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Effect of Irradiation and Packaging on the Shelf Life of Foxtail Millet Flour

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Abstract

The use of irradiation alone as a preservation technique will not solve the problems of post-harvest food losses but it can play an important role in cutting losses in many cases when used judiciously along with good packaging. Hence, the study was planned to irradiate the foxtail millet flour at 1.5 kGy (IR) and stored in different packaging materials (LDPE, PP, PET and MPP) for a period of three months by taking flour stored without irradiation in steel box as control. Set of flour packed in different packaging materials (LDPE, PP, PET and MPP) without irradiation served as non-irradiated sample (NIR). Every fortnight the samples in three different treatments were drawn for biochemical changes (moisture, peroxide value and FFA), insect infestation and microbial growth. Significantly higher increase of moisture, peroxide value and FFA content was noticed in control sample followed by non irradiated PP and LDPE packed flour. Insect infestation started after 30 and 45 days of storage in steel boxes and non irradiated PP, LDPE covers, respectively, while no infestation of insects in case of MPP and PET packed flour. Further, significantly less biochemical changes (moisture, peroxide value and FFA) without fungal growth was noticed in irradiated MPP and PET packed samples. Thus, the foxtail millet flour stored in MPP and PET pouches with irradiation dose of 1.5 kGy was found suitable for safe storage up to three months under room temperature.

Keywords: Peroxide value, Insect infestation, Free fatty acids, Irradiation, Foxtail millet

India is the world's largest producer of millets. Millets are important crops of Asia and Africa (especially in India, Nigeria and Niger) with 97 per cent of millet production occurring in developing countries (McDonough *et al*., 2000). Millets have been considered as important food staples in human history. They have been in cultivation in East Asia for the last 10,000 years. National Nutrition Monitoring Bureau has reported that the consumption of millets was higher in the states of Gujarat (pearl millet, maize), Karnataka (finger millet), Maharashtra (sorghum) but negligible in the states of Kerala, Orissa, West Bengal and Tamil Nadu where rice is the most consumed cereal (NNMB, 2006). Millets contain 60-70 per cent carbohydrates, 7-11 per cent proteins, 1.5-5 per cent fat and 2-7 per cent crude fibre and are also rich in vitamins and minerals. They are excellent source of vitamin B, magnesium and antioxidants. Milles are also a good source of other dietary minerals like manganese, phosphorus and iron. Millet proteins are good source of essential amino acids except lysine and threonine but are relatively high in sulpture containing amino acids methionine and cysteine and are gluten free (Singh *et al.,* 2012). Foxtail millet is grown in china, Bangladesh and India. It requires warm weather and matures quickly in the hot summer months. They are nutritionally comparable or even superior to staple cereals such as rice and wheat in protein, fat and fiber contents (Gopalan *et al*., 2004).

Due to increasing awareness of consumers regarding advantages of consumption of millet based staple foods, the production, availability and access plays a key role towards increasing consumption. The major drawback of millet consumption is its smaller grain size, accidental addition of pebbles or stones, lack of availability of processing machinery at local places and non-awareness of women folk regarding methods of cooking that has made it difficult for production of recipes. In addition to this, increased availability of preferred cereals such as rice and wheat at subsidized prices also contributes for lesser usage. However, with the support of governments, the area under millets is increasing now-a-days so millet consumption has also increased among urban consumers due to awareness with respect to health benefits of millet consumption in urban dwellers. Today's woman finds it difficult to cook many of our traditional recipes due to non availability of millet flour in ready–to-useable form like wheat flour or rice flour. As such whole foxtail millet will not deteriorate readily, once the outer coat is removed or milled into flour, it readily deteriorates due to rancidity and attack of insects and micro organisms. The deterioration in storage due to the infestation by red flour beetle (*T. castaneum)* and other microorganisms leads to losses which in turn has adverse effects on the economy of the nation and health of the people. Grains milled into flours could intensify the activity of secondary pests in storage (Haines 1991). The rust-red flour beetle *T. castaneum* (Herbst) is a serious secondary storage pest of flours of all the important cereals namely maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), wheat (*Triticum aestivam* L.), rice (*Oryza sativa* L.) and Bajra (*Pennisetum glaucum* L.). The infestation by *T. castaneum* could directly result in weight loss and the beetle indirectly imparts a brownish tinge and pungent smell to infested flour by secretion of benzequinones (Appert, 1987 and Hodges *et al.,* 1996).

It is therefore necessary that such losses can be reduced through the use of technology so as to provide adequate information that will guarantee food security and food safety to the population.

Food irradiation is already recognized as a technically feasible method for reducing post harvest food losses, ensuring the hygienic quality of food and facilitating wider food trade (Jyoti *et al.*, 2009). Food is irradiated to utilize the destructive power of ionization radiation on the microorganisms with minimum changes in food constituents (Zenthen and Sorensen, 2003). The use of irradiation alone as a preservation technique will not solve the problems of post-harvest food losses which are severe but it can play an important role in cutting losses in many cases. Extensive research work done at the Bhabha Atomic Research Center (BARC) Mumbai have shown that low dose gamma irradiation (0.2-0.3 kGy) is effective in controlling insect infestation in rawa (Rao *et al*., 1994) and many other food products.

As per the literature cited, wheat and soya flours are normally irradiated at the rate of 1.0 kGy and health mix containing ragi is irradiated at the rate of 0.5 kGy. However, FSSAI proposed standards for irradiation of foods under class 3 (cereals, pulses and their milled products) provided the range of 0.25-1.0 kGy for insect disinfestations and 1.5 to 5.0 kGy for reduction of microbial load. Results of innumerous studies assured that the intake of irradiated food is absolutely safe for the consumers (Farkas, 2006). Cleaned and dehusked millet grains are already available in the market in good number of packages; however millet flours stored in suitable packing material with good shelf life is very essential as a staple food for daily consumption. Flour packed and stored in right conditions can prevent the loss or gain of moisture, entry of microorganisms, changes in fatty acid profile. Good packaging serves two purposes which are essentially technical and presentational. Technical aspects in packaging aim to extend the shelf life by providing better protection from all the hazards during storage. The temperature variation in flour products could result in either hydrolytic or oxidative rancidity, triggering destabilization of flour quality. Hence, good and shelf stable package under sealed condition could prevent moisture absorption, free radical build up, prolong keeping quality and prevent microbial proliferations**.** Hence, Shelf life of any flour is very important from the point of producer as well as the consumer. Studies on storage of millets in different conditions and different packaging materials are available in plenty (Thilagavathi *et al*., 2015 and Chaturvedi *et al*., 2013). However, systematic studies on storage of millet flour which is the basic raw material for the preparation of conventional (Ranganna *et al*., 2012 and Kalpana *et al*., 2013) as well as fancy products (Nargis *et al*., 2021) is available in very less numbers except for pearl millet flour (Bunkar *et al.,* 2014, Sindhu *et al*., 2016 and Bhatt *et al*., 2017)**.** However, studies on combined effect of radiation as well as packaging on quality of foxtail millet flour are not available. Hence, the study entitled 'Effect of Irradiation and Packaging on the

Shelf Life of Foxtail Millet Flour' was taken up to assess the effect of different packaging and radiation treatment on the shelf life of foxtail millet flour under room temperature.

MATERIAL AND METHODS

The foxtail millet (SIA-3088), was procured from AICRP (Small millets), ZARS, V.C. Farm, Mandya and was cleaned and dehusked at 'Centre of Excellence for Small Millet Processing', GKVK, Bengaluru. The dehusked grains were milled into flour using domestic flour mill and packed in different packaging material [250 gauge Low density polyethylene (LDPE), 250 gauge Polypropylene (PP), 400 gauge Metalized Polyester Polyethylene (MPP) and 420 gauge Polyethylene Teraphthalate (PET)] as per the experimental design. One set of flour samples immediately after milling packed into above packaging material were sent to BARC (Bhabha Atomic Research Centre) Mumbai for irradiation. The irradiation process was carried out by exposing the packed milled flour samples to gamma irradiation at the rate of 1.5 kGy (IR). Another set of flour samples without irradiation treatment packaged in different packaging material (LDPE, PP, PET and MPP) were kept under refrigeration until the arrival of irradiated samples (NIR). The millet flour samples stored in stainless steel boxes (normal house hold practice) served as Control.

Storeage study: Control, irradiated (IR) and non radiation (NIR) samples packed in different packaging material were stored under normal room temperature (30 ± 2 ^{0}C) with a relative humidity of 75 ± 5 per cent for a period of three months. The stored millet flour samples were analyzed every fortnight for various flour quality parameters.

Nutritional composition: Nutritional composition of the foxtail millet flour (moisture, protein, fat, ash, crude fiber, calcium, iron, magnesium, phosphorus and potassium) immediately after milling were analyzed according to standard AOAC (2005) procedure.

Functional parameters: Water Absorption Index (WAI), Water Solubility Index (WSI), Water Absorption Capacity (WAC) and Oil Absorption Capacity (OAC) of foxtail millet flour were analyzed immediately after milling as per Thilagavathi *et al.* (2015).

Bio-chemical changes: Bio-chemical changes of stored millet flours such as moisture, flour acidity, free fatty acids and peroxide values were analyzed every fortnight as per standard AOAC (2005) protocol.

Insect infestation: Visual observation for dead or live insects (including larvae and adults) was done using the sieve method. Data on insect infestation was recorded on the total number of larvae and adults as insect population from each replication by taking 20 grams of flour into 90 cm diameter petri dish and counting the same using magnifying glass and converting into percentage (Mali and Satyavir, 2005).

Microbial analysis: Microbial load of the stored flour including total bacterial count (TBC), fungal count (FC) and Escherichia coli (*E. oli*) were assessed every fortnight as per Chaturvedi *et al.* (2013). For microbial analysis, Nutrient Agar (Bacteria), Potato Dextrose Agar (Fungi) and MacConkey-Sorbitol Agar (*E. coli*) were procured from Himedia and enumeration was done using serial dilution technique.

Statistical analysis : Data obtained in triplicates was statistically analyzed using three factor ANOVA to assess the significant difference (0.05 %) among the treatments, the time intervals and the packaging material on the shelf life of foxtail millet flour.

RESULTS AND DISCUSSION

Nutritional and Functional Quality of Milled Foxtail Millet Flour

The nutritional and functional properties of foxtail millet flour immediately after milling is depicted in Table 1. The foxtail variety, SIA-3088 contained protein (8.50 %), crude fiber (7.40 %), calcium (32.13 mg %) and iron (2.60 mg %). The values reported in this work are in line with Gopalan *et al.* (2014) for most of the nutrients. The functional properties such as bulk density (1.53 g / ml), water and oil absorption capacity (72.43, 71.30 ml / 100 g) reported for foxtail millet flour in this work are in line with the values reported for selected

TABLE 1
Initial nutritional and functional properties of foxtail millet flour

Nutrients (per 100 g)	Foxtail millet flour (SIA -3088)
Moisture (%)	10.27 ± 0.04
Ash (%)	3.4 ± 0.06
Fat (%)	4.5 ± 0.10
Protein (%)	8.50 ± 0.10
Crude fiber (%)	7.40 ± 0.10
Carbohydrate (%)	66.63 ± 0.15
Energy (K. Cal)	341 ± 11.10
Calcium (mg)	32.13 ± 0.15
Phosphorus (mg)	289.86 ± 0.80
Iron (mg)	2.60 ± 0.09
Functional properties of foxtail millet flour sample	
Bulk density (g/ ml)	1.53 ± 0.01
Water absorption capacity (ml / 100 g)	72.43 ± 0.04
Oil absorption capacity (ml / 100 g)	71.30 ± 0.80
Water absorption Index (%)	8.96 ± 0.27
Water solubility Index (%)	8.72 ± 0.24

Values are mean of three replications ± SD

millet and pulse flour by Thilagavathi *et al.* (2015) and Shobha *et al.* (2012) for maize flour.

Effect of Storage on the Biochemical Parameters

a) Peroxide Value

Peroxide values are usually used as an indicator of deterioration of fats, as oxidation takes place. The double bond in the unsaturated fatty acids is broken down to produce secondary oxidation products which in turn causes rancidity. Initial peroxide value of foxtail millet flour (Table 2) was 4.40 m.eq / kg fat which increased steadily as the storage period progressed. However, by the end of storage period the increase was more significant in control (15.26 m.eq / kg fat) followed by non-irradiated LDPE and PP packed flour (14.40 and 14.30 m.eq / kg fat), respectively. However, by the end of storage period, the changes in peroxide value of stored flour was significantly less in case of irradiated MPP (9.26 m.eq / kg fat) and irradiated PET (10.10 m.eq / kg fat) pouches. Similar kind of peroxide value changes was also reported by Gahalwat and Sehgal (1992) and Kwaku *et al.* (2004). As per report of Eagan *et al.* (1981) the peroxide value of fresh oil and fats is usually below10 meq /kg and for rancid oils

TABLE 2
Effect of storage on Peroxide value of foxtail millet flour

Storage days	Irradiation (IR)					Non irradiation (NIR)				
	B_1	B_2	B_3	B_4	B_5	B_1	B_2	B_3	B_4	B_5
0	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
15	8.40	5.20	6.20	7.20	8.20	9.80	8.40	8.20	9.20	9.20
30	9.13	6.20	7.16	8.26	9.20	11.30	9.13	9.26	10.20	10.20
45	10.20	6.73	8.26	10.16	10.60	12.26	10.20	10.30	11.20	11.26
60	11.20	7.20	9.40	11.26	11.40	13.33	11.20	11.30	12.33	12.36
75	12.33	8.20	9.70	12.40	12.40	14.23	12.33	12.30	13.30	13.26
90	15.26	9.26	10.10	13.40	13.30	15.26	13.26	13.23	14.30	14.30

Parameter		F-Value	SEm ±	CD@5%
Peroxide value (m eq/kg fat)	Between treatment	3285.9	0.023	0.063
	Between packaging	665.3	0.036	0.100
	Between days	4337.08	0.042	0.118
	Treatment x packaging x days	11.07	0.134	0.373

Note: B_1- Control, B_2-MPP, B_3- PET, B_4- LDPE, B_5-PP. Significant @ 5 %

and fats is above 20 meq/ kg. Peroxide values in this study are within the BIS limits (<10 meq/kg of fat) for irradiated MPP followed by irradiated PET packed flour.

b) **Free Fatty Acids (FFA)**

Free fatty acids are indicators of deterioration of fat. Free fatty acids (FFA) are produced by the hydrolysis of oils and fats, since FFA's are less stable than neutral oil, they are more prone to oxidation thus turning to rancid. Thus, FFA is a key feature linked with the quality and commercial value of oils and fat. The FFA in this study increased significantly from 0 to 90 days and the increase was more pronounced in control (steel box) as it was neither irradiated nor packed in specific packaging, followed by non irradiated LDPE (1.62 %) and PP (1.72 %). However, the changes in FFA content were significantly less in irradiated MPP (1.10) and PET (1.20) covers as compared to non-irradiated samples in different packaging types. The changes between the treatments, between the packaging as well as between the storage duration were found to be significant (Table 3). Significantly higher FFA content of foxtail millet flour stored in steel boxes followed by non irradiated PP and LDPE covers was probably because of higher moisture content of these samples which lead to more rapid hydrolytic action of lipases at higher moisture levels (Table 3) rendering to development of more FFAs. Research work carried out by Panjin *et al.* (2006) and Monika and Mridula (2015) on the effect of storage period on the *dragge* (Chikki like product obtained by coating a confectionary sunflower kernel with sugar syrup) sunflower kernel based nutritious bar and maize based fortified nutritious bar respectively indicated a significant increase in free fatty acid content and which was within the acceptable limit for three months of storage. Free fatty acid is an important parameter for storage of bajra flour and FFA was found significant after 16 days of storage in the cotton bag as compared to other packaging material such as Tin and HDPE container (Bhatt *et al.,* 2017). The FFA level should not exceed 1.5 per cent and peroxide value 20-40 meq /kg fat for noticeable rancidity (Shobha *et al.,* 2012).

TABLE 3

Effect of storage on Free fatty acid (FFA) content of foxtail millet flour

Storage days	Irradiation (IR)					Non irradiation (NIR)				
	B_1	B_2	B_3	B_4	B_5	B_1	B_2	B_3	B_4	B_5
0	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
15	0.57	0.26	0.35	0.34	0.43	0.57	0.34	0.42	0.52	0.73
30	0.94	0.36	0.53	0.45	0.62	0.94	0.46	0.66	1.05	1.13
45	1.13	0.46	0.87	0.56	1.06	1.13	0.58	0.71	1.20	1.23
60	1.21	0.63	1.05	0.74	1.21	1.21	0.72	0.89	1.21	1.33
75	1.35	0.83	1.13	0.93	1.23	1.35	0.94	1.03	1.42	1.51
90	1.76	1.10	1.20	1.23	1.32	1.76	1.25	1.30	1.48	1.59

Parameter		F-Value	SEm ±	CD@5%
Free fatty acid	Between treatment	333.15	0.006	0.017
(% oleic acid)	Between packaging	355.67	0.009	0.026
	Between days	1261.5	0.011	0.031
	Treatment x packaging x days	2.839	0.035	0.099

Note : B_1- Control, B_2-MPP, B_3- PET , B_4- LDPE, B_5-PP . Significant @ 5 per cent

c) **Moisture Content**

The moisture of any food product plays an important role in determining the shelf life of particular product. Generally, moisture content decreases or increases during storage depending upon the storage conditions and packaging material. The effect of storage on the moisture content of foxtail millet flour is depicted in Table 4. The flour stored in steel box (control) absorbed the highest moisture from the atmosphere, as it was obvious that during sampling, the lid of the box was widely exposed to the atmosphere leading to higher absorption of atmospheric moisture content. The non irradiated samples stored in LDPE and PP covers exhibited significantly higher moisture absorption of 16.36 and 17.43 per cent, respectively indicating that the permeability for moisture transmission was quite high in these packages irrespective of irradiation treatment. It even crossed the Codex Alimentarius upper acceptable limit of 15.5 per cent for safe storage (Saad *et al.,* 2014). However, the flour stored in MPP and PET (Table 4) showed significantly less changes in moisture content (below 10 %) and is considered to be safe for storage. As per Bhatt *et al.* (2017), the moisture content of bajra flour was found significant after 16 days of storage and the increasing trend was found in treatment of all the varieties of bajra flour kept in cotton bag at room temperature. Even the study of Veena *et al.* (2012) also reports higher moisture gain in papad samples during storage period of 90 days. The increase of moisture content in pearl millet grain over 12 months' storage was reported by Mali and Satyavir (2005) where in initial moisture content (5.15 %) of the grain increased to13.7 per cent after 12 months of storage at 25 °C.

Effect of Storage on Insect Infestation

The effect of storage on the insect infestation of foxtail millet flour is depicted in Fig. 1. Significantly higher numbers of insects (larvae and adults) were noticed in control sample. Insects appeared after 30 days of storage in non-irradiated PP (20/100 g flour) and LDPE (15 / 100 g of flour) packed samples. Number of insects (larvae and adults) increased significantly in steel boxes from 30 days of storage followed by non-irradiated

TABLE 4

Effect of storage on Moisture content of foxtail millet flour

Storage days	Irradiation (IR)					Non irradiation (NIR)				
	B_1	B_2	B_3	B_4	B_5	B_1	B_2	B_3	B_4	B_5
0	7.40	7.40	7.40	7.40	7.40	9.26	9.26	9.26	9.26	7.40
15	11.33	8.20	8.00	10.70	11.10	12.16	9.83	10.36	11.03	11.33
30	12.40	8.70	8.30	11.00	11.50	13.23	10.23	11.40	12.30	12.40
45	14.26	9.10	8.90	11.30	12.00	14.46	11.26	12.40	13.46	14.26
60	15.33	9.35	9.40	11.90	12.50	15.40	12.36	13.40	14.33	15.33
75	16.36	9.51	9.62	12.70	12.70	16.56	13.46	14.46	15.53	16.36
90	17.43	9.60	9.79	13.90	13.90	17.33	14.33	14.88	16.36	17.43

Parameter		F-Value	SEm±	CD@5%
Moisture (%)	Between treatment	2105.3	0.029	0.080
	Between packaging	763.69	0.045	0.127
	Between days	1738.9	0.054	0.150
	Treatment x packaging x days	4.224	0.170	0.475

Note : B1- Control, B2-MPP, B3- PET, B4- LDPE, B5-PP . Significant @ 5 %

PP and LDPE covers (Fig. 1). There was no insect infestation in MPP and PET covers irrespective of irradiation treatment (Fig. 1). The increase in insect infestation in steel boxes as compared to other materials was due to retention of higher moisture inside steel boxes that resulted in faster multiplication of the insect. The present study revealed that the increase of insect population in LDPE and PP packaged flour implies that it is not only the moisture content of the outer environment but also the insect population that created more humidity in the air by their metabolic activity which further increased grain moisture and insect population, as reported by Mali and Satyavir (2000).

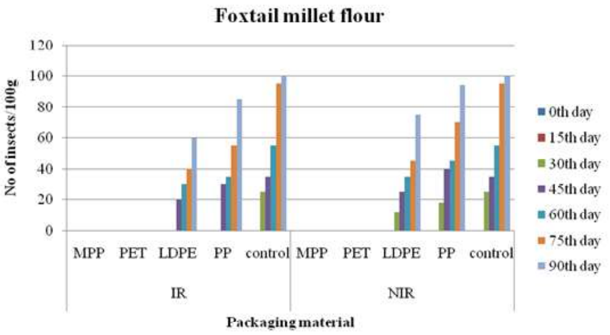

Fig. 1: Effect of storage on insect infestation in foxtail millet flour

The type of insects noticed in this study were majorly red coloured Red flour beetle (*Triboliumca staneum*) followed by black coloured Rice weevil (*Sitophilus oryzae*) and few cream colored larvae of Rice moth (*Corcyra cephalonica*). Since, the unpolished flour was used, the growth of insects is quite high, as polishing reduces the available essential nutrients required for successful growth and development of pest species. Bran of millet contains some essential nutrients and has been implicated in supporting higher population of *T. castaneum* in whole flour than polished flour. Similarly, study conducted by Mali and Satyavir (2005) on the storage of pearl millet found that grains were majorly infested with the larvae and adults of lesser grain borer (*Rhizopertha dominica*) and red flour beetle(*Triboliumca staneum*). Further, insect population (larvae and adults) were significantly higher in tin containers and jute bags at room temperature and 25 °C.

Effect of Storage on Microbial Quality

The perusal of Fig. 2 depicts the microbial load of foxtail millet flour stored in different packaging material, where in there was no *E. coli* infestation in any of the samples, indicating that the methods followed during flour making and storage were hygienically safe. Significantly higher bacteria (18.5 cfu/g) and fungi (5.0 cfu/g) were noticed in control samples by the end of storage period. Number of bacteria and fungi were significantly more in steel boxes followed by non irradiated PP covers (17.8 cfu/g and 7.0 cfu/g), while less than five number of bacteria (1.0 and 1.5 log cfu/ g) were noticed in case of irradiated MPP and PET packed flours which it did not increase throughout the storage period (Fig. 2). No fungal colonies were noticed in irradiated MPP and PET packed flour. The highest bacterial and fungal counts in PP package irrespective of irradiation treatment (Fig.2) might be due to damage caused to PP covers while handling, transportation and storage. Similar results were reported in irradiated processed ragi and barly by Chaturvedi *et al.* (2013). Even the results of Ramasri

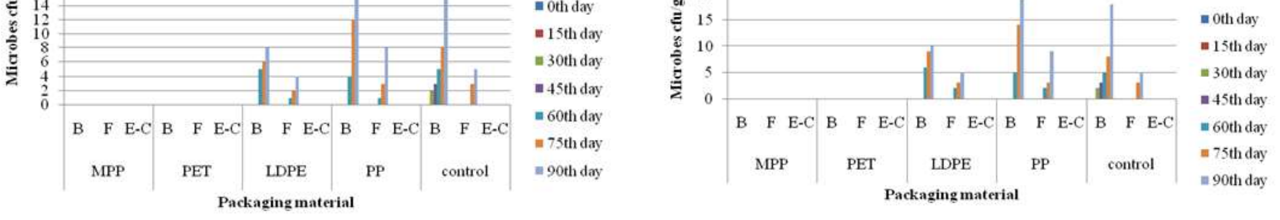

Fig. 2 : Effect of storage on microbial quality of foxtail millet flour

et al. (2014) concluded that irradiation treatment (0.5 kGy upto 3 kGy) of health mix reduced the bacterial count and increased the shelf life. The results are in line with the findings of Singh *et al*. (2006), Mallesi *et al*. (1996) where in they found that there was no mould growth in irradiated formulation at the dosage of 0.5 kGy.

In the present study, the MPP and PET packages served as better packaging material for safe storage of foxtail millet flour. Further, irradiation along with good packaging led to control of insect and bacterial population. Similar kind of study conducted by Panjin *et al*. (2006) reported that metalized polyester polyethylene; labeled metalized PET / PE containers were most suitable for storage of *dragee* product. The packaging materials such as metalized polyester/ polyethylene; labeled metalized PET/ PE containers had lowest oxygen permeability (8.0 mLm-2 / dan "p1bar) which had strong influence in the prevention of hydrolytic and oxidative changes in the final product. Even the results of Bhatt *et al.* (2017) demonstrated that Tin and HDPE container are suitable for storage of bajra flour under room temperature for a short period of 16 days, but with irradiation the storage period can be extended significantly. Thus, the study demonstrates that the irradiation alone will not provide lasting disinfestations effect, therefore, it is also important to select the suitable packaging materials that cannot be penetrated by insects or beetles should be used to avoid post irradiation infestation. The use of irradiation alone as a preservation technique will not solve the problem of post-harvest food losses but it can play an important role in cutting losses in many cases when used judiciously along with good packaging. Hence, the present study revealed that the foxtail millet flour stored in MPP and PET pouches with irradiation dose of 1.5 kGy found suitable for safe storage up to three months under room temperature.

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