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Original article

Evaluating the effect of X ray irradiation in the control of food bacterial pathogens

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ABSTRACT

Food-born pathogens need to be controlled in food industry. The efficiency of X ray irradiation to eliminate pathogens has been shown but the efficient dose of irradiation has not been standardized. The optimum dose, which controls pathogenic bacteria and does not deteriorate food quality, needs studies on many different foods. The efficiency of different energy levels of X-ray irradiation and the treatment cycles needed to control food bacteria were tested. X ray doses of 0.1, 0.5, 1.0, 1.5 and 2.0 kGy/*sec* for 10 min (3 cycles) were used to solid and liquid foods, which were experimentally inoculated with bacterial pathogens *Campylobacter jenjuni, Brucella abortus, Escherichia coli, Bacillus cerus,* and *Clostridium perfringes*. The inoculation resulted high bacterial contamination, the colony forming units (CFU) were too high to be counted. After one cycle of irradiation with the highest dose, more than 100 CFU was counted. The efficient treatment was three cycles of 2.0 kGy irradiation, where no bacterial growth was observed. The dose of 1.5 gGy was almost as efficient. The lowest dose, 0.1 kGy, gave ca 10 CFU after three cycles. The analysis of sugar, fat, protein, and vitamins showed no change due to X ray irradiation indicating no deterioration of food quality. X ray irradiation technique is an efficient technique to control food-born pathogens and prevent food-born illnesses.

1. Introduction

Food manufacturing environment may support the growth of pathogenic microorganisms that may cause illnesses and even deaths to humans (Todd, 2014). Human complications are caused by both the ingested microbes through contaminated food and the toxins produced by the microbes present in food.

Natural antimicrobials such as the extracts of different microbial metabolites have been shown to inhibit pathogenic bacteria in food (Lozada et al., 2022; Yassin et al., 2022). The microbial treatment, however, is laborious and cannot easily be used to large amounts of food materials. Nanoparticles of different metals such as silver have been used in food packages to ensure food safety (Carbone et al., 2016). However, serious concern about the accumulation of metal nanoparticles in the environment and humans has raised recently (Rzayev et al., 2022; Siddiqui and Alrumman, 2021) Therefore, interest towards the use of physical control measures such as temperature, UV rays, and X rays has increased (Barkai-Golan and Follett, 2017). The physical methods aim to kill or inhibit the growth of undesirable microbes present in the food or in the food processing environment (Lung et al., 2015). The problem using UV-rays and heating above 150 °C is that they may change the chemical structure, odor, and taste of food (Todd, 2020). The recent advanced commercially available technology is X-ray radiation, of which use is increasing.

X-ray was shown to eliminate bacteria such as *E. coli* from parsley leaves (Mahmoud, 2012a). Dairy products, meat, seafood, berries, and vegetables have successfully been treated with X ray; the amounts of bacteria have decreased to minor amounts (Mahmoud et al., 2016; Moosekian et al., 2012; Ricciardi et al., 2019).More information on different foods and the possible change in taste and nutritional value is still needed, as reviewed recently (Zehi et al., 2020).

For the X ray treatment, the general assumption is that the effectiveness of the treatment depends only on the quantity of energy deposited in the target food (Gomez-Lopez et al., 2022). However, the ISO standard does not include technical requirements for the minimum energy or dose of the treatment. This is

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problematic because a wide range of different values can be chosen. Too low values chosen for energy and too few irradiation cycles are not efficient in eliminating bacteria from food. Too high values are unnecessary and may cause changes in the nutritional value and taste of food. Doses between 0.1 kGy and 10 kGy have been reported as efficient in reducing bacteria in different foods in a recent review (Zehi et al., 2020). More detailed information on the optimal treatment is needed and more food materials should be tested. In this study, we evaluated the efficiency of different doses of X-ray irradiation and the treatment cycles needed to control food bacteria using ten different food materials, both liquid and solid. We hypothesize that higher dose eliminates more bacteria. An experiment consisting of a wide range of doses with three irradiation cycles with a subsequent bacterial count was carried out. We also studied whether the irradiation causes chemical changes in the food.

2. Materials and methods

2.1. Sample collection

Ten chicken and shawarma foods were collected from Riyadh markets and transported to the laboratory of the Department of physics, IMSIU, Riyadh.

2.2. Isolation and molecular identification of bacteria from food

The food samples were serially diluted, plated over nutrient agar medium (NA medium) and incubated overnight at 37 °C. For the molecular identification of bacteria, pure cultures were prepared into nutrient broths, which were incubated at room temperature in orbital shaker. The bacterial DNA was extracted using the extraction kit HiPer following the manufacturer instructions. Bacterial 16S rRNA was amplified using primers 27F and 1492R (Ameen et al., 2020). The PCR reaction mixture (50 µl) contained 2 µl (50–100 ng) of DNA, 1x reaction buffer (TrisKCl-$MgCl_2$), 2 mM $MgCl_2$, 0.2 mM dNTP, 1 µM of each primer, and Taq polymerase (5U/µl, Fermentas). The PCR temperature cycling conditions were as follows: initial denaturation at 94 °C for 2 min; 30 cycles of denaturation at 94 °C for 1 min, annealing at 55 °C for 2 min, and elongation at 72 °C for 2 min followed by extension at 72 °C for 5 min. The product was sequenced by using Big Dye Terminator Sequencing Reaction mix (Applied Biosystem) then the obtained sequence was further subjected to BLAST analysis. The sequences were submitted to GenBank.

2.3. Inoculation of food pathogens into common foods in Riyadh

The bacterial pathogens isolated and identified from chicken and shawarma foods were further experimentally inoculated to different foods. Freshly cooked foods 100 g of rice, chicken, lamp, yogurt, shawarma, Harees, Gursan, Saleeg, Hiniy and Tarid were purchased from high quality restaurants in Riyadh and transported aseptically to the laboratory. The pathogens were first cultured in TSB containing 10 % (v/v) glycerol for 24 h at 37 °C ± 2 °C. The cultures were centrifuged and diluted with 0.85 % (w/v) saline water to obtain the desired pathogen concentration of approximately 106 CFU/mL. Food samples were inoculated with the pathogens (50 µl) and incubated at room temperature overnight.

2.4. Irradiation of test samples

Inoculated food samples were treated with various energy levels of irradiation (X-ray) performed with Siemens X-ray Machine. Radiation doses of 0.1, 0.5, 1.0, 1.5 and 2.0 kGy/*sec* for 10 min at 22 °C and 55 % relative humidity were targeted to foods 1.5 m distance away from the X-ray source three times each. The growth of bacteria was measured after each exposure. All treatments were done as three replicates.

2.5. The growth of bacteria

After the irradiation treatment, the CFU of the pathogens were measured using selective culture mediums, FM medium (Farrell Medium) for *Brucella abortus*, skirrows medium (BD *Campylobacter* Agar) for *Campylobacter jejuni*, lauryl sulphate aniline blue agar for *E. coli*, tryptose sulfite cycloserine agar for *Clostridium perfrigens* and mannitol yolk polymyxin B agar for *Bacillus cereus*. The food samples were serially diluted, plated and incubated at room temperature overnight. The colonies (CFU) were counted using a colony counter.

2.6. Turbidometric analysis of food sample before and after X ray treatment

Turbidometric analysis of the food samples indicating the amount of pathogens in the given sample were carried out spectrophotometrically at 600 nm (Hatiboruah et al., 2020). For this, the original and incubated food samples were serially diluted and the last dilution 10^{-9} was taken for the analysis.

2.7. Food components analysis after and before X ray treatment

Analysis of sugar was carried out using the colorimetric Benedict's method (Hernández-López et al., 2020). Food samples were diluted (10^{-9} dilution) by mixing food with distilled water. Proteins were measured using Biuret reagent titration method (Dawoud et al., 2021). Fat was measured using sudan III method by adding 3–4 drops of sudan dye to the sample solution (Khouri et al., 1989). Vitamin C was measured using the dye titration method (Tee et al., 1988).

3. Results

Five pathogens namely *C. jenjuni, B. abortus, E. coli, B. cerus*, and *C. perfringes* were identified (Table 1).

After the first X ray cycle, the bacterial counts were high (TNTC-Too numerous to count) at the lowest doses (0.1–0.5 kGy/h) (Table 2). Higher doses (1 – 2 kGy/h) gave bacterial counts of 250–100 CFU. The second cycle reduced bacterial counts in all foods remarkably, the bacterial counts varying between 20 and 36 CFU in the two lowest doses (Table 3). The highest dose gave 8 – 15 CFU. After the third cycle, no bacteria were observed at the highest dose 2 kGy/h (Table 4). Low counts (0 – 4 CFU) were observed also with 1.5 kGy/h dose.

The turbidometric analysis of the foods before the treatment gave absorbance values between 1.85 and 8.6 (Table 5). After the treatment (2 kGy/*sec*) the values varied between 0.01 and 0.3 showing a drastic decrease. No changes were observed for the

Table 1
Bacterial pathogens with NCBI accession numbers identified from foods.

Contaminated food	Species	Accession Number
Chicken	*Campylobacter jejuni*	ON307225
	Brucella abortus	ON306907
Shawarma	E. *coli*	ON306906
	Bacillus cereus	ON306905
	Clostridium perfringes	ON306842

Table 2
Colonies of bacterial pathogens counted in different foods (CFU/mL, mean ± SD, n = 3) before and after one X ray irradiation treatment in different concentrations. TNTC = Too numerous to count.

Foods	Before	X ray irradiation **kGy/h**	After				
			C. jejuni	B. *abortus*	*E. coli*	C. *cereus*	*C. perfringes*
Rice	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	166 ± 1	200 ± 1	203 ± 1	179 ± 1	186 ± 1
		1.5	145 ± 2	160 ± 1	158 ± 1	123 ± 2	132 ± 1
		2	126 ± 1	120 ± 2	136 ± 1	100 ± 1	105 ± 2
Chicken	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	186 ± 1	210 ± 1	210 ± 1	165 ± 1	190 ± 1
		1.5	129 ± 2	159 ± 1	196 ± 1	139 ± 2	145 ± 1
		2	106 ± 1	111 ± 2	145 ± 1	100 ± 1	103 ± 2
Lamp	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	170 ± 1	189 ± 1	200 ± 1	185 ± 1	189 ± 1
		1.5	115 ± 2	140 ± 1	166 ± 1	129 ± 2	135 ± 1
		2	100 ± 1	111 ± 2	115 ± 1	100 ± 1	110 ± 2
Yoguart	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	186 ± 1	235 ± 1	219 ± 1	155 ± 1	160 ± 1
		1.5	135 ± 2	186 ± 1	166 ± 1	129 ± 2	125 ± 1
		2	106 ± 1	125 ± 2	135 ± 1	110 ± 1	100 ± 2
Shawarma	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	226 ± 1	200 ± 1	210 ± 1	165 ± 1	190 ± 1
		1.5	185 ± 2	160 ± 1	196 ± 1	139 ± 2	145 ± 1
		2	123 ± 1	120 ± 2	145 ± 1	100 ± 1	103 ± 2
Harees	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	184 ± 1	200 ± 1	210 ± 1	165 ± 1	176 ± 1
		1.5	125 ± 2	168 ± 1	165 ± 1	130 ± 2	135 ± 1
		2	102 ± 1	100 ± 2	125 ± 1	101 ± 1	101 ± 2
Gursan	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	178 ± 1	223 ± 1	235 ± 1	178 ± 1	186 ± 1
		1.5	126 ± 2	189 ± 1	190 ± 1	139 ± 2	158 ± 1
		2	106 ± 1	138 ± 2	147 ± 1	102 ± 1	123 ± 2
Saleeg	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	200 ± 1	210 ± 1	200 ± 1	186 ± 1	223 ± 1
		1.5	169 ± 2	158 ± 1	168 ± 1	130 ± 2	198 ± 1
		2	130 ± 1	118 ± 2	123 ± 1	101 ± 1	132 ± 2
Hiniy	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	223 ± 1	223 ± 1	256 ± 1	220 ± 1	220 ± 1
		1.5	169 ± 2	190 ± 1	189 ± 1	169 ± 2	186 ± 1
		2	120 ± 1	135 ± 2	120 ± 1	123 ± 1	139 ± 2
Tarid	<250	0.1	TNTC	TNTC	TNTC	TNTC	TNTC
		0.5	TNTC	TNTC	TNTC	TNTC	TNTC
		1	189 ± 1	223 ± 1	232 ± 1	170 ± 1	220 ± 1
		1.5	140 ± 2	185 ± 1	169 ± 1	120 ± 2	159 ± 1
		2	116 ± 1	126 ± 2	123 ± 1	100 ± 1	110 ± 2

amounts of sugar, fat, proteins, and vitamin C due to the X ray irradiation (Table 6).

4. Discussion

X-ray technology has been shown efficient in reducing bacterial pathogens in foods as reviewed recently (Zehi et al., 2020). However, the technique needs the clarification of the doses used. Both low and high doses have been used. While a low dose of 0.75 kGy decreased bacterial counts to almost zero in ready-to-eat shrimp (Mahmoud, 2009), a relatively high dose of 3 kGy was needed to eliminate bacteria in raw chicken meat (Song et al., 2018).

This study was conducted in three parts, in first part the food samples were treated with X ray in five different doses (0.1, 0.5, 1.0, 1.5 and 2.0 kGy/*sec* for 10 min). Here, 40–45 % of reduction observed in last dose (2.0 kGy/*sec*). In the second treatment there was a slight variation occurred between the last dose of 1st treatment and 1st dose of 2nd treatment. Similarly, last dose of 2nd treatment and 1st dose of 3rd treatment also have 30–35 % of variation. It is because of the influence of X ray on the growth and multiplication of the pathogens (Nohemi et al., 2022). Besides, there is no variation in components and taste of the checked food materials. Inactivation of pathogens isolated from spinach leaves by the application of X ray dose 0.1–2 kGy with no changes in colour or texture, in other hand this irradiation effectively control the pathogenic microbiota while preservation of food (Mahmoud et al., 2010).

Radiation processing of food one of the most valuable methods for the preservation and disinfection of food (Lima et al., 2018; Mahmoud, 2012a; Mahmoud et al., 2016).Irradiation of 2 kGy reduced natural bacteria in chicken meat, shrimps and strawberries (Van Calenberg et al., 1999). Similarly, *Salmonella enterica*

Table 3
Colonies of bacterial pathogens counted in different foods (CFU/mL, mean ± SD, n = 3) after two X ray irradiation treatments in different concentrations.

Foods	X ray irradiation **kGy/h**	After two treatments				
		C. jejuni	D. *abortus*	*E. coli*	E. *cereus*	*C.perfringes*
Rice	0.1	29 ± 2	32 ± 2	31 ± 1	26 ± 2	25 ± 2
	0.5	20 ± 1	25 ± 1	28 ± 1	22 ± 1	20 ± 1
	1	16 ± 1	20 ± 1	23 ± 1	17 ± 1	18 ± 1
	1.5	14 ± 2	10 ± 1	15 ± 1	12 ± 2	13 ± 1
	2	12 ± 1	12 ± 2	13 ± 1	10 ± 1	10 ± 2
Chicken	0.1	30 ± 1	35 ± 1	32 ± 1	23 ± 1	35 ± 1
	0.5	25 ± 1	26 ± 1	26 ± 1	20 ± 1	26 ± 1
	1	18 ± 1	21 ± 1	20 ± 1	15 ± 1	19 ± 1
	1.5	12 ± 2	15 ± 1	19 ± 1	13 ± 2	14 ± 1
	2	10 ± 1	11 ± 2	14 ± 1	10 ± 1	10 ± 2
Lamp	0.1	32 ± 2	28 ± 2	30 ± 1	29 ± 2	28 ± 2
	0.5	20 ± 1	26 ± 1	25 ± 1	22 ± 1	20 ± 1
	1	17 ± 1	18 ± 1	20 ± 1	18 ± 1	19 ± 1
	1.5	13 ± 2	10 ± 1	16 ± 1	19 ± 2	13 ± 1
	2	8 ± 1	11 ± 2	15 ± 1	10 ± 1	11 ± 2
Yoguart	0.1	31 ± 1	30 ± 1	36 ± 1	26 ± 1	25 ± 1
	0.5	25 ± 1	26 ± 1	28 ± 1	20 ± 1	21 ± 1
	1	18 ± 1	23 ± 1	21 ± 1	15 ± 1	16 ± 1
	1.5	13 ± 2	16 ± 1	16 ± 1	12 ± 2	12 ± 1
	2	6 ± 1	15 ± 2	13 ± 1	10 ± 1	8 ± 2
Shawarma	0.1	31 ± 1	34 ± 1	31 ± 1	30 ± 1	33 ± 1
	0.5	26 ± 1	26 ± 1	25 ± 1	23 ± 1	26 ± 1
	1	22 ± 1	20 ± 1	21 ± 1	16 ± 1	19 ± 1
	1.5	18 ± 2	16 ± 1	19 ± 1	13 ± 2	14 ± 1
	2	13 ± 1	12 ± 2	14 ± 1	10 ± 1	10 ± 2
Harees	0.1	26 ± 2	30 ± 2	32 ± 1	25 ± 2	24 ± 2
	0.5	21 ± 1	28 ± 1	26 ± 1	20 ± 1	20 ± 1
	1	18 ± 1	20 ± 1	21 ± 1	16 ± 1	17 ± 1
	1.5	12 ± 2	16 ± 1	16 ± 1	13 ± 2	13 ± 1
	2	8 ± 1	10 ± 2	12 ± 1	10 ± 1	10 ± 2
Gursan	0.1	27 ± 2	31 ± 2	30 ± 1	25 ± 2	26 ± 2
	0.5	22 ± 1	26 ± 1	26 ± 1	20 ± 1	22 ± 1
	1	17 ± 1	22 ± 1	23 ± 1	17 ± 1	18 ± 1
	1.5	12 ± 2	18 ± 1	19 ± 1	13 ± 2	15 ± 1
	2	10 ± 1	13 ± 2	14 ± 1	10 ± 1	12 ± 2
Saleeg	0.1	28 ± 2	30 ± 2	29 ± 1	26 ± 2	29 ± 2
	0.5	25 ± 1	26 ± 1	25 ± 1	22 ± 1	26 ± 1
	1	20 ± 1	21 ± 1	20 ± 1	18 ± 1	23 ± 1
	1.5	16 ± 2	15 ± 1	16 ± 1	13 ± 2	19 ± 1
	2	13 ± 1	11 ± 2	12 ± 1	10 ± 1	12 ± 2
Hiniy	0.1	29 ± 2	30 ± 2	38 ± 1	30 ± 2	33 ± 2
	0.5	26 ± 1	28 ± 1	32 ± 1	26 ± 1	29 ± 1
	1	22 ± 1	22 ± 1	25 ± 1	22 ± 1	22 ± 1
	1.5	16 ± 2	19 ± 1	18 ± 1	16 ± 2	18 ± 1
	2	12 ± 1	15 ± 2	12 ± 1	12 ± 1	13 ± 2
Tarid	0.1	29 ± 2	30 ± 2	31 ± 1	31 ± 2	30 ± 2
	0.5	22 ± 1	28 ± 1	28 ± 1	28 ± 1	26 ± 1
	1	18 ± 1	22 ± 1	23 ± 1	17 ± 1	22 ± 1
	1.5	14 ± 2	18 ± 1	16 ± 1	12 ± 2	15 ± 1
	2	11 ± 1	12 ± 2	12 ± 1	10 ± 1	11 ± 2

was reduced in chicken meat to acceptable levels (Mahmoud et al., 2015). *E.coli* was reduced in meat with 0.3 to 0.8 kGy (Cho and Ha, 2019; Curry et al., 2000; Kundu, 2013). (Zehi et al., 2020) reported that by the application of X ray doses between 1 and 5 kGy decreased the bacterial growth in Atlantic oysters (*Crassostrea virginica*, without causing any changes in colour. Moreover, the count of pathogenic bacteria such as *E. coli, Salmonella* and *Listeria* were decreased by the application of X ray dose 0.6 kGy (Mahmoud, 2012b). (Tallentire and Miller, 2015) explained that X rays have high penetration power which have the ability to kill bacteria by damaging its DNA. No human health effects have been shown so far (Zehi et al., 2020). Our study showed that the efficient X ray dose was 1.5 and 2 kGy when the dose was given three times, ten min per cycle. We can report two remarkable observations. The first is that a very high amounts of bacteria, too high to be counted, was reduced to uncountable amounts with this treatment. The second is that the efficiency was shown with ten different foods including solid and liquid materials.

Table 4
Colonies of bacterial pathogens counted in different foods (CFU/mL, mean ± SD, n = 3) after three X ray irradiation treatments in different concentrations.

Foods	X ray irradiation **kGy/h**	After three treatments				
		C. jejuni	F. *abortus*	*E. coli*	G. *cereus*	*C. perfringes*
Rice	0.1	9 ± 2	8 ± 2	10 ± 1	10 ± 2	10 ± 2
	0.5	5 ± 1	6 ± 1	7 ± 1	8 ± 1	8 ± 1
	1	3 ± 1	3 ± 1	4 ± 1	6 ± 1	4 ± 1
	1.5	0 ± 2	1 ± 1	2 ± 1	3 ± 2	1 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2
Chicken	0.1	8 ± 1	7 ± 1	9 ± 1	10 ± 1	8 ± 1
	0.5	6 ± 1	4 ± 1	7 ± 1	8 ± 1	6 ± 1
	1	3 ± 1	2 ± 1	4 ± 1	5 ± 1	9 ± 1
	1.5	1 ± 2	0 ± 1	1 ± 1	3 ± 2	4 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2
Lamp	0.1	7 ± 2	10 ± 2	10 ± 1	10 ± 2	10 ± 2
	0.5	5 ± 1	8 ± 1	6 ± 1	8 ± 1	7 ± 1
	1	3 ± 1	6 ± 1	2 ± 1	3 ± 1	5 ± 1
	1.5	0 ± 2	3 ± 1	0 ± 1	1 ± 2	3 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2
Yoghurt	0.1	5 ± 1	10 ± 1	10 ± 1	9 ± 1	10 ± 1
	0.5	2 ± 1	6 ± 1	8 ± 1	6 ± 1	8 ± 1
	1	0 ± 1	3 ± 1	3 ± 1	4 ± 1	6 ± 1
	1.5	0 ± 2	1 ± 1	1 ± 1	2 ± 2	2 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2
Shawarma	0.1	10 ± 1	8 ± 1	9 ± 1	10 ± 1	10 ± 1
	0.5	6 ± 1	6 ± 1	7 ± 1	8 ± 1	7 ± 1
	1	3 ± 1	2 ± 1	4 ± 1	5 ± 1	3 ± 1
	1.5	1 ± 2	1 ± 1	2 ± 1	2 ± 2	1 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2
Harees	0.1	7 ± 2	10 ± 2	8 ± 1	10 ± 2	8 ± 2
	0.5	5 ± 1	8 ± 1	6 ± 1	8 ± 1	5 ± 1
	1	3 ± 1	5 ± 1	2 ± 1	6 ± 1	3 ± 1
	1.5	1 ± 2	2 ± 1	0 ± 1	3 ± 2	1 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2
Gursan	0.1	6 ± 2	10 ± 2	10 ± 1	7 ± 2	6 ± 2
	0.5	4 ± 1	8 ± 1	6 ± 1	4 ± 1	2 ± 1
	1	2 ± 1	5 ± 1	3 ± 1	2 ± 1	0 ± 1
	1.5	0 ± 2	2 ± 1	0 ± 1	0 ± 2	0 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2
Saleeg	0.1	8 ± 2	10 ± 2	9 ± 1	9 ± 2	9 ± 2
	0.5	5 ± 1	6 ± 1	5 ± 1	7 ± 1	6 ± 1
	1	3 ± 1	2 ± 1	0 ± 1	5 ± 1	3 ± 1
	1.5	1 ± 2	0 ± 1	0 ± 1	2 ± 2	1 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2
Hiniy	0.1	6 ± 2	10 ± 2	6 ± 1	10 ± 2	10 ± 2
	0.5	3 ± 1	5 ± 1	2 ± 1	6 ± 1	7 ± 1
	1	2 ± 1	2 ± 1	0 ± 1	2 ± 1	4 ± 1
	1.5	0 ± 2	0 ± 1	0 ± 1	0 ± 2	1 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2
Tarid	0.1	9 ± 2	10 ± 2	8 ± 1	9 ± 2	10 ± 2
	0.5	7 ± 1	8 ± 1	6 ± 1	7 ± 1	6 ± 1
	1	5 ± 1	4 ± 1	3 ± 1	5 ± 1	2 ± 1
	1.5	2 ± 2	1 ± 1	1 ± 1	2 ± 2	0 ± 1
	2	0 ± 1	0 ± 2	0 ± 1	0 ± 1	0 ± 2

Table 5
Turbidometric analysis of foods (absorbance, mean ± SD, n = 3) before and after one X ray treatment (2.0 kGy/*sec*).

Foods	**Absorbance** (Before treatment) 600 nm					**Absorbance** (After treatment)				
	C. jejuni	*B. abortus*	*E. coli*	*B. cereus*	*C.perfringes*	*C. jejuni*	*B. abortus*	*E. coli*	*B. cereus*	*C. perfringes*
Rice	3.25 ± 1	4.65 ± 1	3.6 ± 1	4.6 ± 1	5.2 ± 1	0.017 ± 1	0.011 ± 1	0.02 ± 1	0.019 ± 1	0.02 ± 1
Chicken	5.6 ± 1	6.0 ± 1	6.2 ± 1	5.8 ± 1	5.9 ± 1	0.010 ± 1	0.026 ± 1	0.02 ± 1	0.013 ± 1	0.009 ± 1
Lamp	2.8 ± 1	3.5 ± 1	3.8 ± 1	4.1 ± 1	3.2 ± 1	0.012 ± 1	0.023 ± 1	0.027 ± 1	0.032 ± 1	0.031 ± 1
Yoghurt	3.2 ± 1	2.6 ± 1	2.9 ± 1	3.3 ± 1	3.9 ± 1	0.018 ± 1	0.023 ± 1	0.028 ± 1	0.032 ± 1	0.030 ± 1
Shawarma	7.23 ± 1	8.1 ± 1	8.2 ± 1	7.3 ± 1	8.6 ± 1	0.023 ± 1	0.019 ± 1	0.018 ± 1	0.022 ± 1	0.02 ± 1
Harees	5.2 ± 1	2.2 ± 1	2.5 ± 1	2.9 ± 1	3.2 ± 1	0.018 ± 1	0.026 ± 1	0.031 ± 1	0.03 ± 1	0.038 ± 1
Gursan	2.65 ± 1	3.9 ± 1	3.2 ± 1	3.6 ± 1	4.2 ± 1	0.010 ± 1	0.02 ± 1	0.025 ± 1	0.026 ± 1	0.028 ± 1
Saleeg	1.85 ± 1	2.5 ± 1	2.3 ± 1	3.1 ± 1	3.5 ± 1	0.011 ± 1	0.025 ± 1	0.019 ± 1	0.018 ± 1	0.013 ± 1
Hiniy	3.2 ± 1	2.6 ± 1	2.8 ± 1	2.5 ± 1	2.9 ± 1	0.008 ± 1	0.012 ± 1	0.014 ± 1	0.016 ± 1	0.018 ± 1
Tarid	4.0 ± 1	3.5 ± 1	2.5 ± 1	5.2 ± 1	3.6 ± 1	0.01 ± 1	0.05 ± 1	0.02 ± 1	0.03 ± 1	0.02 ± 1

Table 6
Colour based food component analyses before and after three X ray irradiation treatments. Nil = Component not present.

Foods	Sugar		Fat		Protein		Vitamin C	
	Before	After	Before	After	Before	After	Before	After
Rice	Orange	Orange	Red ring	Red ring	Darker light blue	Darker light blue	Nil	Nil
Chicken	Nil	Nil	Red ring	Red ring	Purple	Purple	Nil	Nil
Lamp	Nil	Nil	Red ring	Red ring	Purple	Purple	Clear	Clear
Yoghurt	Nil	Nil	Red ring	Red ring	Lavender	Lavender	Clear	Clear
Shawarma	Green	Green	Red ring	Red ring	Purple	Purple	Clear	Clear
Harees	Nil	Nil	Red ring	Red ring	Purple	Purple	Clear	Clear
Gursan	Nil	Nil	Red ring	Red ring	Light blue	Light blue	Nil	Nil
Saleeg	Nil	Nil	Red ring	Red ring	Light blue	Light blue	Nil	Nil
Hiniy	Nil	Nil	Red ring	Red ring	Light blue	Light blue	Nil	Nil
Tarid	Nil	Nil	Red ring	Red ring	Light blue	Light blue	Nil	Nil

5. Conclusion

The results obtained from the study revealed that the X ray dose 1.5 kGy and 2 kGy have effective power for the inactivation of food pathogens in various solid and liquid foods. The treatment was efficient for ten types of liquid and solid foods opening up an immense possibility for the control of bacteria causing severe infection to humans.

Declaration of Competing Interest

The author declare that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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