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Nutritional Value of Sesame Meal Treated by Gamma Ray and Microwave irradiation

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ABSTRACT

An extensive ruminal degradation of protein can reduce its quality indices such as amino acid balance and digestibility. When the degradability of crude protein in the rumen is high, the bypass protein to intestine and its digestibility is lower. Therefore, the extent of protein degradation in the rumen determines the amount of nitrogen available to microorganisms in the rumen and supply of amino acids in the small intestine of the animal. The aim of this study was to evaluate the effect of gamma ray irradiation (GR) at doses of 20 and 40 kGy and microwaving (MW) at 800 W for 3 and 5 minutes on ruminal degradation kinetics and *in vitro* digestibility of sesame meal (SSM). Degradability parameters of irradiated samples were measured by nylon bag technique. The amount of histidine, threonine, valine, alanine, arginine, glutamine, glycine, and serine were lower, but the amount of methionine and phenylalanine were higher in GR and MW treated samples compared to untreated ones. Irradiation reduced the fibre content of SSM and altered its chemical composition compared to untreated SSM. Ruminal degradability of DM and CP was diminished in the treated SSM. Effective degradability (ED) of DM and CP was found to be lower in the GR irradiated SSM compared to the MW irradiated SSM and the control. After sixteen hours of ruminal incubation of the treated SSM the degradability of isoleucine, methionine, phenylalanine, and threonine were lower, but those of glycine and serine were higher. The *in vitro* digestibility of DM (DMD) and organic matter (OMD), as well as the organic matter in the dry matter (DOMD) were lower and higher in GR and MW irradiated SSM respectively, compared to unirradiated SSM. It can be concluded that irradiation of sesame meal by gamma ray irradiation was effective in protecting crude protein and some amino acids including, methionine and phenylalanine from ruminal degradation.

***Keywords*:** Sesame Meal, Gamma Ray, Microwave, *In situ*, *In vitro*

INTRODUCTION

Characterized by a high crude protein content (30.56% to 52.9%) and good balance of amino acids, sesame seed meal (*Sesamum indicum* L.) can be used in ruminant nutrition (Onsaard et al., 2010; Kaneko et al., 2002; Mamputu and Buhr, 1995). However, while sesame seed meal protein is rich in methionine, it is relatively poor in lysine (Passi et al., 2019).

Iran is situated in a dry region, characterised by low rainfall, poor natural pasture and low quality fodder. As a result, modern dairy farming relies on hand feeding rather than grazing, which is of intensive labour and costly. In this context, enhancing the animals' feed utilization is both nutritionally and economically advantageous for the farmers. The modern high-producing and fast-growing ruminants require greater amount of protein synthesized by the ruminal microbial ecosystem. Increasing the fraction of protein of the ration not to be degraded and to bypass the rumen can increase the protein supplied for the animal (Waltz and Stern, 1989). Protecting protein through irradiation is known as a bypass protein technology. Radiation is classified in two forms of ionizing and non-ionizing methods.

The ionizing radiation (such as gamma ray) generates enough energy to remove electrons from atom and causes radiolysis of cell components, including water, protein, peptides, and amino acids (Gaber, 2005; Garrison, 1987; Davies and Delsignore, 1987). Non-ionizing radiation (such as microwave processing) lacks sufficient energy to remove electrons from atoms, but causes atom movements or vibration (Sant'Ana, 2017). During the heating process, any alteration in tertiary structure of peptides and proteins (such as the uncoiling plated structure and denaturation of the whole protein molecule) reduces protein degradation in the rumen (Peng et al., 2014). The effect of gamma radiation and microwave on ruminal degradation of certain feedstuffs has already been studied, finding that different feedstuffs respond differently to the same irradiation (Ghanbari et al., 2015; Sadeghi and Shawrang, 2007). The research showed that GR irradiation of cottonseed meal at 10, 20, and 30 kGy doses (Bahraini et al., 2017), the GR irradiation of soybean meal (Shawrang et al., 2007), canola meal (Shawrang et al., 2008), cottonseed meal (Ghanbari et al., 2012), and sunflower meal (Ghanbari et al., 2015) at 25, 50 and 75 kGy doses, and the GR irradiation of canola seed (Taghinejad et al., 2016) at 15, 30, and 45 kGy dose, reduce ruminal degradability of CP. More studies need to be carried out to identify the effect of irradiation on nutritive value of different types of feeds and their by-products. Microwave energy penetrates a food or feed material and produces a volumetrically distributed heat source, due to molecular

friction, resulting from dipolar rotation of polar solvents and from conductive migration of dissolved ions. The dipolar rotation is caused by variations of the electrical and magnetic fields in the organic components (Alton, 1998). In conventional thermal processing, energy is transferred to the material through convection, conduction, and radiation of heat from the surfaces of the material. In contrast, microwave energy is delivered directly to materials through molecular interaction with the electromagnetic field. The molecular structure affects the ability of the microwaves to interact with materials and transfer energy (Chandrasekaran., 2012).

The by-products of the oil extraction industry are generally protein-rich cakes and meals that are comparable in CP content. Many of these by-products such as cottonseed, sunflower meal and etc. have previously been treated by radiation to reduce their intense ruminal degradation (Bahraini et al., 2017; Shawrang et al., 2007; Taghinejad et al., 2016). However, there is a lack of information on the effects of GR and MV irradiation on SSM protein degradability. Therefore, the purpose of present study was to evaluate and compare the effects of 20 and 40 kGy gamma ray (non-thermal method) and 3-5- minute microwave irradiation (thermal method) on ruminal DM, CP, and AA degradation kinetics using nylon bag (*in situ*) technique and *in vitro* digestibility of SSM. The method of irradiation by other researchers and the results gave us the idea for planning present research.

MATERIALS AND METHODS

Sample Preparation and Irradiation

The sesame seed used in this study was obtained from the Oilseed Developing and Cultivation Company (Tehran, Iran). The oil of the seeds was extracted mechanically by hot extraction system and the remaining meal was collected to be used in the study. The irradiation of SSM samples was carried out in Radiation Applications Research School, affiliated with the Nuclear Science and Technology Research Institute of the Iranian Atomic Energy Organization. The moisture of the samples increased by roughly 25% via adding water prior to the irradiation process. The gamma-ray irradiation was accomplished in a gamma cell irradiator of gc-220 calibrated according to the ISO/ASTM 51026:2015. The dose rate was 1.023 G/S (61.5 Gy per minute) and the irradiations were 20 kg (in 4 hours, 31 minutes and 34 seconds) and 40 kg (in 9 hours, 3 minutes and 13 seconds). Two polyethylene bags of SSM samples were irradiated in the gamma cell. The samples were freeze-dried after finishing the irradiation and subsequently allowed to air equilibrate for 2 h before

being fastened in plastic bags. A second set of SSM samples were exposed to microwave irradiation at 800 W power for 3 to 5 minutes. The processed samples were cooled to reach room temperature and then packed in zipper bags. All samples were kept at −20°C temperature for subsequent analyses.

Chemical Analyses

The SSM samples were ground using a laboratory hammer mill equipped with a 1 mm sieve. The DM and CP of the SSM, the residues of SSM after rumen incubation, the EE and ash in samples were determined as described in AOAC (1995). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) (sequentially after NDF) were determined as described by Van Soest et al. (1991).

The essential amino acids (His, Ile, Leu, Lys, Met, Phe, Thr, and Val) and non-essential amino acids (Ala, Arg, Glu, Gly, Ser, and Tyr) of the SSM samples were determined before and after rumen incubation (*in sacco*). About 15 ml of 6 M hydrochloric acid was added to 100 milligrams of dried powderif SSM samples, and stored for 24 hours at 110°C to be hydrolyzed. The cooled samples were filtered using a 0.45 µm syringe filter and analyzed by high performance liquid chromatography (HPLC Biochrom Plus amino acid analyzer, Pharmacia, Cambridge, UK) (Caidan et al., 2014).

***In Situ* Ruminal Degradability**

In this research three rumen cannulated bulls with an average body weight of 397 (± 5) kg were used for bags incubation. The Animals were fed a mixed ration according to nylon bags standard techniques on maintenance level. The ration was formulated on the basis of 67 percent forage (alfalfa and wheat straw) and 33 percent concentrate (barley, corn, wheat bran, cottonseed meal and vitamin supplement). Both SSM samples (treated and untreated) were ground separately to pass a 2 mm sieve, and samples of 6 g each were retained in the polyester bags (10 × 20 cm; 45-50 µm pore size). Two bags were incubated at each incubation time (totally, 6 bags per treatment). The bags were inserted in the rumen simultaneously, just before providing the bulls with their first meal (i.e., 08:00 A.M). At the end of each incubation time, the bags were removed from the rumen and immediately washed with tap water until the rinsing water became clear. Similarly, disappearance at zero time was obtained by washing the bags not incubated. All of the washed bags were dried in a forced-air oven at 65°C for 48 hours and weighed.

In Vitro Digestibility of SSM

The two-step digestion technique was used to determine the digestibility of SSM samples (Tilly and Terry, 1963). The samples were dried at 65°C for 48 hours in an oven and milled through a 1.0 mm screen. About 500 mg of the milled sample was poured into each of three Erlenmeyer flasks and three extra Erlenmeyer flasks without sample were considered as blanks. Rumen liquor was collected before the morning meal by vacuum pump (60 mL syringes) of the fistulated bulls rumen. Animals were fed a total mixed ration (TMR). The diet was formulated on the basis of 60% forage and 40% concentrate. The diets (based on 67% forage and 33% of concentrate) were formulated according to recommendations to provide approximately 12.7% CP on a DM basis. The liquor from each animal was filtered through eight layers of gauze cloth, was purged with CO_2 and was kept in a pre-warmed (39 °C) thermos flask until use (within approximately 20 min). The liquor of the rumen and buffer were mixed at a 1:4 (v/v) ratio and 50 ml of the inoculum was added to each Erlenmeyer flasks. The Erlenmeyer flasks then closed with a rubber cap and purged with CO_2 for 15 seconds and anaerobically incubated for 48 hours in an automatic shaking water bath kept at 39°C during the incubation. At the end of the incubation, 6 ml of hydrochloric acid (HCl, 20%) and two mL of pepsin solution (pepsin, 20%) were added to each Erlenmeyer flask, and were then incubated anaerobically for another 48 hours. At the end of this stage, the remaining sample were filtered using a Whatman paper no. 41 that had previously being marked and numbered. The residual contents and filter papers were dried in a forced air oven at 105°C for 24 h and the DM was determined. To determine the ash content, all the samples were ashed at 560 °C for 4 h to calculate digestible organic matter content in DM (OMD).

The residual contents and filter papers were dried in a forced air oven at 105°C for 24 hours, and the DM was determined. Finally, all samples were burned at 560°C for 4 hours to determine the digestible organic matter (OMD) in DM.

Calculations and statistical Analysis

Degradability of DM, CP, and AA was calculated as the difference between the weight of the sample and the portion remained after incubation in the rumen. The DM and CP degradability parameters of un-irradiated and irradiated SSM were estimated using the *Fit Curve* software. Moreover, the Ørskov and McDonald's (1979) model was fitted based on the percentage of DM and CP disappearance as follows:

$$P=a+b(1-e^{-ct}) \quad (1)$$

where the P is the DM or CP degradability at time t (h), "a" stands for the washout or Soluble Fraction, "b" represents Potentially Degradable Fraction, and "c" shows the degradation Rate (h^1) of b Fraction. Also, the effective ruminal disappearance (ED) of DM and CP were estimated at outflow rates (k) of 0.02, 0.05 and 0.08 h^{-1} (Tuncer and Sacakli, 2003). Using the following model:

$$ED= a+((b\times c)/(c+k)) \quad (2)$$

The chemical composition, pre-incubation amino acids concentration, and *in vitro* digestibility data of SSM were analyzed using a completely randomized design (3), and the degradability data were analyzed as a randomized complete block design (4) (three animals × two bags for each sample at each incubation time per bull) via the GLM SAS procedure. The significance of the differences of the means were tested using the Duncan's multiple range test (Steel and Torrie, 1980), at a significance level of $P < 0.05$. Also, orthogonal contrasts were used to detect significant differences among the treatments.

$$Y_{ij} = \mu + T_i + e_{ij} \quad (3)$$

$$Y_{ijk} = \mu + T_i + K_j + e_{ijk} \quad (4)$$

where Y_{ijk} and Y_{ij} are dependent variable, μ is the overall mean, T_i stands for irradiation effect, K_j shows the animal effect, and e_{ijk} and e_{ij} are residual error, which were assumed to have normal distribution.

RESULTS AND DISCUSSION

The average of OM, NDF, and ADF content of SSM (Table 1) were within the range of values reported in the literature (Maneemegalai and Prasad, 2011; Onsaard et al., 2010; Wang et al., 2016). However, the CP and EE contents were slightly higher and lower, respectively, than those reported by Wang et al. (2016) and Onsaard et al. (2010). GR and MW irradiation decreased the contents of OM, CP, NDF, ADF, and EE compared to unirradiated SSM. In some studies, chemical composition of cottonseed (Taghinejad et al., 2016), canola meal (Shawrang et al., 2008) and whole flaxseed (Beheshti Moghadam et al., 2019) were not affected by gamma ray, microwave or electron radiation. Yalcin et al. (2011) irradiated linseed with GR at 2.5-7 kGy doses and reported a loss in protein and oil contents. While the MW irradiation of the whole soybeans for 2, 4, and 6 minutes did not affect the OM, CP, and EE caused significant increase in NDF and ADF (Golshan et al., 2019). Also, Bahraini et al. (2017) reported a decrease in crude fiber of cottonseed meal following the GR radiation at 10-30 kGy doses. Al-Masri and Guenther (1999) have also reported that

193 irradiation can break down the lignocellulosic materials of the plant cell walls. Tang et al. (2012)
194 reported that, the reduction in crude fiber by GR irradiation may be due to oxidation of the
195 cellulose, and conversion of cellulose and lignin to the cell wall solution. By irradiation fibre level
196 could be reduced due depolymerization and delignification (Sandev and Karaivanov, 1977). The
197 discrepancy between the results of the studies concerning the chemical composition of irradiated
198 seeds and meals could be attributed to factors such as seed type, whole seed or seed meal, the oil
199 extraction method (hot or cold press), and the conditions of the processing method (e.g.,
200 temperature, moisture, processing duration, dosage).
201
202 **Table 1.** Effects of irradiation processing on chemical composition[2] of sesame meal (g/kg).

Treatment[1]	OM	CP	NDF	ADF	EE
untreated	915.60^{a}	377.60^{a}	222.45^{a}	124.90^{a}	151.60^{a}
GR20	897.90^{b}	369.35^{b}	169.95^{a}	87.50^{a}	147.35^{b}
GR40	897.35^{b}	368.90^{c}	162.40^{d}	77.40^{d}	137.10^{c}
MW3	898.50^{b}	357.05^{d}	220.00^{e}	95.00^{e}	65.00^{d}
MW5	897.05^{b}	348.15^{e}	172.55^{c}	90.00^{c}	50.10^{e}
SEM	2.417	3.454	8.717	5.343	14.508
Orthogonal contrasts					
Unirradiated vs. irradiated	<0.01	<0.01	<0.01	<0.01	<0.01
Unirradiated vs. GR	0.67	<0.01	<0.01	<0.01	<0.01
Unirradiated vs. MV	<0.01	<0.01	<0.01	<0.01	<0.01
GR vs.MV	<0.01	<0.01	<0.01	<0.01	<0.01

203 SEM, standard error of the means.
204 [1)] Different treatments were as follow, untreated, intact sesame meal; GR20= 20 kGy gamma irradiation, GR40= 40
205 kGy gamma irradiation, MV3= microwaving for 3 minutes, MV5= microwaving for 5 minutes.
206 [2)] OM, organic matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; EE, ether extract.
207

208 Table 2 shows the results of irradiation effect on amino acids profile before ruminal incubation
209 of un-irradiated and irradiated SSM. Irradiation of SSM was found to have significant effects on
210 amino acids quantity except for the isoleucine, leucine, lysine, and tyrosine (P<0.01), leading to an
211 increase in SSM methionine and phenylalanine content (P<0.01). Concentrations of certain
212 essential and non-essential amino acids were higher or lower in irradiated SSM compared to the
213 control. However, while the concentration of methionine and phenylalanine increased when treated
214 by gamma rays and microwave, the concentration of histidine, threonine, valine, alanine, arginine,
215 glutamine, glycine, and serine decreased under the same treatment. The results of Erkan and Ozden
216 (2007) study showed a significant difference in the contents of the sea bream amino acids following
217 the gamma irradiation at 2.5 and 5 kGy doses. Also, Xiang et al. (2020) reported that irradiation of
218 gluten with 1000 W microwave for 5 minutes resulted in a cross-linkage between amino acids,
219 reducing their total amount. Moreover, Bamidele and Akanbi (2015) showed a decrease in essential

and nonessential amino acids of pigeon pea flour when they were irradiated by gamma irradiation at 5-20 kGy doses. Xiang et al. (2020) suggested that the impact of irradiation on amino acids depended on the irradiation dosage and the structure of amino acids. Accordingly, the reduction in the radiated amino acids could be attributed to the deamination and dehydrogenation-induced formation of amino acid radicals, the breakdown of amino acids induced by the loss of groups of NH_3, H_2O, and COOH, the breakdown of covalent and peptide bonds, and the water-based chemical reactions (Cheftel et al., 1985; Cho and Song, 2000). Reacting with water molecules, ionizing rays destroy the structure of amino acids by forming free radicals. In current study it was found that the amount of crude protein (Table 1) and amino acids (Table 2) decreased with an increase in the moisture (Table 1) of irradiated sesame meal. As found by previous studies, sulfur-containing and aromatic amino acids are extremely sensitive to radiation. However, the current study found that whereas radiation increased the concentration of methionine (a sulfur-containing amino acid) and phenylalanine (an aromatic amino acid), it reduced the concentration of histidine. In this regard, Orias et al. (2002) argued that those amino acids protected in the protein complex structure were not affected by irradiation, and that the same might held true for isoleucine (a nonpolar amino acid) which remained unaltered when irradiated.

Irradiation may result in physical, chemical and biological changes in some feed materials (Afify et al., 2011). Studies on the effect of gamma radiation on the protein profile and functional properties of sesame seeds are scarce. It is known that the physiochemical properties of proteins are modified by irradiation as reported by Hafez et al. (1985). Afify and Shousha (1988) demonstrated that γ-irradiation caused molecular changes resulting in condensation or polymerization, degradation, hydrogen-bonding distribution and cleavages of intermolecular disulphide bonds (Casarett, 1968). Therefore, it is assumed that such molecular rearrangements may change the secondary structure and distribution of the native conformation of proteins, especially at higher dose levels or probably increase bioavailability of amino acid for animal. Different types of amino acids have different variations in the microwave heating process. The concentration of sulfur-containing and hydrophobic amino acids increases under the influence of

heat and Maillard reaction (Some feed sources contain cystine, which is formed from two cysteine amino acids, Cystine may break under the influence of radiation and produce two cysteines or even be converted to methionine) while the concentration of histidine decreases. Of course, the variation trends of the same amino acid in different feed are different, which could be connected to feed type and microwave and Gama irradiation processing settings.

Table 2. Effects of irradiation processing on amino acid[2] profile (%) of sesame meal prior incubation in rumen.

Treatment[1]	Unirradiated	Irradiated				SEM	P-values			
		GR20	GR40	MW3	MW5		Unirradiated vs. irradiated	Unirradiated vs. GR	Unirradiated vs. MV	GR vs. MV
Essential										
His	0.48^{a}	0.35^{b}	0.24^{c}	0.37^{b}	0.35^{b}	0.022	<0.01	<0.01	<0.01	0.03
Ile	0.71^{ab}	0.54^{b}	0.92^{a}	0.43^{b}	0.61^{ab}	0.057	0.45	0.88	0.14	0.06
Leu	1.69^{ab}	1.25^{c}	1.96^{a}	1.43^{bc}	1.53^{bc}	0.081	0.35	0.62	0.22	0.36
Lys	0.05^{ab}	0.06^{ab}	0.07^{a}	0.02^{b}	0.02^{b}	0.006	0.48	0.54	0.08	<0.01
Met	0.05^{c}	0.23^{ab}	0.26^{a}	0.10^{c}	0.19^{b}	0.022	<0.01	<0.01	<0.01	<0.01
Phe	0.05^{c}	0.45^{b}	0.55^{ab}	0.46^{b}	0.73^{a}	0.063	<0.01	<0.01	<0.01	0.14
Thr	0.84^{a}	0.35^{c}	0.30^{c}	0.34^{c}	0.50^{b}	0.055	<0.01	<0.01	<0.01	0.03
Val	1.04^{a}	0.66^{bc}	0.47^{c}	0.60^{c}	0.87^{ab}	0.060	<0.01	<0.01	<0.01	0.03
Non-essential										
Ala	0.85^{a}	0.53^{cd}	0.35^{d}	0.58^{bc}	0.73^{ab}	0.050	<0.01	<0.01	0.03	<0.01
Arg	1.71^{a}	1.16^{b}	1.02^{b}	1.32^{ab}	1.20^{b}	0.083	<0.01	<0.01	0.03	0.28
Glu	3.77^{a}	3.30^{b}	2.45^{c}	2.61^{c}	3.43^{ab}	0.142	<0.01	<0.01	<0.01	0.27
Gly	1.08^{a}	0.80^{bc}	0.67^{c}	0.085^{d}	0.85^{b}	0.090	<0.01	<0.01	<0.01	<0.01
Ser	0.82^{a}	0.48^{c}	0.50^{bc}	0.51^{bc}	0.68^{ab}	0.042	<0.01	<0.01	0.01	0.127
Tyr	0.62	0.53	0.58	0.57	0.46	0.028	0.26	0.43	0.21	0.53

SEM, standard error of the means.

[1)] Different treatments were as follow, untreated, intact sesame meal; GR20= 20 kGy gamma irradiation, GR40= 40 kGy gamma irradiation, MV3= microwaving for 3 minutes, MV5= microwaving for 5 minutes.

[2)] His, histidine; Ile, isoleucine; Leu, leucine; Lys, lysine; Met, methionine; Phe, phenylalanine; Thr, threonine;Val, valine; Ala, alanine; Arg, arginine; Glu, glutamin; Gly, glycine; Ser, serine; Tyr, tyrosine.

Table 3 shows the ruminal degradability parameters of DM and CP in treated SSM. The irradiation of SSM by GR and MW decreased the rapidly degradable fraction (a) and effective degradability (ED) of DM and CP at ruminal outflow rates of 0.02, 0.05, and 0.08h^{-1} and increase of ($P<0.01$) the slowly degradable fraction (b) without any influence on potential degradability compared to the control ($P<0.01$). Furthermore, GR irradiation at 40 kGy had the greatest effect on

reducing the ED of DM and CP, which could be attributed to a low soluble fraction, high insoluble fraction, and low degradation rate of DM and CP in GR-irradiated SSM. In this regard, the results of previous studies have shown some changes in rapidly degradable fraction and potentially degradable fraction of DM and CP when irradiated by GR at 25 - 75 kGy doses (Shawrang et al., 2007) and 2-6-min MW (Sadeghi et al., 2005) in soybean meal, which our results are consistent with their reports.

For instance, Maity et al. (2009) rerpoted dose-dependent reduction in total and soluble protein content of rice seeds when irradiated at 6 kGy by GR. Moreover, Sadeghi and Shawrang (2007) argued that the post irradiation decreases in DM degradability could be attributed to the decrease in degradability of starch and/or protein due to the formation of complex bonds between protein and non-protein compounds, which consequently reduced their accessibility to rumen microorganisms. Depressive effect of GR on protein solubility could also be related to changes in the physicochemical properties of the protein. The oxygen radicals generated in the radiolysis of water can change protein conformation in the forms of fragmentation (breakdown of the polypeptide chain and formation of low-molecular weight molecules), aggregation (development of inter-protein cross-linkage, disulfide bonds, and formation of high-molecular-weight molecules), and oxidation of amino acids (Lee and Song, 2002; Cho and Song, 2000) all of which are dependent upon the protein concentration and the irradiation dosage (Lee and Song, 2002). Heat processing methods such as microwave radiation can alter the structure of proteins by uncoiling the β-pleated sheets or denaturizing the whole protein molecule. Some factors such as racemization, cross-linkages among the uncoiled peptides and amino acids, and Maillard reaction can decrease the CP solubility, and thus, increase the resistance of protein molecules to microbial degradation (Yan et al., 2014). Significant negative relationship was observed between the ED of DM, and irradiation dosage (R^2=0.91), as well as MV time (R^2=0.97) (Fig 1 a and b). The percentage of effective ruminal degradability of DM was decreased linearly as the irradiation dosage of GR and time of the MW increased. The DM- ED decreased 6% with every 1 kGy increase of GR and 2% for every 1 minute increase in MW time, respectively.

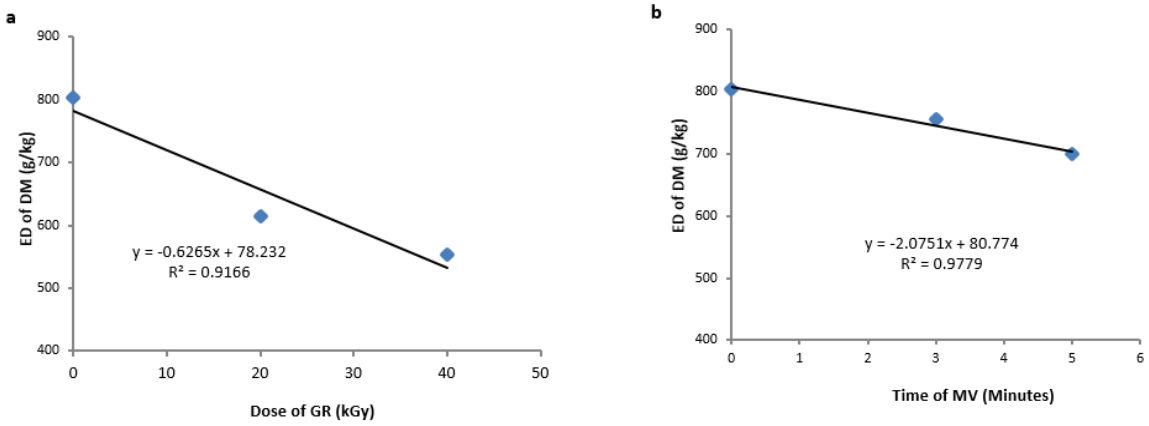

Fig. 1. Relation of effective ruminal degradability (ED) (g/kg) of dry matter (DM) with GR irradiation dose and MW time.

A negative linear relationship was also found between CP effective ruminal degradability of SSM and GR irradiation dose (R^2=0.90), and MW time (R^2=0.98) (Fig 2 c and d). The effective ruminal degradability of CP decreased by 6% for each 1 kGy increase in GR dose and by 21% for each 1 min increase in MW time.

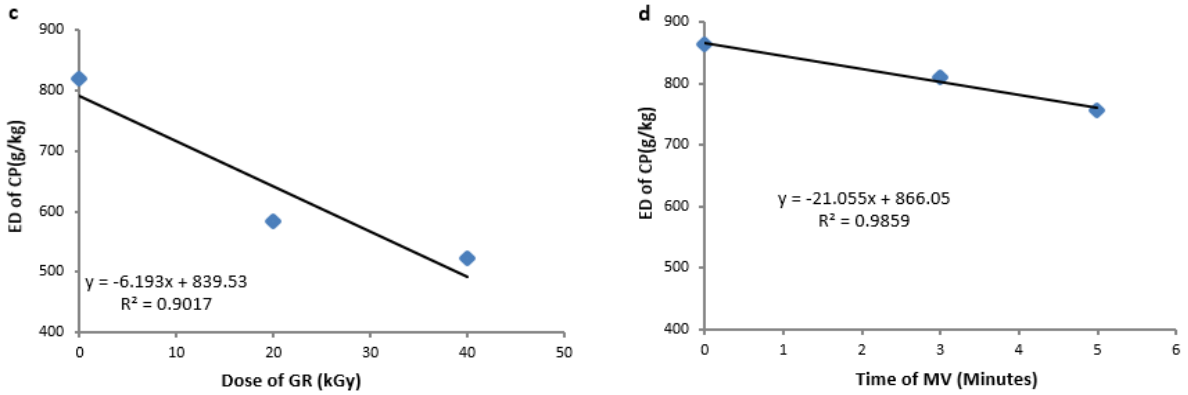

Fig. 2. Relation of effective ruminal degradability (ED) (g/kg) of crude protein (CP) with GR irradiation dose and MW time.

Table 3. Effects of irradiation processing of sesame meal on ruminal degradation characteristics of dry matter and crude protein[2].

Treatments[1]	Unirradiated	Irradiated				SEM	P-values			
		GR20	GR40	MW3	MW5		Unirradiated vs. irradiated	Unirradiated vs. GR	Unirradiated vs. MV	GR vs. MV
Dry matter										
a(g/kg)	476.53^{a}	173.83^{d}	120.67^{e}	389.59^{b}	299.60^{c}	35.426	<0.01	<0.01	<0.01	<0.01
b(g/kg)	500.07^{e}	825.53^{b}	879.23^{a}	606.23^{d}	673.33^{c}	37.615	<0.01	<0.01	<0.01	<0.01

a+b(g/kg)	976.60	999.37	999.90	995.82	972.93	4.262	0.13	0.05	0.46	0.10
c(h^{-1})	0.095^{a}	0.058^{bc}	0.049^{c}	0.080^{ab}	0.076^{abc}	0.0061	0.03	<0.01	0.19	0.03
Effective degradability at outflow rate (g/kg)										
0.02 h^{-1}	889.57^{a}	783.54^{c}	742.38^{d}	867.13^{a}	826.24^{b}	15.683	<0.01	<0.01	0.02	<0.01
0.05 h^{-1}	804.14^{a}	613.39^{c}	553.55^{d}	754.51^{ab}	698.58^{b}	25.932	<0.01	<0.01	<0.01	<0.01
0.08 h^{-1}	748.02^{a}	517.94^{d}	452.93^{e}	686.00^{b}	621.43^{c}	30.168	<0.01	<0.01	<0.01	<0.01
Crude protein										
a(g/kg)	588.60^{a}	268.73^{d}	195.90^{e}	476.13^{b}	343.67^{c}	38.075	<0.01	<0.01	<0.01	<0.01
b(g/kg)	402.80^{e}	726.56^{b}	803.83^{a}	517.90^{d}	649.70^{c}	38.719	<0.01	<0.01	<0.01	<0.01
a+b(g/kg)	991.40	995.29	999.73	994.03	993.36	1.595	0.36	0.23	0.64	0.35
c(h^{-1})	0.107^{a}	0.062b^{c}	0.054^{c}	0.095^{a}	0.090^{ab}	0.0072	0.02	<0.01	0.28	<0.01
Effective degradability at outflow rate (g/kg)										
0.02 h^{-1}	927.91^{a}	815.06^{c}	784.08^{d}	899.37^{b}	871.09^{b}	14.803	<0.01	<0.01	<0.01	<0.01
0.05 h^{-1}	863.14^{a}	668.44^{d}	615.42^{e}	810.15^{b}	756.42^{c}	25.054	<0.01	<0.01	<0.01	<0.01
0.08 h^{-1}	819.19^{a}	584.37^{d}	521.97^{e}	752.85^{b}	683.26^{c}	29.728	<0.01	<0.01	<0.01	<0.01

SEM, standard error of the means.

[1)]Different treatments were as follow, untreated, intact sesame meal; GR20= 20 kGy gamma irradiation, GR40= 40 kGy gamma irradiation, MV3= microwaving for 3 minutes, MV5= microwaving for 5 minutes.

[2)] ERD, effective ruminal degradability; a, wash out fraction degradation; b, potentially degradable fraction; a+b, potential degradability; c, rate constant of degradation of b fraction.

The results of ruminal disappearance of amino acids in unirradiated and irradiated SSM after 16 h of ruminal incubation are shown in Table 4. Ruminal disappearance of methionine, phenylalanine and threonine were decreased and that of glycine and serine were increased by GR irradiations ($P<0.01$). For GR-irradiated SSM, ruminal disappearance of threonine decreased as the irradiation dose increased from 20 to 40 kGy ($P<0.01$). The ruminal disappearance of isoleucine, methionine, phenylalanine, and threonine decreased and that of the serine increased with the increase of MW irradiation time ($P<0.01$). In general, the effectiveness of MV to decrease ruminal degradability of AA was greater than GR. Reducing the extent of protein breakdown in the rumen and increasing the amount of the protein passage from the rumen to the intestine are among the significant goals in setting the diet of high-producing animals seeking to optimize the absorbable amino acids (Borucki Castro et al., 2007). In this regard, the current study found that processing sesame meal increased the resistance of isoleucine, methionine, phenylalanine and threonine, but decreased the resistance of glycine and serine to microbial degradation in the rumen, which could be related to their structure type (Matloubi et al., 2004). Little evidence is available concerning the effects of seed meals irradiation on the level of amino acids resistance to ruminal degradation. In a study, Fathi Nasri et al (2008) found significant decrease in ruminal degradation of amino acids when roasted (thermal method) and steep-roasted at 140-145 °C, suggesting that the influence of processing on the degradability of amino acids in the rumen depends on the amino acid profile of the feed sample before its processing. In other studies, the treatment made at 25, 50, and 75 kGy

doses of electron and gamma rays decreased ruminal disappearance of amino acids in sunflower meal (Ghanbari et al. 2015) and cotton seed meal (Ghanbari et al. 2012). In this research, the irradiation of SSM increased the amount of methionine and phenylalanine but exerted no influence on the amount of isoleucine (Table 2) and decreased the ruminal degradability of these amino acids (methionine, phenylalanine and isoleucine) (Table 4). Therefore, iradiation processing by GR and MV can be effective in increasing bypass of methionine, phenylalanine and isoleucine amino acids from the rumen

Table 4. Amino acid[2] ruminal degradation (%) of unirradiated and irradiated sesame meal.

Treatment[1]	Unirradiated	Irradiated				SEM	P-values			
		GR20	GR40	MW3	MW5		Unirradiated vs. irradiated	Unirradiated vs. GR	Unirradiated vs. MW	GR vs. MW
Essential										
His	20.54^{b}	25.29^{ab}	37.24^{a}	21.43^{ab}	14.66^{b}	2.646	0.48	0.12	0.69	0.03
Ile	67.01^{a}	71.81^{a}	28.84^{b}	22.02^{b}	12.83^{b}	7.084	<0.01	0.15	<0.01	<0.01
Leu	63.03^{ab}	93.80^{a}	9.25^{c}	64.58^{ab}	23.35^{bc}	9.644	0.31	0.485	0.25	0.57
Lys	31.10	59.72	48.02	53.33	58.89	4.945	0.11	0.15	0.12	0.85
Met	75.17^{a}	18.88^{b}	27.54^{b}	59.25^{a}	29.43^{b}	6.268	<0.01	<0.01	<0.01	<0.01
Phe	91.55^{a}	33.70^{bc}	50.98^{b}	18.89^{c}	13.26^{c}	8.010	<0.01	<0.01	<0.01	0.01
Thr	87.14^{a}	42.81^{b}	12.67^{c}	45.09^{b}	31.89^{bc}	6.862	<0.01	<0.01	<0.01	0.11
Val	24.51^{ab}	27.55^{ab}	24.81^{ab}	51.48^{a}	16.66^{b}	4.816	0.601	0.89	0.43	0.43
Non-Essential										
Ala	39.15^{ab}	41.67^{a}	9.71^{b}	26.87^{ab}	12.53^{ab}	5.157	0.16	0.28	0.13	0.55
Arg	40.65^{a}	33.65^{ab}	37.84^{a}	13.10^{b}	25.11^{ab}	3.781	0.15	0.60	0.05	0.06
Glu	40.61^{ab}	15.16^{b}	43.77^{a}	17.12^{b}	18.51^{ab}	4.331	0.09	0.28	0.05	0.18
Gly	18.79^{c}	62.61^{ab}	78.41^{a}	53.33^{b}	14.28^{c}	7.346	<0.01	<0.01	0.1301	<0.01
Ser	18.22^{c}	31.38^{b}	32.22^{b}	31.43^{b}	51.47^{a}	4.083	<0.01	<0.01	0.0033	0.90
Tyr	23.15^{ab}	21.21^{b}	53.44^{a}	37.34^{ab}	46.47^{ab}	5.034	0.16	0.26	0.15	0.65

SEM, standard error of the means.
1) Different treatments were as follow, untreated, intact sesame meal; GR20= 20 kGy gamma irradiation, GR40= 40 kGy gamma irradiation, MV3= microwaving for 3 minutes, MV5= microwaving for 5 minutes.
2) His, histidine; Ile, isoleucine; Leu, leucine; Lys, lysine; Met, methionine; Phe, phenylalanine; Thr, threonine; Val, valine; Ala, alanine; Arg, arginine; Glu, glutamine; Gly, glycine; Ser, serine; Tyr, tyrosine.

The results of *In vitro* digestibility of the SSM dry matter (DMD), organic matter (OMD), and its digestible organic matter in dry matter (DOMD) were affected by treatment, differed among the treatments, the highest and lowest values for these variables which were observed in 5-min MW and 20 kGy-dose GR treatments, respectively (Table 5). The results of the current study regarding the *in vitro* trial are consistent with the results found by Zarei et al. (2015) who reported a decreased *in vitro* DMD and OMD of pomegranate seeds when irradiated by gamma ray and electron beam at 5-20 kGy doses. Similarly, Shishir et al. (2020) reported that the MW- treatment for 20–80 seconds could increase the digestibility of some hays. However, contrary to what found in the current study, GR irradiation at 25-75 kGy (Ghanbari et al., 2015) and 8-12 kGy (Hahm et al., 2013) increased the *in vitro* digestibility of the DM and OM of sunflower meal and the whole cottonseed, respectively. Some reports indicate cross-linkages between protein molecules and trapping the protein within the cellulose fibers cell wall can have a large effect on the reduction of DMD and OMD (Tien et al., 2000). Moreover, GR-induced cross linkages between protein molecules increase the protein molecular weight, causing changes in the protein structure and making it insensitive to degradation by proteolytic enzymes (Englard and Seifter, 1990). The MW irradiation may affect the unfolding of the protein and its denaturation, helping the digestion of the proteins by exposing the hydrophobic amino acids (especially aromatics) that are well-suited for the activity of pepsin and trypsin enzymes (Bhat et al., 2021).

Table 5. *In vitro* digestibility[2] of unirradiated, and irradiated sesame meal (%).

Treatment[1]	Unirradiated	Irradiated				SEM	P-values			
		GR20	GR40	MW3	MW5		Unirradiated vs. irradiated	Unirradiated vs. GR	Unirradiated vs. MV	GR vs.MV
DMD	74.37^{b}	70.37^{c}	69.50^{c}	74.87^{ab}	75.62^{a}	0.839	<0.01	<0.01	0.04	<0.01
OMD	72.82^{b}	68.54^{c}	67.17^{c}	73.70^{ab}	74.46^{a}	0.983	<0.01	<0.01	<0.01	<0.01
DOMD	65.32^{b}	61.55^{c}	60.12^{c}	66.22^{b}	68.17^{a}	1.004	0.01	<0.01	0.05	<0.01

SEM, standard error of the means.

[1)] Different treatments were as follow, untreated, intact sesame meal; GR20= 20 kGy gamma irradiation, GR40= 40 kGy gamma irradiation, MV3= microwaving for 3 minutes, MV5= microwaving for 5 minutes.

[2)] DMD, digestible dry matter; OMD, digestible organic matter; DOMD, digestible organic matter in dry matter.

CONCLUSIONS

The results of this experiment showed that irradiation increased the *in-vitro* digestibility of sesame meal, while the ruminal degradability of some amino acids, including methionine, phenylalanine and isoleucine decreased. Overall, irradiation of SSM appears to increase its protein content bypassing rumen degradation, thereby increasing the amount of digestible protein entering the small intestine.

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ارزش غذایی کنجاله کنجد تیمار شده با اشعه گاما و مایکروویو

تجزیه گسترده پروتئین در شکمبه می تواند شاخص های کیفی آن مانند تعادل اسید آمینه و قابلیت هضم را کاهش دهد. هنگامی که تجزیه پذیری پروتئین خام در شکمبه بالا باشد، پروتئین بای پس به روده و قابلیت هضم آن کمتر می شود. بنابراین، میزان تخریب پروتئین در شکمبه میزان نیتروژن موجود برای میکروارگانیسم‌ها در شکمبه و تامین اسیدهای آمینه در روده کوچک حیوان را تعیین می‌کند. هدف از این مطالعه بررسی اثر تابش پرتو گاما (GR) در دوزهای 20 و 40 کیلوگری و مایکروویو (MW) در 800 وات به مدت 3 و 5 دقیقه بر سینتیک تخریب شکمبه و قابلیت هضم در شرایط آزمایشگاهی کنجاله کنجد (SSM) بود. پارامترهای تجزیه پذیری نمونه های پرتودهی شده با روش کیسه نایلونی اندازه گیری شد. مقدار هیستیدین، ترئونین، والین، آلانین، آرژنین، گلوتامین، گلیسین و سرین کمتر بود، اما میزان متیونین و فنیل آلانین در نمونه‌های تیمار شده با GR و MW بیشتر از نمونه‌های تیمار نشده بود. تابش محتوای فیبر SSM را کاهش داد و ترکیب شیمیایی آن را در مقایسه با SSM تیمار نشده تغییر داد. تجزیه پذیری شکمبه DM و CP در SSM تحت درمان کاهش یافت. تجزیه پذیری موثر DM (ED) و CP در SSM تابیده شده با GR در مقایسه با SSM تابش شده با MW و کنترل کمتر بود. پس از شانزده ساعت انکوباسیون شکمبه ای SSM تیمار شده، تجزیه پذیری ایزولوسین، متیونین، فنیل آلانین و ترئونین کمتر بود، اما گلیسین و سرین بیشتر بود. قابلیت هضم در شرایط آزمایشگاهی (DMD) DM و ماده آلی (OMD)، و همچنین ماده آلی در ماده خشک (DOMD) به ترتیب در SSM تابیده شده با GR و MW در مقایسه با SSM پرتوده نشده کمتر و بالاتر بود. می توان نتیجه گرفت که تابش کنجاله کنجد با پرتو گاما در محافظت از پروتئین خام و برخی اسیدهای آمینه از جمله متیونین و فنیل آلانین در برابر تخریب شکمبه موثر است.