tamil Nadu, Bihar, Punjab, Gujarat, and the hills of Uttarakhand (Kumar *et al.* 2000) [12].

Barnyard millet is an excellent grain. Though comparable to rice and wheat, it also contains minerals and vitamins, making it an interesting source of valuable nutrients such as carbohydrates, fats, proteins, and dietary fiber. Due to their slow digestibility rate, barnyard millets serve as a good protein source with low carbohydrate levels, positioning them as a natural nutraceutical food, particularly beneficial for those at high risk of non-infectious diseases like diabetes, heart conditions, obesity, and cancer (Rajeswari and Priyadharshini, 2021) [19]. Millets provide distinct health benefits as they are rich in micronutrients, especially minerals and B vitamins, as well as nutraceuticals. While millets aren't a major component of the daily diets in America and Europe, these regions have now acknowledged their significance as an ingredient in gluten-free and multigrain cereal products. Nonetheless, in several Asian and African nations, millet serves as the primary food for the inhabitants of millet-producing regions and is utilized to create a variety of traditional dishes and drinks such as idli, dosa, papad, chakli, porridges, breads, baby foods, and snacks (Chandrasekara *et al.* 2011) [3].

Nowadays, numerous RTE (ready-to-eat) snacks, including fried chips, wafers, flakes, granules, extruded and spiced items, popcorn, and puffed cereals, have become essential

elements of consumer eating patterns. Popping or the preparation of expanded items from cereals and legumes is a traditional food processing technique utilized to create RTE light and crispy products (Ushakumari *et al.* 2007) [25].

Puffing grains is a traditional method of preparing grains for snacks or breakfast cereals, served either plain or with added flavours, salt, or sugar. Starch is the primary element in human diet and provides a variety of essential functional characteristics. The quality of starch is evidently dependent on its structure and preparation (Lehman *et al.* 2007) [14]. Puffed grain, as a pre-cooked Ready-to-eat ingredient, can serve in snack foods, specialty items, and as a foundation for creating supplementary foods (Hoke *et al.* 2005) [8].

1.1 Add line for connectivity

In accelerated shelf-life testing (ASLT), products are stored in a precisely controlled setting that aims to speed up the deterioration process of the product. To develop models predicting shelf life in different storage conditions, the deterioration rate can be compared to that under standard ambient conditions. While accelerated tests yield valuable outcomes, numerous risks arise if the tests are conducted improperly.

Sullivan *et al.* (1974) [22], performed storage studies to assess the stability of explosion-puffed, dried potato cubes concerning the emergence of browning and undesirable flavours. The findings from this storage test indicate that all samples kept at 23 °C or below, irrespective of the packaging atmosphere, maintain stability in browning and flavour over the course of one year.

Another type of degradation of breakfast cereals post-processing and packaging is moisture absorption, leading to a loss of the unique crispy texture. The appropriate type and quality of moisture vapour-proof packaging materials prevents moisture absorption (Fast, 1987) [6].

The reduction in crispiness of hot-air puffed kodo millet was notably less in MMPE, followed by PP, HDPE, and LDPE packages (Farzana *et al.* 2022) [5].

Quast and Karel, (1972) [18] documented critical water activity for popcorn and potato chips as 0.50 and 0.40, respectively. Khodke, (2002) [11] indicated a crucial water activity of 0.48 for dehydrated ready-to-eat potato cubes. Nath, (2006) [15] indicated that the critical water activity values for RTE potato and RTE potato-soy snack foods were approximately 0.471 and 0.449, respectively. The water activity of the product was viewed as a measure of the shelf life of crispy items, as noted by previous researchers (Labuza and Medellin 1981; Katz and Labuza, 1981; Tubert and Iglesias, 1986) [13, 10, 23].

2. Materials and Methods

2.1 Storage of hot air puffed grain samples

Storage investigations of hot air puffed Barnyard Millet were carried out at 40 °C and 95% relative humidity, focusing on packaging materials for the final puffed grain products made under optimized processing conditions. Metalized Polyester (MP) and HDPE were utilized for storage experiments (Pawar, 2018) [17].

2.2 Sorption isotherm of hot air puffed grain samples

The sorption isotherm behaviour of the puffed grain sample under environmental conditions was analyzed to show the impact of water activity (a_w) on moisture content. The Texture Analyser was used to assess crispness, the main

factor for product approval concerning differences in moisture level. These studies determined the essential moisture level and crucial water activity at which the product became less crisp (Pardeshi, 2008) [16].

2.3 Determination of water vapor transmission rate (WVTR) of packaging material

A ten-gram dried silica gel desiccant was placed in a small glass beaker without a spout, and the packaging materials selected for the experiment effectively covered the beaker's opening. A saturated solution of potassium nitrate (KNO_3) was utilized in the desiccator to keep the temperature at 40 ± 1 °C and relative humidity at $90 \pm 1\%$ for every beaker. The beakers holding the silica gel desiccant were weighed consistently every 24 hours for ten days. The overall moisture absorbed by silica gel was assessed in beakers wrapped with MP and HDPE packing materials (Sahu and Khokhar, 2024) [20].

The permeability of packaging material was calculated using following equation:

$$K_A = \frac{\Delta W / \Delta \theta}{P_{out} A'} \quad \dots (2.1)$$

Where, W = weight gain by desiccant (g)

θ = time (days)

K_A = permeability ($kg\ m^{-2}\ day^{-1}\ Pa^{-1}$) for given thickness (x) of the packaging material

A' = area of the package (m^2)

x = thickness of packaging material (mm)

P_{out} = water vapour pressure at 40 °C (Pa)

The values of permeability for given thickness of the packaging materials was determined as per given by Khodke, (2002) [11] and Pardeshi, (2008) [16].

2.4 Shelf life calculation

The time required for the moisture content of the puffed grain sample to increase from an initial value of M_i (kg water per kg dm) to its critical value M_c , at which it lost its crispness, was computed numerically to establish the shelf life of the puffed product " θ " (days).

(Balaji, 2020) [2]

(Das, 2005) [4].

$$\theta = \frac{W_s}{P^* K_A A'} \int \frac{M}{RH - a_w} \quad \dots (2.2)$$

Where, θ = shelf life (days)

W_s = dry matter of the puffed product (kg)

W_{gain} = weight gain due to moisture uptake = $W_s (M_c - M_i)$

P^* = saturation vapor pressure of water at T °C (Pa)

$$= \exp \left(23.0633 - \frac{3723.67}{222.857 + T} \right) \dots \text{(Geankoplis, 1983) [7]} \dots (2.3)$$

K_A = permeability of the packaging material ($kg\ m^{-2}\ day^{-1}\ Pa^{-1}$)

A' = area of the package (m^2)

RH = relative humidity in which package is placed (fraction)

a_w = water activity (fraction) of the product at T °C = f (M)

a_{wc} = critical water activity and is less than or equal to RH

M = Moisture content of the puffed product (kg water per kg dm)

i and c = are the suffix for initial and critical moisture contents respectively.

3. Result and Discussion

3.1 Storage Studies of the Hot Air Puffed Barnyard Millet Grain

This segment explores the changes observed in the hot air-puffed grains stored at 40 °C with 95% relative humidity. As noted earlier in Section 2.1, the puffed grains were maintained in identical conditions within two types of packaging materials (MP and HDPE). Pawar, (2018) ^[17]

utilized this packaging material for a storage study of ready-to-eat snacks made from sprouted soy fortified millet flour

3.1.1 Properties of Packaging Materials

As indicated in section 2.3, measurements tracked the total moisture increase over time by silica gel contained in two pouches, namely Metalized Polyester (MP) and High Density Poly Ethylene (HDPE), at 40±2 °C and 95±1% relative humidity. The WVTR was determined using the slope of the relevant curves, and the findings are presented in Table 1.

Table 1: Properties of Packaging Material

Sr. No.	Packaging Material	Thickness (microns)	WVTR (kg water/day m ²)	Permeability (kg water/day m ² Pa)
1	MP	51	0.000975	1.33816 x 10 ⁻⁷
2	HDPE	100	0.001925	2.6411 x 10 ⁻⁷

3.2 Sorption isotherm of the hot air puffed grains

Sorption isotherms of puffed grains at 40±1°C and 95% RH, showing the variation of moisture content (MC, kg/kg dm) of the puffed grains with water activity (a_w) are given in

Fig. 1. The critical water activity (a_{wc}) value of the hot air puffed barnyard millet with 0.0968 kg/kg dm critical moisture (MC_c) content was found to be 0.63. Moisture content increased slowly with increase in water activity.

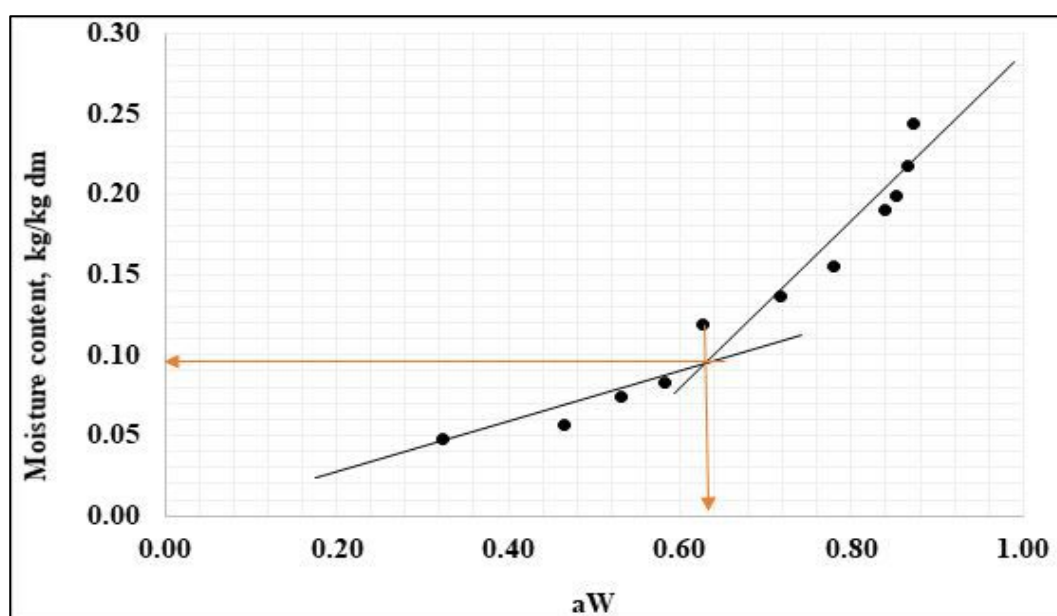


Fig 1: Relation between Moisture content, kg/kg dm and water activity (a_w).

3.3 Moisture content of hot air puffed millets during storage:

The variation in the product's moisture content under various storage settings is shown for hot air-puffed Barnyard Millet and depicted in Fig. 2

Table 2: Shelf life of hot air puffed barnyard millet grains

Product	Temp. (°C)	RH (%)	MP		HDPE	
			Observed Shelf Life (days)	Predicted Shelf Life (Days)	Observed Shelf Life (days)	Predicted Shelf Life (Days)
Barnyard Millet Puff	40	95	52	48	21	23
	40	65	-	96	-	47
	30	95	-	84	-	41
	30	65	-	169	-	83

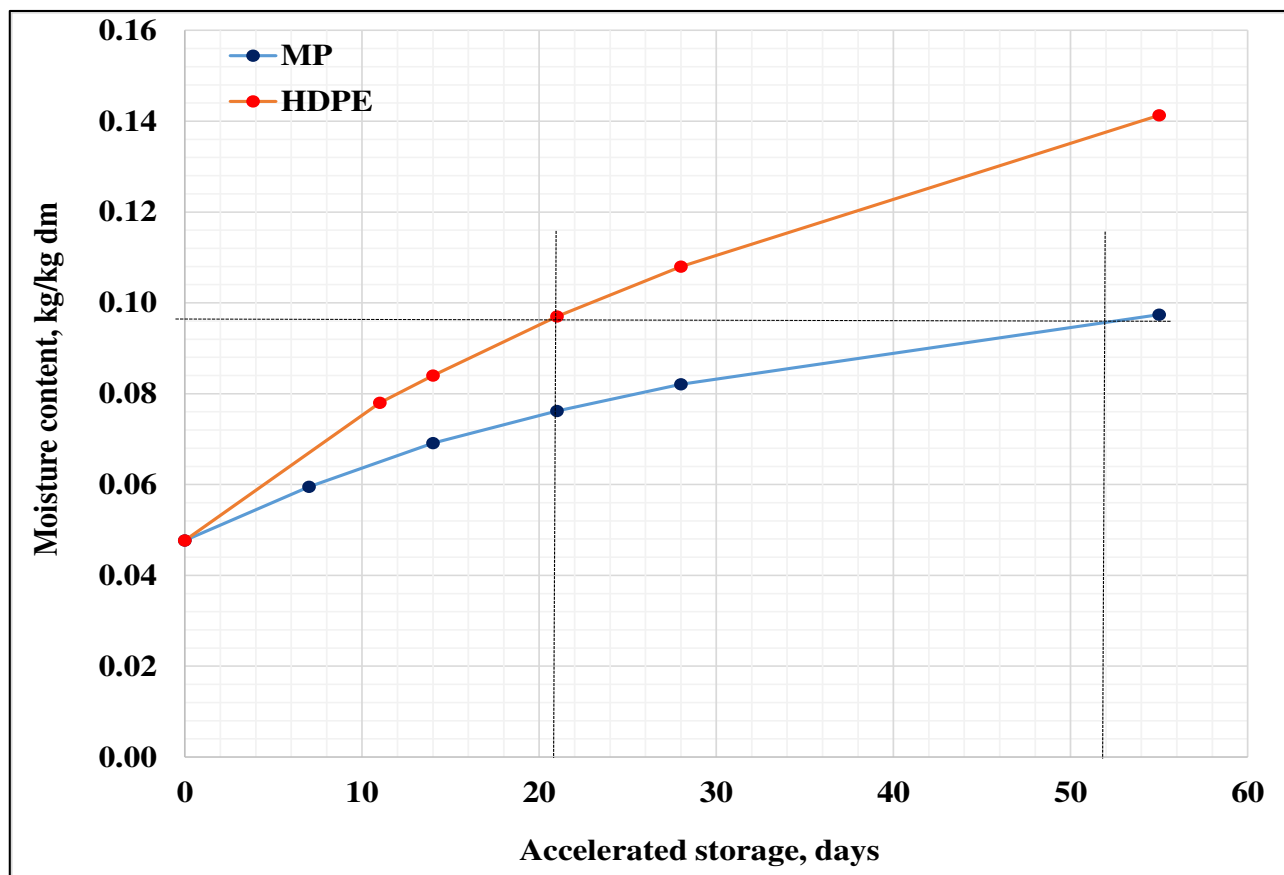


Fig 2: Variation in moisture of products packed in different packaging materials at accelerated storage condition

The moisture level rise from 0.0477 kg/kg dm to 0.1080 kg/kg dm in the HDPE pouch and from 0.0477 kg/kg dm to 0.0821 kg/kg dm in the MP pouch over the 0 to 28 days of the accelerated storage period. According to Fig. 2, puffed barnyard millet stored in MP pouch is practically displayed a shelf life 52 days, while the HDPE pouch showed 21 days, both kept at 40 °C and 95% RH under accelerated storage conditions. The estimated shelf life was determined using Eq. 2.2, as shown in Table 2. The observed (52 days for MP and 21 days for HDPE) and predicted (48 days for MP and 23 days for HDPE) shelf lives at accelerated storage conditions of 40 °C and 95% RH were sufficiently similar for both packaging materials, MP and HDPE. Consequently, the shelf life of the product contained in various packaging materials stored under different conditions was estimated as outlined in Table 2. The predicted shelf in packaging materials of MP at different storage conditions like 30 °C temperature and 95% RH, 40 °C temperature and 65% RH, 30 °C temperature and 65% RH, were calculated to be 84, 96 and 169 days, respectively, whereas in packaging materials of HDPE at different storage conditions like 30 °C temperature and 95% RH, 40 °C temperature and 65% RH, 30 °C temperature and 65% RH, were calculated to be 41, 47 and 83 days, respectively.

4. Discussion

4.1 Sorption isotherm of the hot air puffed grains

Numerous studies on texture show that when the MC or aw of a product rises, a decrease in crispness and an increase in firmness are noted by Kulchan *et al.* (2010) [26]. A small reduction in the crispness of breakfast cereal was observed at $a_w < 0.5$. Subsequently, a swift decline in crispness was noted until $a_w = 0.8$, at which point the product entirely lost

its brittleness (Sauvageot and Blond, 1991) [21]. The critical moisture content (MCc) and critical water activity (a_{wc}), at which the produce lost its crispness, were identified by Pardeshi (2008) [16]. Research by Balaji (2020) [2] indicates that as water activity rises, moisture content swiftly escalates after reaching a critical moisture threshold. The fluctuation in moisture levels for puff millet was greater than that in HM-HDPE packs and lesser in MFF packs

4.2 Storage Studies of Hot Air Puffed Barnyard Millet Grain

In each case, it was found that the moisture level rise rapidly as time passed. The moisture content varied more when the puffed millets were packed in high-density polyethylene (HDPE) than when they were packed in metalized polyester (MP). The level of moisture in food items is essential for influencing their shelf life. Moisture levels usually increase or decrease during storage, based on the storage conditions and type of packaging. The longer shelf life in MP relative to HDPE may be due to the fact that MP pouches possess better barrier properties than HDPE. Comparable findings by Pawar (2018) [17] examined sprouted soy-fortified composite flour-based RTE snack foods and noted that at extremely high humidity (95%), the snack foods' shelf life diminished to 24 days in HDPE and 40 days in MP

5. Conclusion

An accelerated storage study was conducted to estimate the product's shelf life at a temperature of 40 °C and 95% relative humidity. In a shelf life study, it was noted that puffed grains kept in MP have a longer shelf life (52 days) than those stored in HDPE (21 days). The forecasted shelf life in packaging materials of MP under varying storage

conditions such as 30 °C and 95% RH, 40 °C and 65% RH, and 30 °C and 65% RH were estimated at 84, 96, and 169 days, respectively, while in packaging materials of HDPE, the values were determined to be 41, 47, and 83 days, respectively.

References

- Anuradha N, Patro TSSK, Udaya Bhanu K, Madhuri J, Sowjanya A. Multivariate analysis in barnyard millet (*Echinochloa frumentacea* (Roxb.) Link). Int J Food Agric Vet Sci. 2014;4(2):194-199.
- Balaji ST. Development of semi-automated multigrain continuous hot air puffing system [PhD thesis]; 2020.
- Chandrasekara A, Shahidi F. Determination of antioxidant activity in free and hydrolyzed fractions of millet grains and characterization of their phenolic profiles by HPLC-DAD-ESI-MSn. J Funct Foods. 2011;3:144-158.
- Das H. Food processing operations analysis. New Delhi (India): Asian Books Pvt. Ltd.; 2005.
- Farzana W, Patel S, Palanimuthu V. Effect of processing parameters on puffing quality of *Kodo* millet. Pharma Innov J. 2022;11(3):1009-1018.
- Fast RB. Breakfast cereals: processed grains for human consumption. Cereal Foods World. 1987;32(3):241.
- Geankoplis CJ. Transport processes and unit operations. Boston (MA): Allyn & Bacon; 1983.
- Hoke K, Housova J, Houska M. Optimum conditions of rice puffing. Czech J Food Sci. 2005;23(1):1-9.
- Jayabhaye RV, Dhumal CV, Pardeshi IL, Sutar PP. Development of potato and millet based ready-to-eat (RTE) fasting food. J Ready Eat Food. 2014;1(1):11-17.
- Katz EE, Labuza TP. The effect of water activity on the sensory crispness and mechanical deformation of snack food products. J Food Sci. 1981;46:403-409.
- Khodke SU. Freeze-thaw-dehydration technology for the production of instant potato cubes [PhD thesis]. Kharagpur (India): IIT Kharagpur; 2002.
- Kumar P, Jyothi Lakshmi N, Dube SD, Mani VP. Genotypic difference in photosynthesis and its associated parameters in relation to yield among barnyard millet (*Echinochloa frumentacea*) genotypes under hill conditions. Indian J Agric Sci. 2000;70(6):374-377.
- Labuza TP, Medellin R. Prediction of moisture protection requirements for foods. Cereal Foods World. 1981;26:335.
- Lehmann U, Robin F. Slowly digestible starch-its structure and health implications: a review. Trends Food Sci Technol. 2007;18(7):346-355.
- Nath A. Study on process technology for production of potato based ready-to-eat snacks [PhD thesis]. Kharagpur (India): Post Harvest Technology Centre, IIT Kharagpur; 2006.
- Pardeshi IL. Development of cereal based ready-to-eat snack foods [PhD thesis]. Kharagpur (India): IIT Kharagpur; 2008.
- Pawar SG. Development of sprouted soy fortified millet flour based ready-to-eat snack using microwave puffing technique [PhD thesis]. Akola (India): Dr. Panjabrao Deshmukh Krishi Vidyapeeth; 2018.
- Quast DC, Karel M. Effects of environmental factors on the oxidation of potato chips. J Food Sci. 1972;37:584-587.
- Rajeswari N, Priyadarshini VP. Evaluation of nutritional and nutraceutical content of polished and unpolished barnyard millet-an analytical study. Curr Res Nutr Food Sci. 2021;9(3):735-742.
- Sahu R, Khokhar D. Evaluation of water vapour permeability of some food grain packaging materials. J Sci Res Rep. 2024;30(6):558-563. doi:10.9734/jsrr/2024/v30i62072.
- Sauvageot F, Blond G. Effect of water activity on crispness of breakfast cereals. J Texture Stud. 1991;22:423-442.
- Sullivan JF, Konstance RP, Culhoun MJ, Talley FB, Cording JJ, Panasiuk O. Flavour and storage stability of explosion puffed potatoes: non-enzymatic browning. J Food Sci. 1974;39(1):58-60.
- Tubert AH, Iglesias HA. Water sorption isotherms and prediction of moisture gain during storage of packed cereal crackers. Lebensm Wiss Technol. 1986;19:365-368.
- USDA NRCS. Plant materials program. United States Department of Agriculture Natural Resources Conservation Service; 2002. Available from: <http://plant-materials.nrcs.usda.gov>.
- Ushakumari SR, Rastogi NK, Malleshi NG. Optimization of process variables for the preparation of expanded finger millet using response surface methodology. J Food Eng. 2007;82(1):35-42.
- Kulchan R, Boonsupthip W, Suppakul P. Shelf life prediction of packaged cassava-flour-based baked product by using empirical models and activation energy for water vapor permeability of polyolefin films. Journal of Food Engineering. 2010 Oct 1;100(3):461-467.