Extending the Shelf-life of Whole-Wheat Flour by Gamma Irradiation and Organoleptic Characteristics of Cakes Made with Irradiated Flour

Article *in* Current Nutrition & Food Science · January 2019

DOI: 10.2174/1573401315666190115161626

Fereshteh Ansari
Razi Vaccine and Serum Research Institute

Aziz Homayouni
Tabriz University of Medical Sciences

Hadi Pourjafar
Maragheh University of Medical Sciences

RESEARCH ARTICLE

Extending the Shelf-life of Whole-Wheat Flour by Gamma Irradiation and Organoleptic Characteristics of Cakes Made with Irradiated Flour

Fereshteh Ansari[1,2], Aziz Homayouni[3], Parvaneh Mohsennezhad[4,5], Alireza Mohammad Alivand[5] and Hadi Pourjafar[6,*]

[1]Research Center for Evidence-Based Medicine, Health Management and Safety Promotion Research Institute, Tabriz University of Medical Sciences, Tabriz, Iran; [2]Iranian EBM Centre: A Joanna Briggs Institute Affiliated Group; [3]Department of Food Science and Technology, Faculty of Nutrition and Food Sciences, Tabriz University of Medical Sciences, Tabriz, Iran; [4]Maragheh University of Medical Sciences, Maragheh, Iran; [5]Department of Research and Development, Arde Sonbole Maragheh (Altin Flour Company), Maragheh, Iran; [6]Department of Food Sciences and Nutrition, Maragheh University of Medical Sciences, Maragheh, Iran

ARTICLE HISTORY

Received: October 07, 2018
Revised: December 30, 2018
Accepted: January 01, 2019

*DOI:
10.2174/1573401315666190115161626*

Abstract: ***Background***: Extending the shelf-life of food products is very important for food producers, and one of its most significant methods is gamma irradiation.

Objective: The aim of this study is to evaluate extending the shelf-life of whole-wheat flour using gamma irradiation and to study the organoleptic and physical characteristics of the cakes made with irradiated flour.

Method: 900 g packed flour samples were irradiated with different doses of 0.2, 0.5, 2 and 5 kGy of gamma irradiation using Caesium-137 source.

Results: Based on the results, insect growth was not observed in any of the irradiated flour samples up to 180 days after production. The total number of bacteria and the number of mold and yeast significantly reduced during 180 days of storage. With increasing the irradiation dose, the height of the baked cakes was significantly reduced, the size of the air bubbles inside the cake decreased, and the color of the cakes became darker so that a dark and different color was observed at a dose of 5 kGy.

Conclusion: By applying a dose of 5 kGy irradiation, the shelf-life of flour can be longer, with inconsiderable organoleptic changes of baked cakes.

Keywords: Wheat flour, Irradiation, Shelf-life, Cake, Organoleptic, agricultural waste, insect contamination.

1. INTRODUCTION

Extending the shelf-life of food products is one of the main objectives of the food producers, especially about the perishable foods. One of the most important methods for extending of shelf-life is gamma irradiation, which will ultimately improve food health. The history of using food irradiation dates back to the 1950s [1-4].

Currently, the quantities of agricultural waste have been reported to be more than 25 % while this amount can be reduced using gamma irradiation according to national and international standards. The level of flour technology and its related machinery is optimal and advanced in some developing countries, but unfortunately it has made limited progress in terms of producing luxury flour products such as cooking or kitchen flour, ready-made flour for cake, ready-made flour for pastry, as well as fortified flour in small packaging with a long shelf-life. One of the most important obstacles to such development and the export of such products on a small but profitable scale can be the short shelf-life of them which is less than two months. The amount of contamination of flour with the eggs and larvae of insects as well as the level of bacterial and fungal contamination and pH changes determine the shelf life of the product [2, 3, 5, 6].

By improving the quality and extending the shelf-life of these products, their mass production with a long shelf-life can be marketed. Gamma irradiation is one of the useful and effective methods. Various researches have shown that through irradiation with a dose of less than 1 kGy, the shelf-life of the packed flour can be extended to 6 months on the store shelf [2, 7, 8]. In other words, this dose of irradiation, in addition to completely eliminating the eggs and larvae of insects, reduces the total number of all the bacteria in the product [2, 7]. The number of studies conducted on this

*Address correspondence to this author at the Department of Food Sciences and Nutrition, Maragheh University of Medical Sciences, Maragheh, Iran; Tel/Fax: +984137256920; Mobile: +989144082455;
E-mail: pourjafarhadi59@ut.ac.ir

1573-4013/19 $58.00+.00

highly important subject is limited, and the effect of irradiation on the microbial load and pH of the flour as well as the organoleptic characteristics of the obtained product has not been studied. The aim of this study is to evaluate extending the shelf-life of whole-wheat flour using gamma irradiation and to study the organoleptic and physical characteristics of the cakes made with irradiated flour.

2. MATERIALS AND METHODS

2.1. Irradiation of the product

At this stage, 900 g packed flour samples were sent to the National Multipurpose Irradiation Organization. Samples were placed in 43×43×43 cm cartons, each containing 18 flour samples. The packets were divided, registered and marked, and the groups were irradiated using different doses of 0.2, 0.5, 2 and 5 kGy of gamma irradiation (using Caesium-137 source). Finally, the irradiated cartons were returned to the laboratory to perform further experiments.

2.2. Investigating the Elimination of Insect Contamination During 180-Day Storage

Alive and dead insects (larvae or adult insects) were investigated on days 0, 60, 120 and 180 in irradiated flour and control (not irradiated) flour. For this purpose, flour samples were first homogenized. Then the homogenized flour was weighed, and 10 g was poured into sterile plates (the plates were completely covered to a height of 1 cm). Finally, the plates were placed in conditions of 25 ± 2°C and relative humidity of 70 ± 8 %, and the light exposure cycle was 12 h of brightness and 12 h of darkness. Using this method, alive eggs turn into insect larva which is observable [9, 10].

2.3. Total Count of Bacteria and Mold-Yeast Number During 180-Day Storage

The total count of aerobic mesophilic bacteria and the total count of fungi (mold and yeast) were enumerated according to the standard method and by using Plate Count Agar (PCA) for bacterial counting and Potato Dextrose Agar (PDA) for fungi counting on days 0, 60, 120 and 180 in irradiated and control flour samples [2, 11].

2.4. Measurement of pH of the Irradiated Product During 180-Day Storage

The pH of the irradiated and control flour was evaluated on days 0, 30, 60, 90, 120, 150 and 180. One gram of each flour sample was dissolved into 25 ml of distilled water (at 25°C) and shaken for 10 min., and the pH of every suspension of the flour samples was measured by a digital pH meter.

2.5. Investigating the Organoleptic Characteristics of Cakes Made with Irradiated Flour

The evaluation of the organoleptic characteristics of cakes made with irradiated and control flour was performed using a 20-member test panel method. Characteristics such as color, appearance, mouthfeel, desirability, smell, taste and general acceptance in a fixed environment and light with equal conditions were evaluated on days 1, 60, 120, and 180 [2, 12]. Furthermore, differences in height or puffiness and appearance of cakes made from different flour samples were separately compared with each other on days 1, 60, 120 and 180.

2.6. Statistical Analysis

Chi-square test was used to compare the different groups in terms of the presence or absence of insects. For other items, ANOVA test or its nonparametric equivalents were used. Statistical analysis was performed using SPSS software. A p value of < 0.05 considered as significant. All experiments, including insect contamination, total bacterial count, measuring cake height and its organoleptic characteristics as well as triplicate pH measurement were performed, and the results were reported as mean with standard deviation.

3. RESULTS

3.1. The Elimination of Insect Contamination

Based on the obtained results, insect growth was not detected in any of the irradiated flour samples (0.2, 0.5, 2 and 5 kGy) for 180 days and even up to 15 months after production, but the growth of some insects especially red flour beetles (*Tribolium castaneum*) was observed in the control samples after one month of storage at room temperature. Meanwhile, the growth of red flour beetles was also observed in raw wheat samples used to produce tested flour and their bran samples. The rate of infection with red beetles in the non-irradiated flour samples was approximately 50 pcs per 10 g of flour.

3.2. Microbiological Characteristics

Table **1** illustrates the results of the total bacterial count and the total number of fungi (mold and yeast) on different days of 0, 60, 120 and 180.

3.3. pH Changes

Table **2** shows values of pH of irradiated and control flour product during 180-day storage.

3.4. Organoleptic Characteristics of Cake Made with Irradiated Flour

Organoleptic characteristics of cakes made with irradiated and control flour samples are indicated in Table **3**. Baked cake from flours of different experimental groups (control, control2 (freeze for 48 h), 0.2, 0.5, 2 and 5 kGy) is shown in Fig. (**1**) (Notice the height, puffiness, and color of the cakes).

4. DISCUSSION

According to the results obtained in this research, none of the irradiated samples with 0.2, 0.5, 2, and 5 kGy show insect growth during storage days. It has been demonstrated that only a 0.2 kGy dose of flour irradiation was enough to

Table 1. Mean ± SD of total count and mold-yeast count of five studied samples during 180 days.

	Total Bacterial Count					Mold-Yeast Count				
	Day 1	**Day 60**	**Day 120**	**Day 180**	**P Value[a]**	**Day 1**	**Day 60**	**Day 120**	**Day 180**	**P Value[a]**
Control	10333.3 ± 14433.8 ^{aA}	34000.0 ± 14422.0 ^{aA}	1833.3 ± 288.7 ^{aA}	1666.7 ± 577.3 ^{aA}	**0.062**	2500.0 ± 1500.0 ^{aA}	170.0 ± 112.7 ^{aA}	42.7 ± 18.6 ^{aA}	26.7 ± 20.8 ^{aAB}	**0.042**
0.2 kGy	3300.0 ± 2523.9 ^{abA}	14000.0 ± 3605.5 ^{bAB}	7.0 ± 6.1 ^{abA}	0.0 ± 0.0 ^{aB}	**0.032**	1333.3 ± 577.3 ^{aA}	100.0 ± 100.0 ^{aA}	100.0 ± 100.0 ^{aA}	133.3 ± 57.7 ^{aB}	0.096
0.5 kGy	1000.0 ± 0.0 ^{aA}	666.7 ± 577.3 ^{aAB}	0.0 ± 0.0 ^{aA}	0.0 ± 0.0 ^{aB}	0.061	600.0 ± 556.8 ^{aA}	70.0 ± 60.8 ^{aA}	36.0 ± 22.6 ^{aA}	10.0 ± 0.0 ^{aAB}	0.086
2 kGy	100.0 ± 0.0 ^{aA}	100.0 ± 0.0 ^{aAB}	0.0 ± 0.0 ^{aA}	0.0 ± 0.0 ^{aB}	**0.029**	160.0 ± 52.9 ^{aA}	0.0 ± 0.0 ^{aA}	0.0 ± 0.0 ^{aA}	0.0 ± 0.0 ^{aA}	**0.029**
5 kGy	100.0 ± 0.0 ^{aA}	0.0 ± 0.0 ^{aB}	0.0 ± 0.0 ^{aA}	0.0 ± 0.0 ^{aB}	**0.029**	100.0 ± 0.0 ^{aA}	0.0 ± 0.0 ^{aA}	0.0 ± 0.0 ^{aA}	0.0 ± 0.0 ^{aA}	**0.029**
P value[A]	**0.013**	**0.014**	**0.016**	**0.008**		**0.021**	0.073	0.062	**0.009**	

[a] Total bacterial count and mold-yeast count were compared between days of the experiment using the Friedman test. The different lowercase letters in each separated raw indicate significant statistical difference between days in each dose of irradiation. $P<0.05$ considered as the significance level.
[A] In each day, the statistically significant difference between doses was examined using Kruskal-Wallis test. The different uppercase letters in each separated column indicate significant statistical difference between doses in each dose of irradiation. $P<0.05$ considered as the significance level.
All the significant P values are highlighted by bold font.
In some cases despite the overall significant P value, no significant P value was observed in the pairwise comparison.

Table 2. Mean ± SD of pH of five studied samples during 180 days.

	pH				**P Value[a]**
	Day 1	**Day 60**	**Day 120**	**Day 180**	
Control	6.14 ± 0.05	6.20 ± 0.04 ^{A}	6.08 ± 0.01 ^{A}	6.01 ± 0.01 ^{AC}	0.074
0.2 kGy	6.06 ± 0.08 ^{ab}	6.26 ± 0.01 ^{aA}	6.02 ± 0.02 ^{bA}	6.22 ± 0.14 ^{abA}	**0.010**
0.5 kGy	6.12 ± 0.08	6.20 ± 0.03 ^{A}	6.01 ± 0.02 ^{A}	6.0 ± 0.00 ^{AC}	0.175
2 kGy	5.96 ± 0.05	5.94 ± 0.01 ^{B}	5.85 ± 0.01 ^{B}	5.6 ± 0.15 ^{B}	0.100
5 kGy	5.98 ± 0.09	5.83 ± 0.03 ^{C}	5.66 ± 0.07 ^{C}	5.84 ± 0.06 ^{CB}	**0.049**
P value[A]	**0.040**	**<0.001**	**<0.001**	**<0.001**	**<0.001**

[a] pH was compared between days of the experiment using Repeated Measures ANOVA test. The different lowercase letters in each separated raw indicate significant statistical difference between days in each dose of irradiation. $P<0.05$ considered as the significance level.
[A] In each day, the statistically significant difference between doses was examined using One-Way ANOVA test. The different uppercase letters in each separated column indicate significant statistical difference between doses in each dose of irradiation. $P<0.05$ considered as the significance level.
All the significant P values are highlighted by bold font.
In some cases despite the overall significant P value, no significant P value was observed in the pairwise comparison.

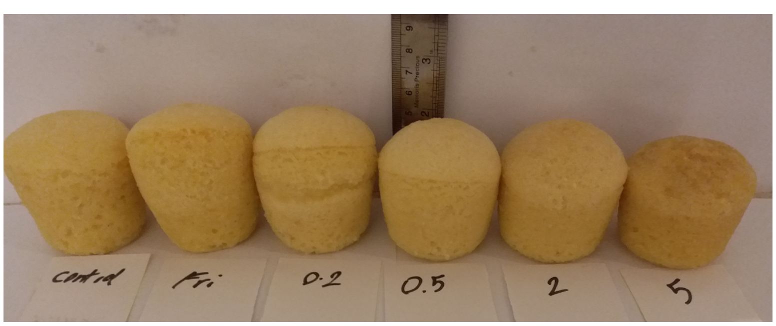

Fig. (1). Baked cake from flours of different experimental groups (control, control2 (freeze for 48 h), 0.2, 0.5, 2 and 5 kGy). Notice the height, puffiness, and color of the cakes.

Table 3. Mean ± SD of the characteristics of the baked cake from five studied samples during 180 days.

	Height of the Cake (cm) (Primary Dough=3)				
	Day 1	**Day 60**	**Day 120**	**Day 180**	**P Value[a]**
Control	6.0 ± 0.0[aA]	6.0 ± 0.1 [aABD]	6.0 ± 0.1 [aA]	5.3 ± 0.1 [aA]	**0.025**
0.2 kGy	6.4 ± 0.1 [aA]	6.5 ± 0.1 [aC]	6.3 ± 0.1 [aA]	5.5 ± 0.1 [aA]	**0.010**
0.5 kGy	6.0 ± 0.1 [aA]	6.1 ± 0.1 [bB]	6.0 ± 0.0 [aA]	5.1 ± 0.2 [aAB]	**0.021**
2 kGy	5.6 ± 0.1 [aA]	5.7 ± 0.1 [aD]	5.6 ± 0.3 [aC]	5.0 ± 0.3 [aAB]	0.160
5 kGy	5.0 ± 0.1 [aB]	5.0 ± 0.1 [aE]	4.9 ± 0.1 [bB]	4.7 ± 0.2 [aB]	**0.019**
P value[A]	**<0.001**	**<0.001**	**<0.001**	**0.004**	
	Taste (0-5)				
Control	3.2 ± 0.3 [aA]	3.2 ± 0.3 [aA]	3.1 ± 0.2 [aA]	3.0 ± 0.0[aA]	0.500
0.2 kGy	3.0 ± 0.0 [aA]	3.0 ± 0.0 [aA]	3.0 ± 0.0 [aA]	3.2 ± 0.3 [aA]	0.500
0.5 kGy	3.2 ± 0.3 [aA]	3.0 ± 0.0 [aA]	3.0 ± 0.0 [aA]	4.0 ± 0.0 [aA]	0.164
2 kGy	3.6 ± 0.2 [aA]	3.5 ± 0.0 [aA]	3.1 ± 0.2 [aA]	3.2 ± 0.3 [aA]	0.392
5 kGy	3.7 ± 0.3 [aA]	3.5 ± 0.0 [aA]	3.2 ± 0.0 [aA]	2.0 ± 0.0 [aB]	0.102
P value[A]	0.192	0.054	0.275	**0.003**	
	Aroma (0-5)				
Control	4.0 ± 0.0[aA]	4.0 ± 0.0 [aA]	3.6 ± 0.2 [aA]	3.5 ± 0.7 [aA]	0.473
0.2 kGy	3.7 ± 0.0 [aAB]	3.5 ± 0.0 [aB]	3.4 ± 0.2 [aA]	3.0 ± 0.0 [aA]	0.126
0.5 kGy	3.9 ± 0.2 [aAB]	3.5 ± 0.0 [aB]	3.4 ± 0.2 [aA]	2.7 ± 0.3 [aA]	0.212
2 kGy	3.4 ± 0.2 [aBC]	3.1 ± 0.2 [aBC]	3.0 ± 0.0 [aA]	2.7 ± 0.3 [aA]	0.238
5 kGy	3.0 ± 0.0 [aC]	3.0 ± 0.0 [aC]	3.0 ± 0.0 [aA]	2.0 ± 0.0 [aA]	**<0.001**
P value[A]	**0.001**	**<0.001**	**0.022**	0.083	
	Text (0-10)				
Control	8.7 ± 0.3 [aA]	8.5± 0.7 [aA]	8.5 ± 0.0 [aA]	7.5 ± 0.7 [aA]	0.259
0.2 kGy	8.6 ± 0.5 [aA]	8.5 ± 0.0 [aA]	8.2 ± 0.3 [aA]	6.5 ± 0.7 [aA]	0.213
0.5 kGy	8.0 ± 0.0 [aA]	8.2 ± 0.3 [aA]	8.1 ± 0.2 [aA]	7.5 ± 0.7 [aA]	0.484
2 kGy	7.7 ± 0.3 [aA]	8.0 ± 0.0 [aA]	8.0 ± 0.0 [aA]	6.5 ± 0.0 [aA]	0.110
5 kGy	7.2 ± 0.3 [aA]	7.0 ± 0.0 [aA]	7.7 ± 0.3 [aA]	7.0 ± 0.7 [aA]	0.500
P value[A]	**0.039**	**0.036**	0.146	0.398	
	Total (0-20)				
Control	16.0 ± 0.7 [aA]	15.7 ± 1.1 [aA]	15.2 ± 0.3 [aA]	15.0 ± 2.8 [aA]	0.662
0.2 kGy	15.4 ± 0.5 [aA]	15.0 ± 0.0 [aA]	14.6 ± 0.5 [aA]	13.7 ± 1.8 [aA]	0.500
0.5 kGy	15.1 ± 0.5 [aA]	14.7 ± 0.3 [aA]	14.5 ± 0.3 [aA]	14.7 ± 0.3 [aA]	0.557
2 kGy	14.7 ± 0.0 [aA]	14.6 ± 0.2 [aA]	14.1 ± 0.2 [aA]	13.5 ± 0.7 [aA]	0.282
5 kGy	14.0 ± 0.0 [aA]	13.5 ± 0.0 [aA]	14.0 ± 0.3 [aA]	12.5 ± 1.4 [aA]	0.375
P value[A]	0.050	0.051	0.100	0.603	

[a] The height of the cake, taste, aroma, text and total organoleptic scores were compared between days of the experiment using repeated measures ANOVA test. The different lower-case letters in each separated raw indicate significant statistical difference between days in each dose of irradiation. P<0.05 considered as the significance level.

[A] In each day, the statistically significant difference between doses was examined using a one-way ANOVA test. The different uppercase letters in each separated column indicate significant statistical difference between doses in each dose of irradiation. P<0.05 considered as the significance level. All the significant P values are highlighted by bold font. In some cases despite the overall significant P value, no significant P value was observed in the pairwise comparison.

control the growth or removal of the eggs of insects. These results are consistent with the studies by Tilton *et al*. (1974), Waters and McQueen (1967) and Marathe *et al*. (2002) [2, 13, 14]. Furthermore, the storage time of the product did not change the results, since no growth was observed on any of the storage days of flour. In the case of control flour the growth of some insects especially red beetles was detected after being placed in ideal conditions for the growth of the eggs of insects, and this was also true in the case of raw wheat from which flour was made and even in the case of their bran. The growth of red beetles was also observed in the samples of control flour as well as their wheat and bran after 30 days in normal conditions and on the shelf at ambient temperature (25-35°C).

In one study by Zolfagharieh *et al*. (2004) on three main groups of agricultural products, including grains, beans, and dried fruits, the effects of different doses of gamma irradiation on the four growth stages of some important warehouse insects were examined. The results of this study showed that the maximum dose of up to 0.7 kGy could stop all growth stages of all studied insects [15].

Tilton *et al*. (1974) studied insect control in wheat flour by gamma irradiation. In this study, after irradiation of wheat flour with a dose of 40 krd of gamma rays with Cobalt 60, no growth of insects was observed in irradiated flour after 3-14 months [13]. In another study by Waters and MacQueen (1967), the growth of five infectious insects was controlled using gamma rays with a dose of 6250 to 150000 rad. The researchers also found that using this dose of gamma rays did not affect the quality of the wheat flour and the baking of the resulting bread [14].

In the present study, the total number of bacteria was significantly reduced during 180 days of storage, and only, the number of bacteria increased on day 60 in the control sample at the 0.2 kGy dose, but on day 120, it reached a level less than that of the first day, and this process continued until the end of day 180. The number of total fungi (mold and yeast) showed a significant gradual decrease. The results of the experiments on pH showed small changes, and the pH decrease was insignificant in most samples. Bashir and Aggarwal (2016) investigated the physicochemical, functional and thermal characteristics of the chickpea flour treated with 0.5, 1, 2.5, 5 and 10 kGy irradiation doses. They showed that the composition of the flour was not changed considerably and pH was reduced significantly with increasing the dosage.

In the present study, by increasing the irradiation dose, the height of the baked cakes significantly reduced, the size of the air bubbles inside the cake became smaller, and the color of the cakes became darker, Furthermore, the desirability of taste, smell and general acceptance decreased by increasing irradiation dose, but this alterations were not enough to have a significant effect on product rejection.

In a similar study, Farag Zeid *et al*. (1996) investigated the chemical and technological properties of the bread baked from irradiated flour. In this study, wheat flour was exposed to gamma rays with doses of 2, 4 and 8 kGy, and the organoleptic properties of baked loaves of bread were evaluated by the test panel, and all irradiated and control samples were acceptable, however, the lowest acceptability belonged to bread irradiated by 4 and 8 kGy. They suggested that the use of 2 kGy dosages, besides preventing the invasion of pathogenic microorganisms and reducing the total bacterial count, can be recommended to maintain wheat flour quality. Higher doses of 4-8 kGy can be used to remove mycotoxins along with some undesirable changes in the quality of flour, and these changes in quality can be improved by adding some allowed additives to flour [7].

Singer *et al*. (2006) investigated the physicochemical and sensory properties of irradiated flour. The wheat used to produce flour was irradiated by doses of 0.5, 1 and 2 kGy of gamma rays. The obtained results showed that different doses did not affect the content of water and protein. Furthermore, the parameters of water absorption and flour stability obtained from the Farinograph analysis were not affected. The falling number significantly decreased with the increase in irradiation dose. Starch gelatinization rate also undergone changes, but the color parameters did not change. Extensograph parameters (ultimate strength and expansion ability) were not affected by irradiation doses. All the results of paste texture analysis showed that irradiation with the studied doses did not affect the characteristics of the spread of paste and the ability of gas retention. Moreover, organoleptic analyses did not show any significant effects on sensory characteristics [16].

CONCLUSION

In general, it can be concluded that by applying a dose of 5 kGy of gamma irradiation, flour with a long shelf can be produced with no insect growing in it, no significant organoleptic alterations in the resulting cake, and no pH changes. As a result, we can probably use this method to produce a flour product with a long shelf-life on the store shelf and even at home consumption of wheat flour and its bread is expected to grow in the nearby future. Gamma irradiation will provide a foundation for production of a good quality flour with prolonged shelf-life. Also, the authors suggest future investigation on applying gamma irradiation with the aim of eliminating the mycotoxins of wheat or other cereal products. Assessing the potential effects of gamma irradiation on the nutritional quality of the final product could also be one of the research prospects.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No Animals/Humans were used for studies that are the basis of this research.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of Altin Flour Company for this industrial research under grant number 64/1D/854.

REFERENCES

[1] Aziz N, Attia ES, Farag S. Effect of gamma-irradiation on the natural occurrence of fusarium mycotoxins in wheat, flour and bread. Mol Nutr Food Res 1997; 41(1): 34-7.
[2] Marathe S, Machaiah J, Rao B, Pednekar M, Sudha Rao V. Extension of shelf-life of whole-wheat flour by gamma radiation. Int J Food Sci Technol 2002; 37(2): 163-8.
[3] Bashir K, Aggarwal M. Effects of gamma irradiation on the physicochemical, thermal and functional properties of chickpea flour. LWT-Food Sci Technol 2016; 69: 614-22.
[4] Sarangapani C, Thirumdas R, Devi Y, Trimukhe A, Deshmukh RR, Annapure US. Effect of low-pressure plasma on physico-chemical and functional properties of parboiled rice flour. LWT-Food Sci Technol 2016; 69: 482-9.
[5] Hammad A, Hassan M, Abu-Shady M, Soliman S. Improving quality and microbial safety of wheat flour by gamma irradiation. Arab J Nucl Sci Appl 2017; 50(3): 240-47.
[6] Calado T, Fernández-Cruz ML, Verde SC, Venâncio A, Abrunhosa L. Gamma irradiation effects on ochratoxin a: Degradation, cytotoxicity and application in food. Food Chem 2018; 240: 463-71.
[7] Zaied S, Abdel-Hamid AA, Attia ESA. Technological and chemical characters of bread prepared from irradiated wheat flour. Food/Nahrung 1996; 40(1): 28-31.
[8] Perez-Mendoza J, Throne JE, Dowell FE, Baker JE. Detection of insect fragments in wheat flour by near-infrared spectroscopy. J Stored Prod Res 2003; 39(3): 305-12.
[9] Hill DS. Pests of stored products and their control. Belhaven Press: London 1990.
[10] Safa M, Yazdanian M, Sarailoo MH. Larval feeding from some artificial diets and its effects on biological parameters of the mediterranean flour moth. Mun Ent Zool 2014; 9(2): 678-86.
[11] Salem E, Soliman S, El-Karamany A, El-Shafea YA. Effect of utilization of gamma radiation treatment and storage on total fungal count, chemical composition and technological properties wheat grain. Egypt J Biol Pest Cont J 2016; 26(1): 163.
[12] Sirisoontaralak P, Suthirak P, Papaka K, Vongsawasdi P. Development of shelf stable chiffon cake using gamma irradiation. LWT-Food Sci Technol 2017; 75: 78-84.
[13] Tilton EW, Brower J, Cogburn R. Insect control in wheat flour with gamma irradiation. Int J Appl Radiat Isot 1974; 25(7): 301-5.
[14] Watters F, MacQueen K. Effectiveness of gamma irradiation for control of five species of stored-product insects. J Stored Prod Res 1967; 3(3): 223-34.
[15] Zolfagharieh H, Bagheri-Zenouz E, Bayat-Asadi H, Mashayekhi Sh FH, Babaii M. Application of gamma radiation for controlling important store-pests of cereals, pulses, and nuts. Iranian J Agric Sci 2004; 35(2): 415-26.
[16] Singer CS. Physicochemical, rheological, thermal, and bread making properties of flour obtained from irradiated wheat [Online] 2018 [cited 2006]. Available at https://inis.iaea.org/search/search.aspx?orig_q=RN:41097657.