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Effect of processing parameters on puffing quality of Kodo millet (*Paspalum scrobiculatum*)

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Abstract
Healthy puffed snack products are nowadays gaining huge importance due to its low cost of production, processing, and semi-skilled labour requirement. However, the quality of the puffed product significantly affects the consumer acceptability of product. The effectiveness of puffing methods (sand, hot-air, gun) under controlled conditions in enhancing the puffing quality was studied and the degradation in quality (moisture content, appearance, color, texture, aroma, taste, overall acceptability, crispiness) upon storage (PP, LDPE, HDPE, and MMPE; 3 months) was studied. The optimized conditions for sand puffing (Variety: Local tiptur, 2% (w/w) salt solution);hot-air puffing (2% (w/w) salt solution, puffing temperature – 300 °C, grain moisture content - 12% w.b., hot-air velocity – 13ms^{-1}); gun-puffing, grain moisture content – (13% w.b. and steam pressure – 0.9 MPa) were employed to obtain the best quality and the observed values for gun puffing were, the volumetric expansion ratio (8.53) and the crispiness (8.52).

Keywords: Puffing, yield, elongation ratio, volumetric expansion ratio, storability, quality

1. Introduction
Millet is a generic term used for small-seeded cereals belonging to the grass family, Graminae. Millets are considered a crop of food security due to their sustainability under adverse agro-climatic conditions in various regions (Ushakumari *et al.*, 2004). These crops have a great potential in widening the genetic diversity in the food basket and also ensuring improved food and nutrition security for the people (Mal *et al.*, 2010) [8]. They are traditional grains more than 10,000 years old grown across many countries in Africa, Asia, and the Middle East before the widely accepted staple food rice and wheat were cultivated. (Sweeney and Mc Couch, 2007 [14]. Lu *et al*, 2009) [5]. Kodo millet which was domesticated in India about 3000 years ago was harvested from ditches and low spots and along the paths in western Africa and India (De wet *et al.*, 1983) [2]. Millets in India are grown over 15.48 Mha (Directorate of Economics and Statistics, 2015). There has been a decline in the production of millets over the past six decades from 22.17 (1950-1951) to 6.94% (2011-12) due to shift in the focus towards other crops especially rice and wheat during green revolution (Malathi *et al.*, 2016) [10]. Kodo millet (*Paspalum scrobiculatum L.*) is one amongst the most widely used species of the family Poaceae (also Gramineae or true grasses). It is a tropical small millet grass crop that is indigenous to India (de Wet *et al.*, 1983 [2]. Patil, 2017) and was under cultivation from ancient times in Northeastern and South of India has been mentioned in *Brihad Sanhita* (Patil, 2017). Though its cultivation was limited to economically backward sectors, several varieties are now available for its exploitation for various purposes. These potential varieties are recommended to be grown in Uttar Pradesh, Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu, and Andhra Pradesh (Anon, 1994). It is known by various names such as kododhan, kodo, kodra, varagu, harika, pakod, manakodra, naraka, arika and arakalu (Kar *et al.*, 2004). Though millets are majorly consumed as whole cooked cereal either in their raw form or modified (flour, parboiled, roasted, quick-cooking, cured, cooked), several products are prepared as fermented products, snacks, and breakfast cereals. It is reported that millets are considered to be highly nutritious, non-glutinous, least allergic, and non-acid forming foods making them soothing and most digestible grain (Michaelraj and Shanmugam, 2013 [12]. Mahanta, 2010) [7]. Millets considered as nutria-cereals have niacin, a high amount of lecithin, B6, and folic acid, and calcium, iron, potassium, magnesium, and zinc are excellent for strengthening the nervous system. Its fibre content also helps to maintain gut health. (Michaelraj and Shanmugam, 2013) [12]. Most executives work for long hours with almost no exercise. Restaurants serve rich food with fats which has led to various health ailments.

Awareness about the inclusion of millets in our daily meals for a healthy living is necessary (Michaelraj and Shanmugam, 2013) [12]. The processing of millets reduces the anti-nutritional factors and increases the bioavailability of millets (Pawar and Machewad, 2006 [13]. Camara and Amaro, 2003) [1]. Puffed millet is becoming increasingly popular as a snack and as an ingredient for different formulations in baby foods due to its ready-to-eat, lighter and crispness characteristics, nutritional quality, and security, pronounced nutty flavor, and increased palatability (Kulkarni *et al.*, 2018) [3]. Popping is a simple technique to make ready-to-eat foods. Popped grain is a crunchy, porous, and pre-cooked product (Kulkarni *et al*, 2018) [3]. Various researchers have reported that the physiochemical characteristics of grain such as amylose content, protein content, moisture content, salt concentration, time of preconditioning affected the puffing quality of millets in terms of puffing percentage and expansion ratio (Mohapatra and Das, 2011). Owing to its gluten-free and anti-hypertension properties, millets have re-emerged as the best option in the current unhealthy lifestyle. The gluten-free property makes it a natural and cheap remedy for various celiac diseases (Kumar, 2018) [4]. These grains which were once considered coarse have now become nutraceuticals as they are rich in iron, zinc, and calcium. Moreover, the protein in the millets forms a part of the protein supplement in the vegan diet (IIMR, 2019).

2. Material and Methods

2.1 Raw material

Freshly harvested Kodo millet variety *Local tiptur*, sourced from a local farmer in Tiptur, Tumkur district of Karnataka (variety: *Local tiptur*) were used for puffing study.

2.2 Parboiling of kodo millet

The plus size grains were parboiled according to the method described by Kar *et al.*, (2014) with a slight modification. The kodo grains were poured into the boiling water (100℃, grain: water =1:2) and allowed to steep for a period of 2 h without additional heat. The soaked grains were spread on a muslin cloth and then steamed in a muslin cloth (1m x 1m) for 10 minutes in an autoclave at 1.5 kgcm^{-2} pressure. The steamed kodo millet was then dried in a tray dryer with bed depth 1 cm for 6h at 50 ℃ until which the moisture content of the grain was reduced to 10 per cent (w.b.) to achieve better dehulling. The dried millet was further dehulled using a millet dehuller (Make: AVM Engineering Works, Salem, Tamil Nadu). The husk was separated using manual winnower. Kodo rice was used for all the experiments with sand puffing and hot-air puffing. The unpolished rice was then stored in PET bottles for further puffing.

2.3 Sand puffing of kodo millet rice

Farmers majorly prefer conventional sand puffing method due to its easy availability, simple construction and economical nature. The kodo millet was pre-cleaned by removing stones and impurities like chaff and dust. The kodo millet was further subjected to parboiling treatment.

2.3.1 Selection of process variables in sand puffing

The conventional sand puffing method was used primarily for screening the various varieties and pre-treatment combinations for the development of best puffed millet product. To identify the process variables and their levels for conducting experiments, initial studies were carried out by selecting three varieties of kodo millet having best dimensions and two pre-treatments (salt and lactic acid) for puffing. In the present study, sample size of 100 g and stirrer speed of 10 rpm and stepwise temperature of heating/puffing (260℃) was fixed. It was necessary to optimize the varieties and pre-treatments to get best quality sand puffed product. After puffing 12 BS sieve was used to separate sand from puffed millet.

2.3.2 Quality parameters of puffed kodo millet

The quality parameters were evaluated as mentioned in Table 1

2.3.3 Sensory quality of puffed kodo millet

The sand puffed kodo product was optimally served just like regular commercially available puffed products and were evaluated for sensory characteristics by a panel of 12 trained judges. For comparison, control was prepared and presented along with experimental samples. The judges scored the puffed kodo for colour, texture, taste, flavour, and overall acceptability based on a nine-point hedonic scale where score 1 represented for unacceptable quality and score 9 represented excellent quality. The design layout of the experiment with two independent variables and their levels is as shown in Table 1.

2.4 Hot-air puffing of kodo millet

Hot-air puffing method was employed for puffing of previously selected variety *Local tiptur* and pre-treatment of 2% salt solution. The process variables i.e. hot-air puffing temperature, hot-air velocity and initial grain moisture content were optimized to obtain the best yield and quality of kodo millet. The temperature, humidity and air velocity was measured with trisense humidity meter. After evaluation of quality parameters, optimized process variables were selected for further studies.

2.4.1 Preparation of sample for puffing

The preparation of sample for hot-air puffing was done following the procedure. The samples of size 100 g were then sprayed with water to adjust the moisture content to 10, 12 and 14% (w.b.) respectively. The salt treatment (2% (w/w)) was given just prior to the introduction of sample to the hot-air puffing machine.

2.4.2 Hot-air puffing technique

The hot-air puffing was conducted in Indian Institute of Food Processing Technology, Thanjavur, Tamil Nadu. The preconditioned grains were fed to the grain inlet and due to the vibratory motion of the conveyor, the grains were dropped into the hot-air puffing outlet from where due to suspension of grains at the adjusted hot-air velocity and temperature, puffing occurred. The best combination of process parameters i.e. puffing temperature and hot-air velocity along with initial moisture content of kodo millet was finalized based upon the quality parameters.

2.5 Gun puffing of kodo millet

Gun puffing method was employed for puffing of previously selected variety *Local tiptur* pre-treated with 2% salt solution. The process variables i.e. gun puffing pressure (0.7,0.9,1.1 MPa) and initial grain moisture content (11, 13 and 15% w.b.) were optimized to obtain the best yield and quality of kodo millet. After evaluation of quality parameters, optimized process variables were selected for further studies.

2.6 Comparison of different puffing methods for kodo millet

The results obtained after puffing of kodo millet with different puffing methods were compared to decide the best method suitable for kodo puffing. The quality parameters were compared to identify the best method for puffing of kodo millet.

2.7 Statistical design and optimization

Analysis of variance was carried out using OPSTAT online statistical software (Make: HAU) and Microsoft Excel 2019 with the solver DSAASTAT ver. 1.101 (Make: Perugia, Italy) which is an Excel macro developed to perform basic statistical analysis on routine agricultural experiments.

2.8 Storage study of puffed kodo millet

The storage study for variety *Local tiptur* was executed under weather conditions in Bengaluru after puffing with different methods *viz*. sand puffing, hot-air puffing and gun puffing with 2% salt solution (Fig 3 (a), (b) and (c)). The puffed products were stored under different packaging materials *viz*. polypropelene (PP), low density polyethylene (LDPE), high density polyethylene (HDPE) and metalized multilayer polyethylene (MMPE). The storage studies were carried out for a duration of 90 days. Freshly puffed kodo millet (approximately 20 g) was filled in each pouch and sealed with a sealing machine. The stored samples were analysed fortnightly and the difference in moisture content, sensory quality and crispiness was observed. The determination of moisture content, sensory quality and crispiness was carried out as discussed in the section 2.3.2 and 2.3.3 respectively.

3. Result and Discussion

3.1 Comparison of different puffing methods for kodo millet: Experimental trials were conducted to identify the most suitable method for puffing of kodo millet. Kodo millet variety (*Local tiptur*) was pre-treated with the above optimized conditions (2% (w/w) salt solution; for hot-air puffing, puffing temperature - 300°C, grain moisture content – 12% w.b. and hot-air velocity – 13ms^{-1}; for gun-puffing, grain moisture content – 13% w.b. and steam pressure – 0.9 MPa) and puffed with three puffing methods (sand puffing, hot-air puffing, and gun-puffing). The quality parameters were studied, and the results are explained below.

3.2 Puffing yield

The puffing yield (PY) of variety, *Local tiptur* puffed by different puffing methods is presented in Fig. 1.a. The puffed yield varied from 23.39 to 92.08%. The mean puffing yield with different methods *viz*. sand puffing, hot-air puffing, and gun-puffing were 87.96, 70.36, and 51.92% respectively. Statistical analysis showed that there was a significant difference between the puffing yields of kodo millet puffed under different methods. The puffing yield was found to be highest with sand puffing in comparison to the other two methods. However, there were certain disadvantages observed like non-uniform puffing quality of grains, sticking of fine sand to the product surface thereby contaminating it, burning of grains in the periphery of the sieve used for sand puffing as the grains were smaller in size, and inefficient use of energy. Hot-air puffed kodo showed lower yield but had certain advantages like uniform puffing due to puffing in a fluidized state, good quality, and free from impurities. Gun puffing showed the least puffing yield but had the best quality of the product in terms of uniformity of puffing in comparison to sand and hot-air puffing.

3.3 Elongation ratio

The elongation ratio (ER) of the variety, *Local tiptur* puffed under different puffing methods is shown in Fig. 1. b. The elongation ratio varied from 0.85 to 1.63. The mean elongation ratio of kodo millet puffed with different methods *viz*. sand puffing, hot-air puffing, and gun-puffing were 1.37, 1.25, and 1.13 respectively. There was a significant difference observed between the elongation ratios of products obtained through different puffing methods. Sand puffing projected the highest elongation ratio in comparison to hot-air puffing and gun puffing. This might be due to higher expansion obtained in sand puffing in comparison to hot-air and gun puffing.

3.4 Volumetric expansion ratio

The volumetric expansion ratio (VER) obtained by the puffing of the variety, *Local tiptur* with different puffing methods is presented in Fig. 1. c. The volumetric expansion ratio was observed to vary between 1.01 to 9.21. The mean volumetric expansion ratio with sand puffing, hot-air puffing, and gun puffing was 5.24, 1.61, and 8.53 respectively. Statistical analysis indicated that there was a significant difference between the volumetric expansions ratios of kodo millet puffed under different methods. Gun puffing displayed the highest volumetric expansion ratio when compared to other puffing methods. This might be due to the expansion of grain with an abrupt pressure drop in the gun puffing machine. Sand puffing and hot-air puffing showed a lower volumetric expansion ratio. This may be due to prior parboiling treatment. Done with kodo grain.

3.5 Bulk density

The bulk density (BD) for kodo millet variety *Local tiptur* puffed under different puffing methods is presented in Fig. 1.d. The bulk density of the product varied between 0.027 and 1.07. The mean bulk density with sand puffing, hot-air puffing, and gun puffing was 0.033, 0.44, and 0.023 respectively. Statistical analysis indicated that there was a significant difference between the bulks densities of kodo millet puffed under different methods. The volumetric expansion ratio decides the bulk density of the product. Since gun puffing displayed the highest volumetric expansion, the bulk density of gun-puffed kodo millet was the least when compared with sand and hot-air puffing. Since hot-air puffing had the lowest volumetric expansion ratio, its bulk density was the highest.

3.6 True density

The true density (TD) for kodo millet variety *Local tiptur* puffed under different puffing methods is presented in Fig. 1.. The true density of the product varied between 0.102 and 6.99. The mean true density with sand puffing, hot-air puffing, and gun puffing was 5.24, 1.63, and 0.129 respectively. Statistical analysis indicated that there was a significant difference between the true densities of kodo millet puffed under different methods. Gun puffing projected the lowest true density in comparison to sand puffing and hot-air puffing. This is due to the highest volumetric expansion ratio obtained when kodo millet is puffed under gun puffing.

3.7 Void ratio

The void ratio (VR) for kodo millet variety *Local tiptur* puffed under different puffing methods is presented in Fig. 1.f. The void ratio of the product varied between 1.57 and 60.9. The mean void ratio with sand puffing, hot-air puffing, and gun puffing were 25, 2.84, and 4.75 void ratios of kodo millet puffed under different methods. The void ratio is decided by the bulk density and true density of the product. Sand puffing displayed the highest void ratio since it had the lowest bulk density and highest true density. Lower void ratio is preferable for puffed products. Hot-air puffing showed the lowest void ratio depending upon the bulk and true densities values. Gun-puffed kodo millet had its void ratio at an optimum value.

3.8 Color

The tristimulus color for kodo millet variety *Local tiptur* in terms of L *a *b values, puffed under different puffing methods is presented in Fig. 1.g. With three different puffing methods namely, sand puffing, hot-air puffing, and gun puffing, the color of the puffed product varied as -L, lightness: 66.43 to 78.29, 29.94 to 42.93, and 42.38 to 70.40; a*: 2.98 to 5.34, 7.14 to 8.79 and 2.86 to 10.75; b*: 17.4 to 20.9, 16.16 to 22.17 and 10.75 to 25.72 respectively. Sand puffing showed the highest value followed by gun-puffing and hot-air puffing. Higher values of lightness in sand and gun-puffing can be attributed to a higher volumetric expansion ratio in these samples than the hot-air puffed samples. Darker samples in hot-air puffing are due to higher temperatures employed in this method.

3.9 Crispiness

The crispiness (C) of variety, *Local tiptur* puffed by different puffing methods is presented in Fig. 1 h. The value of crispiness varied from 6.17 to 11.25. The mean crispiness with different methods *viz.* sand puffing, hot-air puffing, and gun-puffing were 8.43, 7.60, and 8.52 respectively. Statistical analysis showed that there was a significant difference between the crispiness of kodo millet puffed under different methods. The crispiness of the product was found to be highest with gun puffing in comparison to the other two methods. However, there were certain disadvantages like loss of crispiness of the product with prolonged exposure to air over a period. This may be due to the process of gun puffing where a sudden drop of pressure leads to expansion of the grain. Sand puffed products were able to retain the crispiness for a longer duration of time. The least value of crispiness was observed in hot-air puffing. This may be due to non-uniform puffing as the puffing occurred due to convective hot-air fluidized current.

3.10.7 Selection of best puffing method for kodo millet

Trials were conducted to select the best method for puffing of kodo millet which would yield the best puffing quality attributes and sensory quality. One best variety, *Local tiptur* was selected and puffed under sand, hot-air and gun puffing method. The selection of the best puffing method was based on good quality parameters. It was observed that sand puffing had higher puffing yield (87.96%), expansion ratio (1.37) and volumetric expansion ratio (5.24) but it had certain shortcomings like silica contamination, non-uniform puffing, scorching of grains. In hot air puffing the product obtained was clean and free from impurities. It had certain advantages like resetting of hot-air velocity and temperatures were not required as the feeding was continuous. However, it had certain drawbacks of low volumetric expansion ratio (1.61), less crispiness (7.60) and very high void ratio (25). In case of gun puffing, though the puffing yield and elongation ratio (1.25) was comparatively low, the volumetric expansion ratio (8.53) and the crispiness (8.52) was the highest. The product produced was uniform, round and with a slight tinge of browning caused due to Millard reaction which gave very appealing effect. Also, the sensory quality (Fig 1 i) was best with scores for appearance (7.29), color (7.77), texture (8.11), aroma (7.30), taste (7.36) and overall acceptability (8.22). The Physico-chemical properties of gun-puffed kodo millet were comparatively good. Hence, gun puffing method was considered best for puffing of kodo millet.

3.11 Storage studies on puffed kodo millet

The results for storage studies are described as below.

3.11.1 Effect of storage on the moisture content of puffed kodo millet

During the storage period, the modification in moisture content of kodo millet puffed with different methods and stored in different packaging materials was studied and the results are shown in Table 2 and Fig 2 a, b and c. The initial moisture content of the sand-puffed kodo millet was found to be 2.37, 2.34, 2.45, and 2.41% (w.b.) for PP, LDPE, HDPE, and MMPE respectively. As the duration of storage increased, the moisture content of the sand-puffed kodo millet increased to 3.47, 3.58, 3.67, 3.89, 4.18 and 4.37% (w.b.) in PP; 4.52, 4.77, 4.86, 4.97, 5.11 and 5.27% (w.b.) in LDPE; 3.87, 3.96, 4.11, 4.27, 4.39 and 4.67% (w.b.) in HDPE; and 2.57, 2.64, 3.44, 3.49, 3.75 and 3.84% (w.b.) in metalized multilayer polyethylene (MMPE) respectively for 15, 30, 45, 60, 75 and 90 days of storage. It was observed that the rate of moisture increase was low in all the packages till the storage period of 15 days after which the accumulation of moisture in the product was much faster. The increase in moisture content of sand-puffed kodo millet was appreciably lower in MMPE followed by PP packages. Furthermore, the sand-puffed kodo millet stored in HDPE acquired lesser moisture content in comparison to LDPE. This was anticipated as LDPE had higher permeability in comparison to all the other packaging materials. Numerous studies have been carried out with conclusions that hardness, bulk density, expansion ratio, crispiness decreases with increase in moisture content, meanwhile increase in storage life was observed with decrease in the initial grain moisture content (Mariotti *et al.*, 2006 [11]. Maisont and Narkrugsa, 2010 [9]. Patel, 2017). The initial moisture content of the hot-air puffed kodo millet was found to be 2.42, 2.16, 2.28, and 2.30% (w.b.) for PP, LDPE, HDPE, and MMPE respectively. As the duration of storage increased, the moisture content of the hot-air puffed kodo millet increased to 3.01, 3.21, 3.85, 4.58, 6.25 and 6.57% (w.b.) in PP; 4.55, 5.67, 6.72, 8.79, 9.12 and 9.83% (w.b.) in LDPE; 4.51, 4.82, 6.38, 6.71, 7.22 and 7.46% (w.b.) in HDPE; and 2.47, 3.15, 3.58, 3.81, 4.77 and 4.83% (w.b.) in metalized multilayer polyethylene (MMPE) respectively for 15, 30, 45, 60, 75 and 90 days of storage. It was observed that the rate of moisture increase was low in all the packages till the storage period of 15 days after which the accumulation of moisture in the product was much faster. The increase in moisture content of hot-air puffed kodo millet was appreciably lower in MMPE followed by PP, HDPE, and LDPE packages. The initial moisture content of the gun-puffed kodo millet was found to be 2.47, 2.63, 2.77, and 2.64% (w.b.) for PP, LDPE, HDPE, and MMPE respectively. As the duration of storage increased, the moisture content of the gun-puffed kodo millet increased to 4.78, 5.93, 6.95, 7.95, 8.77 and 8.98% (w.b.) in PP; 5.75, 6.77, 7.83, 9.87, 10.89 and 11.91% (w.b.) in LDPE; 4.68, 6.74, 6.78, 8.78, 9.82 and 9.88% (w.b.) in HDPE; and 3.47, 4.59, 5.65, 6.78, 6.81 and 7.88% (w.b.) in metalized multilayer polyethylene (MMPE) respectively for 15, 30, 45, 60, 75 and 90 days of storage. It was observed that the rate of moisture increase was low in all the packages till the storage period of 15 days after which the accumulation of moisture in the product was much faster. The increase in moisture content of gun-puffed kodo millet was appreciably lower in MMPE followed by PP packages. Furthermore, the gun-puffed kodo millet stored in HDPE accumulated lesser moisture content in comparison to LDPE.

The moisture content of the puffed kodo millet increased along with an increase in the storage duration regardless of the packaging material owing to the characteristic water vapor transmission rate of the packaging material and the hygroscopic nature of the product. The rise in moisture was also influenced by the final moisture content of the product after puffing. On the 30th day of storage, the highest moisture content of 6.77% (w.b.) was observed in gun-puffed LDPE packages and the lowest moisture content of 2.64% (w.b.) was estimated in sand-puffed MMPE packaging. On the 60th day of storage, the moisture content raised to a maximum of 9.87 and a minimum of 3.49% (w.b) respectively. Further on the 90th day of storage, the moisture content increased to a maximum of 11.91% and a minimum of 3.84% respectively. It can be concluded that the moisture absorption by puffed kodo millet in MMPE packaging was lesser in comparison to other packaging materials probably due to the impervious characteristic property of the MMPE packaging. The moisture absorption was highest in LDPE packages due to its high water vapor transmission rate. Statistical analysis showed that there was a significant difference ($p<0.05$) in moisture content of products in various packaging materials following the storage period of 30, 60, and 90 days. The interaction effect of treatment and storage was also significant. The moisture absorption in gun-puffed samples was higher in comparison to sand-puffed and hot-air puffed samples. This can be attributed to the fact that moisture desiccation occurred when kodo was puffed at high temperatures both in the sand and hot-air puffing. In gun-puffing, as the puffing occurs due to abrupt pressure drop and also no parboiling was employed, unlike the other methods, the internal structure built during puffing was partially inert to moisture absorption making the product obtained to be relatively higher in moisture content.

3.11.2.7 Effect of storage on crispiness of puffed kodo millet

During the storage period, the modification in the crispiness of kodo millet puffed with different methods and stored in different packaging materials was studied and the results are shown in Table 3 and Fig 2 a, b and c. The initial crispiness of the sand-puffed kodo millet was found to be 47, 46, 48, and 45 for PP, LDPE, HDPE, and MMPE respectively. As the duration of storage increased, the crispiness of the sand-puffed kodo millet increased to 38, 36, 34, 30, 25, and 22 in PP; 29, 16, 13, 10, 9, and 8 in LDPE; 31, 19, 16, 14, 11 and 10 in HDPE; and 45, 42, 40, 37, 36 and 33 in metalized multilayer polyethylene (MMPE) respectively for 15, 30, 45, 60, 75 and 90 days of storage. It was observed that the crispiness decreased over the storage duration. The decrease in the crispiness of sand-puffed kodo millet was appreciably lower in MMPE followed by PP, HDPE, and LDPE packages. This was anticipated as LDPE had higher moisture gain in comparison to all the other packaging materials. The moisture content of sand-puffed kodo millet during the storage period was observed to substantially vary with the type of packaging material thus affecting the crispiness of the product. The crispiness of hot-air puffed kodo millet was initially found to be 25,24,26 and 25 for PP, LDPE, HDPE, and MMPE respectively. As the duration of storage increased, the crispiness of hot-air puffed kodo millet reduced to 20, 14, 10, 7, 4, and 3 in PP; 12, 10, 5, 4, 3, and 2 in LDPE; 14, 10, 9, 7, and 6 in HDPE; and 23, 18, 15, 11, 9, and 8 in metalized multilayer polyethylene (MMPE) respectively for 15, 30, 45, 60, 75 and 90 days of storage. The decrease in the crispiness of hot-air puffed kodo millet was appreciably lower in MMPE followed by PP, HDPE, and LDPE packages. The crispiness of hot-air puffed kodo millet during the storage period was observed to vary considerably with the type of packaging material. The crispiness of the gun-puffed kodo millet was initially found to be 31, 30, 29, and 30 for PP, LDPE, HDPE, and MMPE respectively. As the duration of storage increased, the crispiness of the gun-puffed kodo millet decreased to 25,22,19,16 and 15 in PP; 8,7,5,4,4 and 3 in LDPE; 17,15,14,12,11 and 10 in HDPE; and 28, 26, 23, 20, 18 and 16 in metalized multilayer polyethylene (MMPE) respectively for 15, 30, 45, 60, 75 and 90 days of storage. It was observed that the crispiness reduced in all the packages till the storage period of 15 days after which the reduction was faster due to the accumulation of moisture in the product at a faster rate. The decrease in the crispiness of gun-puffed kodo millet was appreciably lower in MMPE followed by PP packages. Furthermore, the gun-puffed kodo millet stored in HDPE displayed higher crispiness in comparison to LDPE. The crispiness of gun-puffed kodo millet during the storage period was observed to appreciably differ with the type of packaging material due to the difference in characteristic permeability of different packaging materials. The crispiness of the puffed kodo millet decreased along with the storage duration regardless of the packaging material owing to the characteristic water vapor transmission rate of the packaging material and the hygroscopic nature of the product. On the 30th day of storage, the highest crispiness of 42 was observed in sand-puffed MMPE and the lowest (7) in gun-puffed LDPE packages was estimated. On the 60th day of storage, the crispiness reduced 37 and 4 respectively. Further on the 90th day of storage, the crispiness reduced to 33 and 2 respectively. The crispiness was lowest in LDPE packages due to the highest moisture absorption by the stored puffed product due to the high water vapor transmission rate. Statistical analysis showed that there was a significant difference ($p<0.05$) in the crispiness of products in various packaging materials following the storage period of 30, 60, and 90 days. The interaction effect of treatment and storage was also significant. The crispiness in gun-puffed samples was lower in comparison to sand-puffed and hot-air puffed samples. It can be concluded that the crispiness of puffed kodo millet in MMPE packaging was higher in comparison to other packaging materials due to the impervious nature and low water vapor transmission rate of the MMPE packaging.

3.11.2.8 Selection of best package for storage of puffed kodo millet

Based on the storage study of puffed kodo millet for *Local tiptur* variety in different packages, it was found that MMPE was best for the storage of puffed kodo millet. The product after storage of 90 days recorded lowest moisture content accumulation (3.96% (w. b.)), good sensory characteristics like appearance (7.57), color (6.02), aroma (7.29), texture (6.71), taste (6.22), overall acceptability (8.27) and highest crispiness (40).

Table 1: Quality parameters for sand puffing of kodo millet

	Parameter	**Reference method**
Independent variable	Variety (Local tiptur, Indira kodo-1 and KMV-545) Pre-treatment (Na Cl- 0.5, 1, 1.5 and 2%; Lactic acid-0.25, 0.75, 1.25 and 1.5%)	
Dependent variables	Puffing yield	Joshi *et al*., 2005
	Elongation ratio	Premavalli *et al*., 2005
	Volumetric expansion ratio	Mohapatra and Das, 2011
	Bulk density	Vishwakarma *et al*., 2012; and Mohsenin, 1970
	True density	Vishwakarma *et al*., 2012; and Mohsenin, 1970
	Void ratio	Vishwakarma *et al*., 2012; and Mohsenin, 1970
	Puffed product color	Spectrophotometer (Make: Konika Minolta Instrument, Osaka, Japan, Model-CM 5)
	Crispiness	Texture Analyser
	Sensory quality (Appearance, color, aroma, texture, taste and overall acceptability)	Amerine *et al.*, 1980

Table 3: Crispiness of variety *Local tiptur* puffed using different puffing methods and packaging materials

Puffing method		**Storage period (days)**							**mean**
		1	**15**	**30**	**45**	**60**	**75**	**90**	
Sand puffing	PP	47	38	36	34	30	25	22	33
	LDPE	46	29	16	13	10	9	8	19
	HDPE	48	31	19	16	14	11	10	21
	MMPE	45	45	42	40	37	36	33	40
Hot-air puffing	PP	25	20	14	10	7	4	3	12
	LDPE	24	12	10	5	4	3	2	9
	HDPE	26	14	10	9	7	6	4	11
	MMPE	25	23	18	15	11	9	8	16
Gun-puffing	PP	31	25	22	19	16	15	12	20
	LDPE	30	8	7	5	4	3	2	8
	HDPE	29	17	15	14	12	11	10	15
	MMPE	30	28	26	23	20	18	16	23
Mean		34	24	20	17	14	13	11	
Grand mean									19
ANOVA									

Puffing method	Sand puffing	Hot-air puffing	Gun-puffing	
Mean	28.25	12	16.5	
Packaging material	PP	LDPE	HDPE	MMPE
Mean	21.67	12	15.67	26.33
	F-Value	SEM	CD (@5%)	
Treatment (T)	**	1.026	2.860	
Storage (S)	**	1.568	4.369	
T x S	**	2.716	7.567	

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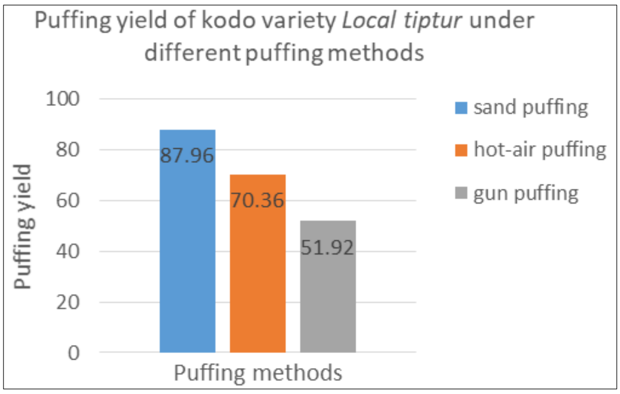
ANOVA									
Puffing method				Sand puffing		Hot-air puffing		Gun-puffing	
Mean				28.25		12		16.5	
Packaging material				PP	LDPE		HDPE	MMPE	
Mean				21.67	12		15.67	26.33	
				F-Value		SEM		CD (@5%)	
Treatment (T)				**		1.026		2.860	
Storage (S)				**		1.568		4.369	
T x S				**		2.716		7.567	



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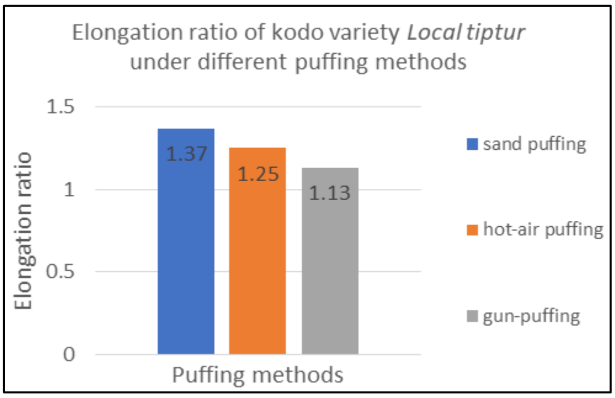

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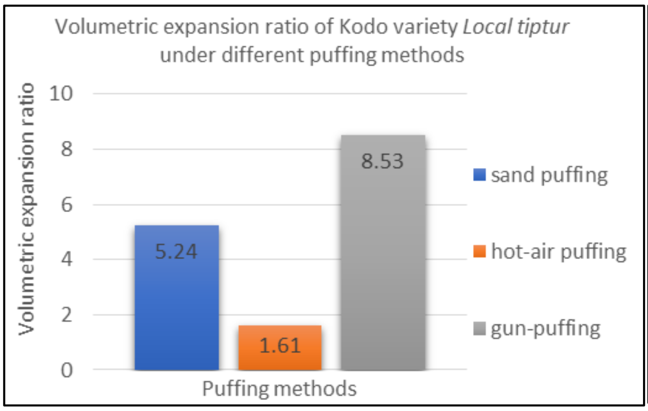

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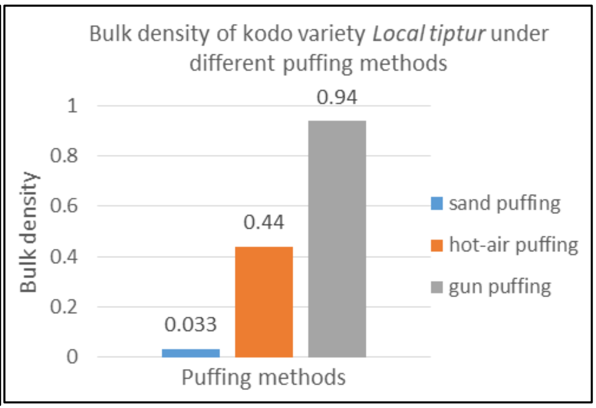

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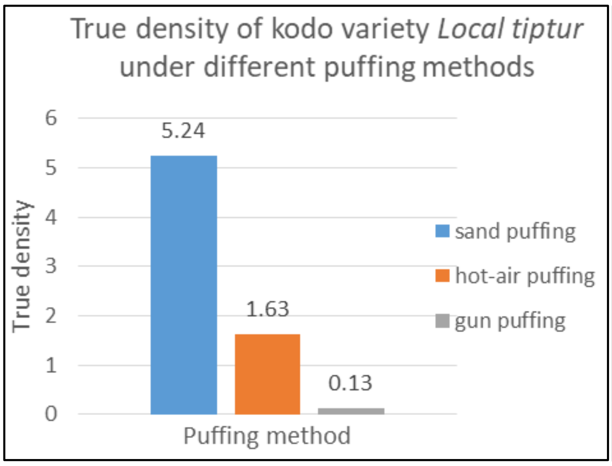

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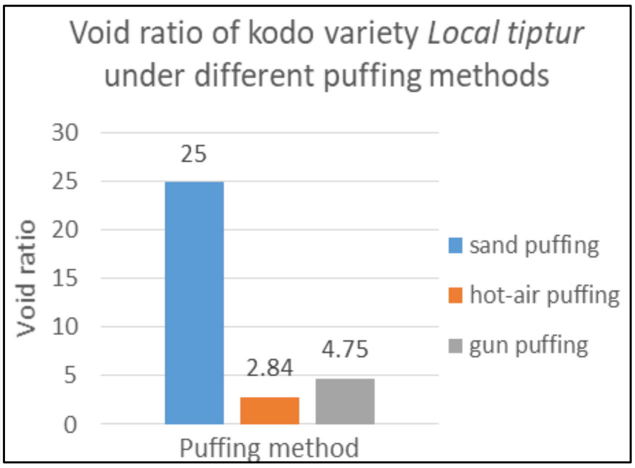

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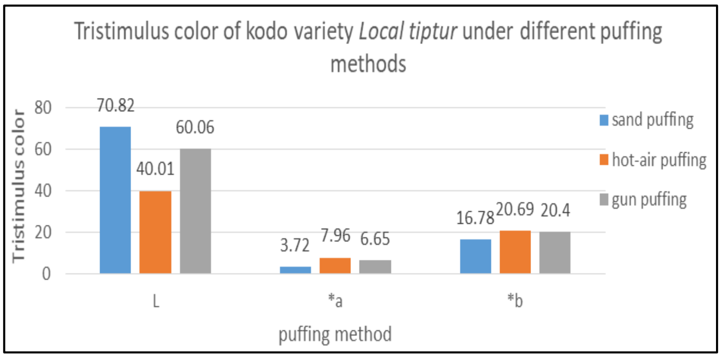

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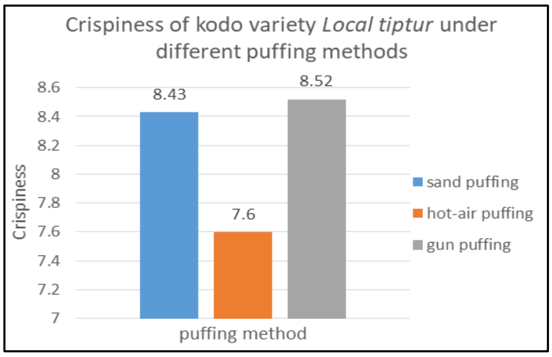

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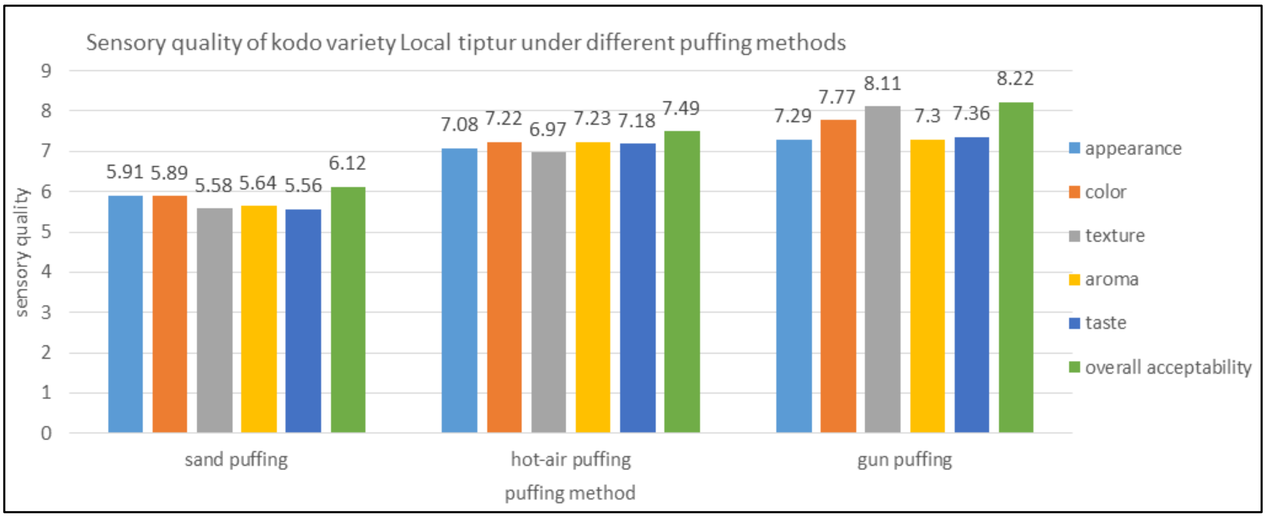
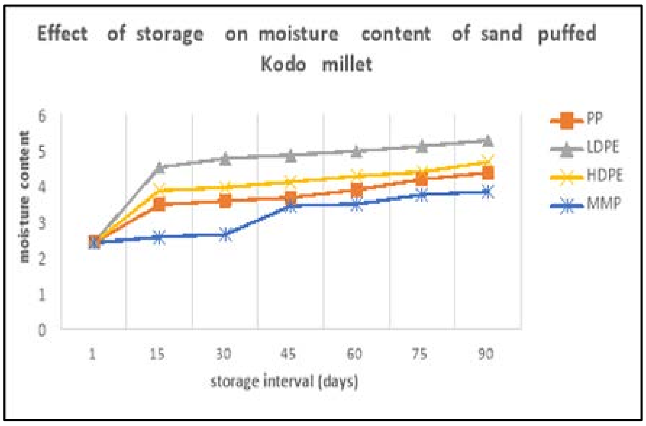


I

Fig 1: a. Puffing yield, b. elongation ratio c. volumetric expansion ratio d. bulk density e. true density, f. void ratio, g. tri-stimulus color, h. crispiness and i. sensory quality of kodo variety *Local tiptur* under different puffing methods



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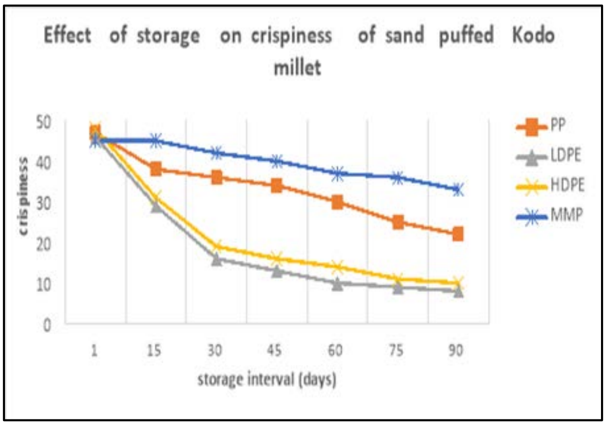

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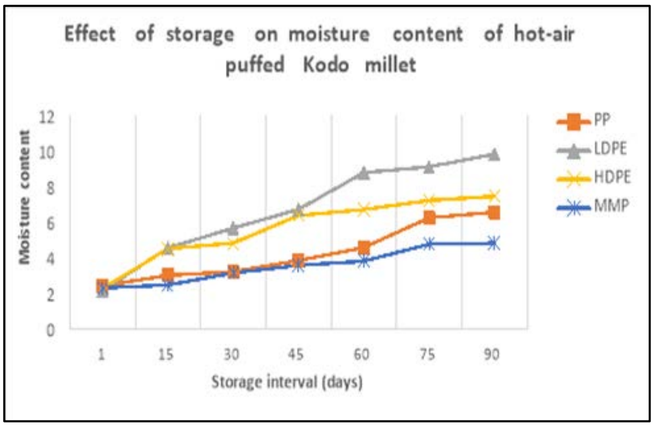

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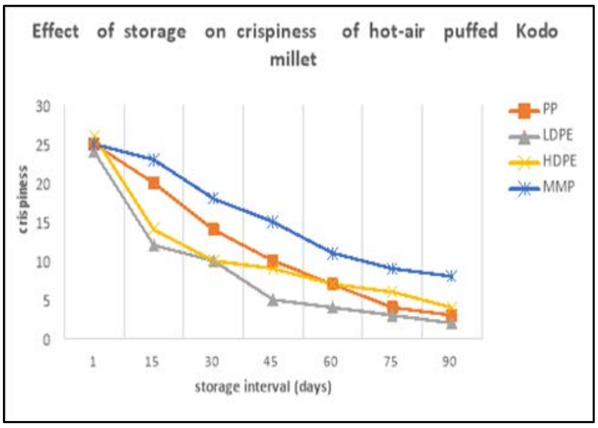

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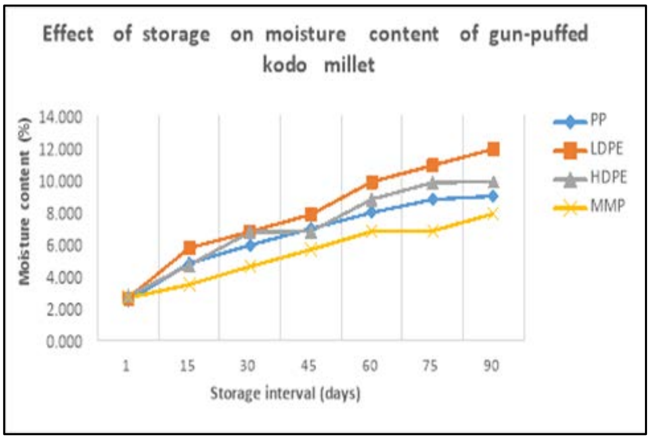

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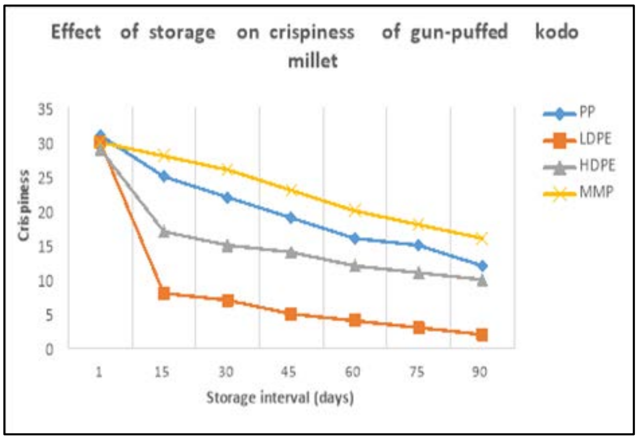

F

Fig 2: a Moisture content and b. crispiness of variety *Local tiptur* puffed using different packaging materials and puffing methods
(a) Sand puffing
(b) Hot-air puffing
(c) Gun puffing

A

B

C

Fig 3: Storage studies on a. sand puffing, b. hot-air puffing and c. gun-puffed kodo millet

Conclusion

From the current study the following important conclusions can be drawn: It is possible to puff kodo millet of good quality with different pretreatments and puffing methods. Salt treatment of 2% gave the best quality product with quality parameters like puffing yield (92.08%), elongation ratio (1.63), volumetric expansion ratio (6.67), bulk density (0.026), true density (0.69), void ratio (25.5), color (L*, 68.09; a*,3.58; b*,18.7) and crispiness (9.21). The sensory scores obtained were highest appearance (7.60), color (7.50), texture (7.00), aroma (7.70), taste (7.80) and overall acceptability (7.57). MMPE packages were best suited for the storage of puffed kodo millet. They provided the lowest accumulation of moisture (3.96% (w.b.) in the product maintaining highest crispiness (40) and good sensory quality characteristics like appearance (7.57), color (6.02), aroma (7.29), texture (6.71), taste (6.22), overall acceptability (8.27) after 90 days.

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