

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

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ABSTRACT

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 800W 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 fiber content of SSM and altered its chemical composition compared to the untreated SSM. Ruminal degradability of DM (Dry Matter) and CP (Crude Protein) 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 16 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: Degradability parameters, *In vitro* Digestibility, Ruminal degradation.

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, characterized 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 labor 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,

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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-Roudbaneh *et al.*, 2016) at 15, 30, and 45 kGy dose, reduced ruminal degradability of crude protein (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 *et al.*, 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-Roudbaneh *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 the 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 the 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^{-1} (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 hours 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, then, packed in zipper bags. All samples were kept at -20°C 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 (Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Valine) and non-essential amino acids (Alanine, Arginine, Glutamine, Glycine, Serine, Tyrosine) 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 $0.45\ \mu\text{m}$ 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% forage (alfalfa and wheat straw) and 33% 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; $45\text{--}50\ \mu\text{m}$ 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 AM). 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 the 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 the 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 CO₂ and 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, which were then closed with a rubber cap and purged with CO₂ 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 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 hours and the DM was determined. To determine the ash content, all the samples were ashed at 560°C for 4 hours to calculate digestible Organic Matter content in DM (OMD).

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, 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 (Equation 3), and the degradability data were analyzed as a randomized complete block design (Equation 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 the unirradiated SSM. In some studies, chemical composition of cottonseed (Taghinejad-Roudbaneh 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

Table 1. Effects of irradiation processing on chemical composition² of sesame meal (g kg⁻¹).^a

| Treatments | 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 ^c | 95.00 ^c | 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 |

^a Different treatments were as follow: Untreated: Intact sesame meal; GR20= 20 kGy Gamma irradiation; GR40= 40 kGy Gamma irradiation; MV3= Microwaving for 3 minutes, and MV5= Microwaving for 5 minutes. SEM: Standard Error of the Means; OM: Organic Matter; CP: Crude Protein; NDF: Neutral Detergent fiber; ADF: Acid Detergent Fiber, and EE: Ether Extract.

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) also reported that irradiation can break down the lignocellulosic materials of the plant cell walls. Tang *et al.* (2012) reported that the reduction in crude fiber by GR irradiation may be due to oxidation of the cellulose, and conversion of cellulose and lignin to the cell wall solution. By irradiation, fiber level could be reduced due depolymerization and delignification (Sandev and Karaivanov, 1977). The discrepancy between the results of the studies concerning the chemical composition of irradiated seeds and meals could be attributed to factors such as seed type, whole seed or seed meal, the oil extraction method (hot or cold press), and the conditions of the processing method (e.g., temperature, moisture, processing duration, dosage).

Table 2 shows the results of irradiation effect on amino acids profile before ruminal incubation of un-irradiated and irradiated SSM. Irradiation of SSM was found to have significant effects on amino acids quantity, except for the isoleucine, leucine, lysine, and tyrosine ($P < 0.01$), leading to an increase in

SSM methionine and phenylalanine content ($P < 0.01$). Concentrations of certain essential and non-essential amino acids were higher or lower in irradiated SSM compared to the control. However, while the concentration of methionine and phenylalanine increased when treated by gamma rays and microwave, the concentration of histidine, threonine, valine, alanine, arginine, glutamine, glycine, and serine decreased under the same treatment. The results of Erkan and Ozden (2007) showed a significant difference in the contents of the sea bream amino acids following the gamma irradiation at 2.5 and 5 kGy doses. Also, Xiang *et al.* (2020) reported that irradiation of gluten with 1000 W microwave for 5 minutes resulted in a cross-linkage between amino acids, 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

**Table 2.** Effects of irradiation processing on amino acid profile (%) of sesame meal prior to incubation in rumen.^a

| Treatments | 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 |

^a Different treatments were as follow: Untreated: Intact sesame meal; GR20= 20 kGy Gamma irradiation; GR40= 40 kGy Gamma irradiation; MV3= Microwaving for 3 minutes, and MV5= Microwaving for 5 minutes. SEM: Standard Error of the Means; 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, and Tyr: tyrosine.

the loss of groups of NH₃, H₂O, 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 the 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 in 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 hold true for isoleucine (a nonpolar amino acid) that 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 3 shows the ruminal degradability parameters of DM and CP in the 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 0.08 h⁻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, and our results are consistent with their reports.

For instance, Maity *et al.* (2009) reported 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, 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 ($R^2 = 0.97$) (Figure 1 a and b). The percentage of effective ruminal degradability of DM 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.

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 ($R^2 = 0.98$) (Figures 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.

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

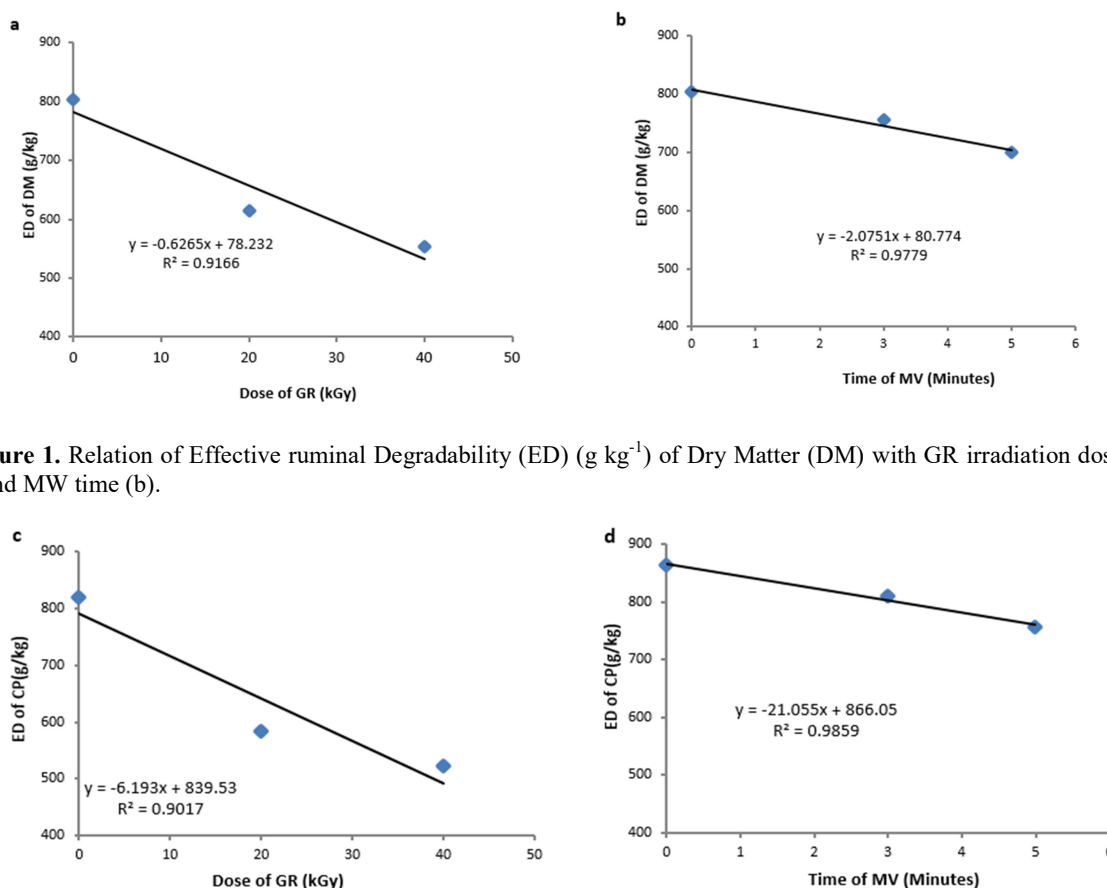


Figure 1. Relation of Effective ruminal Degradability (ED) (g kg^{-1}) of Dry Matter (DM) with GR irradiation dose (a) and MW time (b).

Figure 2. Effective ruminal Degradability (ED) (g kg^{-1}) of Crude Protein (CP) with GR irradiation dose (a) and MW time (b).

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

Table 3. Effects of irradiation processing of sesame meal on ruminal degradation characteristics of dry matter and crude protein.^a

| Treatments | Unirradiated | Irradiated | | | | SEM | P-values | | | |
|---|---------------------|---------------------|---------------------|----------------------|----------------------|--------|--------------------------------|------------------------|------------------------|--------------|
| | | | | | | | Unirradiated vs. irradiated | Unirradiated vs. GR | Unirradiated vs. MV | GR vs. MV |
| | | GR20 | GR40 | MW3 | MW5 | | | | | |
| Dry matter | | | | | | | | | | |
| a (g kg ⁻¹) | 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 ⁻¹) | 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 ⁻¹) | 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 ⁻¹) | | | | | | | | | | |
| 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 ⁻¹) | 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 ⁻¹) | 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 ⁻¹) | 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 ⁻¹) | | | | | | | | | | |
| 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 |

^a Different treatments were as follow: Untreated: Intact sesame meal; GR20= 20 kGy Gamma irradiation; GR40= 40 kGy Gamma irradiation; MV3= Microwaving for 3 minutes, and MV5= Microwaving for 5 minutes. SEM: Standard Error of the Means; ERD: Effective Ruminant Degradability; a: Wash out fraction degradation; b: Potentially degradable fraction; a+b: Potential degradability, and c: Rate constant of degradation of b fraction.

**Table 4.** Amino acid ruminal degradation (%) of unirradiated and irradiated sesame meal.^a

| Treatment | Unirradiated | Irradiated | | | | SEM | P-values | | | |
|---------------|---------------------|---------------------|---------------------|---------------------|---------------------|-------|--------------------------------|------------------------|------------------------|--------------|
| | | | | | | | Unirradiated vs. irradiated | Unirradiated vs. GR | Unirradiated vs. MW | GR vs. MW |
| | | GR20 | GR40 | MW3 | MW5 | | | | | |
| 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 |

^a Different treatments were as follow: Untreated: Intact sesame meal; GR20= 20 kGy Gamma irradiation; GR40= 40 kGy Gamma irradiation; MV3= Microwaving for 3 minutes, and MV5= Microwaving for 5 minutes. SEM: Standard Error of the Means; 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, and Tyr: tyrosine.

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, irradiation processing by GR and MV can be effective in increasing bypass of methionine, phenylalanine, and isoleucine amino acids from the rumen.

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 the treatment, differed among the treatments. The highest and lowest values for these variables 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 was 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 that 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).

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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REFERENCES

1. Afify, A. E. M. M., Rashed, M. M., Mahmoud, E. A. and El-Beltagi, H. S. 2011. Effect of Gamma Radiation on Protein Profile, Protein Fraction and Solubility's of Three Oil Seeds: Soybean, Peanut and Sesame. *Not. Bot. Horti Agrobot. Cluj-Napoca*, **39**: 90–98.
2. Afify, A. M. R. and Shousha, M. A. 1988. Effect of Low-Dose Irradiation on Soybean Protein Solubility, Trypsin Inhibitor Activity and Protein Patterns Separated by Polyacrylamide Gel Electrophoresis. *J. Agric. Food. Chem.*, **36**(4): 810-813.
3. Al-Masri, M. R. and Guenther, K. D. 1999. Changes in Digestibility and Cell Wall Constituents of Some Agricultural By-products due to Gamma Irradiation and



- Urea Treatments. *Radiat. Phys. Chem.*, **55**: 323-329.
4. Alton, W. J. 1998. Microwave Pasteurization of Liquids. *Eng. Paper*, **2**: 98-211
 5. AOAC. 1995. *Official Methods of Analysis*. 16th Edition, AOAC international, Arlington, VA, USA.
 6. Bahraini, Z., Salari, S., Sari, M., Fayazi, J. and Behgar, M. 2017. Effect of Radiation on Chemical Composition and Protein Quality of Cottonseed Meal. *Anim. Sci. J.*, **88(9)**: 1425-1435.
 7. Bamidele, O. P. and Akanbi, C. T. 2015. Effect of Gamma Irradiation on Amino Acids profile, Minerals and Some Vitamins Content in Pigeon Pea (*Cajanus Cajan*) Flour. *Br. J. Appl. Sci. Technol.*, **5(1)**: 90-98.
 8. Beheshti-Moghadam, M. H., Rezaei, M., Behgar, M. and Kermanshahi, H. 2019. Effects of Gamma and Electron Radiation on Chemical Composition and Some Phytochemical Properties of Whole Fax Seed. *J. Radioanal. Nucl., Chem.*, **321(3)**: 1019-1025.
 9. Bhat, Z. F., Morton, J. D., Bekhit, A. E. A., Kumar, S. and Bhat, H. F. 2021. Thermal Processing Implications on the Digestibility of Meat, Fish and Seafood Proteins. *Compr. Rev. Food Sci. Food Saf.*, **20(5)**: 4511-4548.
 10. Borucki Castro, S. I., Phillip, L. E., Lapierre, H., Jardon, P. W. and Berthiaume, R. 2007. Ruminal Degradability and Intestinal Digestibility of Protein and Amino Acids in Treated Soybean Meal Products. *J. Dairy Sci.*, **90(2)**: 810-822.
 11. Caidan, R., Cairang, L., Liu, B. and Suo, Y. 2014. Amino Acid, Fatty Acid, and Mineral Compositions of Fruit, Stem, Leaf and Root of *Rubus amabilis* from the Qinghai-Tibetan Plateau. *J. Food Compost. Anal.*, **33(1)**: 26-31.
 12. Casarett, A. P. 1968. Radiation Chemistry. In: "*Radiation Biology*". Englewood Cliffs, Prentice-Hall, New Jersey, PP. 57-89.
 13. Chandrasekaran, S., Ramanathan, S. and Basak, T. 2012. Microwave Material Processing: A Review. *AIChE J.*, **58**: 330-363.
 14. Cheftel, J. C., Cug, J. L. and Lorient, D. 1985. *Amino Acids, Peptides and Proteins*. In: "*Food Chemistry*", (Ed.): Fennema, O. 2nd Edition, Marcel Dekker, NY, PP. 245-370.
 15. Cho, Y. and Song, K. B. N. 2000. Effect of Gamma-Irradiation on the Molecular Properties of Bovine Serum Albumin and Beta-Lactoglobulin. *J. Biochem. Mol. Biol.*, **33**: 133-137.
 16. Davies, K. J. A. and Delsignore, M. E. 1987. Protein Damage and Degradation by Oxygen Radicals III. Modification of Secondary Structure and Tertiary Structure. *J. Biol. Chem.*, **262(20)**: 9908- 9913.
 17. Englard, S. and Seifter, S. 1990. Precipitation Techniques. *Meth. Enzymol.*, **182**: 285-306.
 18. Erkan, N. and Ozden, o. 2007. The Changes of Fatty Acid and Amino Acid Compositions in Sea Bream (*Sparus aurata*) during Irradiation Process. *Radiat. Phys. Chem.*, **76**: 1636-1641.
 19. Fathi- Nasri, M. H., France, J., Danesh Mesgaran, M. and Kebreab, E. 2008. Effect of Heat Processing on Ruminal Degradability and Intestinal Disappearance of Nitrogen and Amino Acids in Iranian Whole Soybean. *Livest. Sci.*, **113**: 43-51.
 20. Gaber, M. 2005. Effect of γ -Irradiation on the Molecular Properties of Bbovine Serum Albumin. *J. Biosci. Bioeng.*, **100(2)**: 203-206.
 21. Garrison, W. M. 1987. Reaction Mechanisms in the Radiolysis of Peptides, Polypeptides, and Proteins. *Chem. Rev.*, **87(2)**: 381-398.
 22. Ghanbari, F., Ghoorchi, T., Shawrang, P., Mansouri, H. and Torbati-Nejad, N. M. 2012. Comparison of Electron Beam and Gamma Ray Irradiations Effects on Ruminal Crude Protein and Amino Acid Degradation Kinetics, and *in Vitro*

- Digestibility of Cottonseed Meal. *Radiat. Phys. Chem.*, **81(6)**: 672-678.
23. Ghanbari, F., Ghoochi, T., Shawrang, P., Mansouri, H. and Torbati-Nejad, N. M. 2015. Improving the Nutritional Value of Sunflower Meal by Electron Beam and Gamma Ray Irradiations. *Iran. J. Appl. Anim. Sci.*, **5(1)**: 21-28.
 24. Golshan, S., Pirmohammadi, R. and Khalilvandi-Behroozyar, H. 2019. Microwave Irradiation of Whole Soybeans in Ruminant Nutrition: Protein and Carbohydrate Metabolism *in Vitro* and *in Situ*. *Vet. Res. Forum.*, **10(4)**: 343-350.
 25. Hafez, Y. S., Mohamed, A. I., Singh, G. and Hewedy, F. M. 1985. Effects of Gamma Irradiation on Proteins and Fatty Acids of Soybean. *J. Food. Sci.*, **50**: 1271 - 1274.
 26. Hahm, S., Son, H., Kim, W. and Son, Y. S. 2013. Effects of Gamma Irradiation on Nutrient Composition, Anti-Nutritional Factors, *in Vitro* Digestibility and Ruminal Degradation of Whole Cotton Seed. *J. Anim. Sci. Technol.*, **55(2)**: 123-130.
 27. Holm, N. W. and Berry, R. J. 1970. Manual on Radiation Dosimetry. Marcel Dekker, New York 450 PP.
 28. Kaneko, K., Yamasaki, K., Tagawa, Y., Tokunaga, M., Tobisa, M. and Furuse, M. 2002. Effects of Dietary Sesame Meal on Growth, Meat Ingredient and Lipid Accumulation in Broilers. *Jpn. Poult. Sci.*, **39**: 56-62.
 29. Lee, Y. and Song, K. B. 2002. Effect of Gamma-Irradiation on the Molecular Properties of Myoglobin. *J. Biochem. Mol. Biol.*, **35(6)**: 590-594.
 30. Maity, J. P., Kar, S., Banerjee, S., Chakraborty, A. and Santra, S. C. 2009. Effects of Gamma Irradiation on Long-Storage Seeds of *Oryza sativa* (cv. 2233) and Their Surface Infecting Fungal Diversity. *Radiat. Phys. Chem.*, **78**: 1006-1010.
 31. Mamputu, M. and Buhr, R. J. 1995. Effect of Substituting Sesame Meal for Soybean Meal on Layer and Broiler Performance. *Poult. Sci. J.*, **74(4)**: 672-684.
 32. Maneemegalai, S. and Prasad, R. 2011. Evaluation of Proximate Composition and Mineral Content of Commercially Available Groundnut and Sesame Meal. *Agric. Sci. Digest.*, **31(2)**: 136-139.
 33. Matloubi, H., Aflaki, F. and Hadjiezadegan, M. 2004. Effect of G-Irradiation on Amino acids Content of Baby Food Proteins. *J. Food. Compost. Anal.*, **17**: 133-139.
 34. Onsaard, E., Pomsamud, P. and Audtum, P. 2010. Functional Properties of Sesame Protein Concentrates from Sesame Meal. *As. J. Food Ag-Ind.*, **3(4)**: 419-430.
 35. Orias, F., Aldrich, C. G., Elizalde, J. C., Bauer, L. L. and Merchen, N. R. 2002. The Effects of Dry Extrusion Temperature of Whole Soybeans on Digestion of Protein and Amino Acids by Steers. *J. Anim. Sci.*, **80**: 2493-2501.
 36. Ørskov, E. R. and McDonald, I. 1979. The Estimation of Protein Degradability in Rumen from Incubation Measurements Weighted According to Rate of Passage. *J. Agric. Sci.*, **92(2)**: 499-503.
 37. Passi, Z. O. S., Beski, S. S. M. and Kokten, S. S. M. 2019. Effect of Graded Levels of Dietary Raw Sesame Seeds on Growth Performance, Serum Biochemistry and Nutrient Digestibility of Broiler Chickens. *Iraqi J. Agric. Sci.*, **50(1)**: 369-381.
 38. Peng, Q., Khan, N. A., Wang, Z. and Yu, P. 2014. Moist and Dry Heating-Induced Changes in Protein Molecular Structure, Protein Subfractions, and Nutrient Profiles in Camelina Seeds. *J. Dairy Sci.*, **97**: 446-457.
 39. Sadeghi, A. A., Nikkhah, A. and Shawrang, P. 2005. Effects of Microwave Irradiation on Ruminal Degradation and *in Vitro* Digestibility of Soya-Bean Meal. *Anim. Sci.*, **80(3)**: 369-375.
 40. Sadeghi, A.A. and Shawrang, P. 2007. Effects of Microwave Irradiation on Ruminal Protein Degradation and Intestinal Digestibility of Cottonseed Meal. *Livest. Sci.*, **106**: 176-181.



41. Sandev, S. and Karaivanov, I. 1977. The Composition and Digestibility of Irradiation Roughage. In: "Decontamination of Animal Feeds by Irradiation". FAO/IAEA Division of Atomic Energy in Food and Agriculture, 17-21 October 1977, Sofia, Bulgaria, PP. 83-87
42. Sant'Ana, A. D. S. 2017. Quantitative Microbiology in Food Processing. Modeling the Microbial Ecology. In: "Impact of Irradiation on the Microbial Ecology of Foods", (Ed.): Unluturk, S. University of Campinas, Sao Paulo, Brazil, PP. 176-180.
43. Shawrang, P., Nikkhah, A., Zare-Shahneh, A., Sadeghi, A. A., Raisali, G. and Moradi-Shahrebabak, M. M. 2008. Effects of Gamma Irradiation on Chemical Composition and Ruminal Protein Degradation of Canola Meal. *Radiat. Phys. Chem.*, **77**(7): 918-922.
44. Shawrang, P., Nikkhah, A., Zare-Shahneh, A., Sadeghi, A. A., Raisali, G. and Moradi-Shahrebabak, M. M. 2007. Effects of Gamma Irradiation on Protein Degradation of Soybean Meal in the Rumen. *Anim. Feed Sci. Technol.*, **134**(1-2): 140-151.
45. Shishir, M. S. R., Brodie, G., Cullen, B., Kaur, R., Cho, E. and Cheng, L. 2020. Microwave Heat Treatment Induced Changes in Forage Hay Digestibility and Cell Microstructure. *Appl. Sci.*, **10**: 1-11.
46. Steel, R. G. D. and Torrie, J. H. 1980. *Principles and Procedures of Statistics: A Biometrical Approach*. 2nd Edition. McGraw-Hill, NY, USA.
47. Taghinejad-Roudbaneh, M., Kazemi-Bonchenari, M., Abdelfattah, Z. M., Salem, A. and Kholif, A. E. 2016. Influence of Roasting, Gamma Ray Irradiation and Microwaving on Ruminal Dry Matter and Crude Protein Digestion of Cottonseed. *Ital. J. Anim. Sci.*, **15**(1): 144-150.
48. Tang, J., Fernandez Garcia, I., Vijayakumar, S., Martinez, H., Illa Bochaca, I. and Nguyen, D. 2012. Systems Modelzring of Stem/Progenitor Self-Renewal Romotion Following Ionizing Radiation. *The 58th Annual Meeting of the Radiation Research Society*, San Juan, Puerto Rico, Vol. 18.
49. Tien, L. C., Letendre, M., Ispas-Szabo, P., Mateescu, M. A., Delmas-Patterson, G., Yu, H. L. and Lacroix, M. 2000. Development of Biodegradable Films from Whey Proteins by Cross-Linking and Entrapment in Cellulose. *J. Agric. Food Chem.*, **48**: 5566-5575.
50. Tilly, J. M. A. and Terry, R. A. 1963. A Two Stage Technique for the *in Vitro* Digestion of Forage Crops. *J. Brit. Grassl. Soc.*, **18**(2): 104-111.
51. Tuncer, S. D. and Sacakli, P. 2003. Rumen Degradability Characteristics of Xylose Treated Canola and Soybean Meals. *Anim. Feed. Sci. Technol.*, **107**(1): 211-218.
52. Van Soest, P. J., Robertson, J. B. and Lewis, B. A. 1991. Methods for Dietary Fiber, Neutral Detergent Fiber and Non-Starch Polysaccharides in Relation to Animal Nutrition. *J. Dairy. Sci.*, **74**(10): 3583-3597.
53. Waltz, D. M. and Stern, M. D. 1989. Evaluation of Various Methods for Protecting Soya-Bean Protein from Degradation by Rumen Bacteria. *Anim. Feed Sci. Technol.*, **25**(1): 111-122.
54. Wang, Y., Jin, L., Wen, Q. N., Kopparapu, N. K., Liu, J., Liu, X. L. and Zhang, Y. G. 2016. Rumen Degradability and Small Intestinal Digestibility of the Amino Acids in Four Protein Supplements. *Asian-Australas J. Anim. Sci.*, **29**(2): 241-249.
55. Xiang, S., Zou, H., Liu, Y. and Ruan, R. 2020. Effects of Microwave Heating on the Protein Structure, Digestion Properties and Maillard Products of Gluten. *J. Food Sci. Technol.*, **57**(6): 2139-2149.
56. Yalcin, H., Ozturk, I., Hayta, M., Sagdic, O. and Gumus, T. 2011. Effect of Gamma-Irradiation on Some Chemical Characteristics and Volatile Content of Linseed. *J. Med. Food.*, **14**(10): 1223-1228.
57. Yan, X., Khan, N. A., Zhang, F., Yang, L. and Yu, P. 2014. Microwave Irradiation Induced Changes in Protein Molecular

- Structures of Barley Grains: Relationship with Changes in Protein Chemical Profile, Protein Sub Fractions and Digestion in Dairy Cows. *J. Agric. Food Chem.*, **62**(28): 6546-6555.
58. Zarei, M., Kafizadeh, F. and Shawrang, P. 2015. *In Vitro* Gas Production and dry matter Digestibility of Irradiated Pomegranate (*Punica granatum*) Seeds. *Iran. J. Appl. Anim. Sci.*, **6**(1): 25-34.

ارزش غذایی کنجاله کنجد تیمار شده با اشعه گاما و مایکروویو

حبیب امینی اسفید وجانی، امیر فتاح، و سید روح الله ابراهیمی محمودآباد

چکیده

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 میکروارگانیسم ها در شکمبه و تامین اسیدهای آمینه در روده کوچک حیوان را تعیین می کند. هدف از این مطالعه بررسی اثر تابش پرتو گاما (GR) در دوزهای ۲۰ و ۴۰ کیلوگری و مایکروویو (MW) در ۸۰۰ وات به مدت ۳ و ۵ دقیقه بر سینتیک تخریب شکمبه و قابلیت هضم در شرایط آزمایشگاهی کنجاله کنجد (SSM) بود. پارامترهای تجزیه پذیری نمونه های پرتو دهی 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 نمونه های تیمار شده با GR و MW بیشتر از نمونه های 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 تاییده 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 تاییده 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.