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Pellet Production from Green Pistachio Shell Waste with Varying Levels in Livestock Feed

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ABSTRACT

Green pistachio shells, a common agricultural waste in the country, face limited use as animal feed due to harmful microbes and bacteria. To enhance their nutritional value, additives like barley, corn, and beet pulp were mixed in ratios of 0, 20, 50, and 80 kg per 100 kg of pistachio shell. Using a pelletizing machine, the effects of temperature (50, 70, and 80°C), additive levels (0, 20, 50, and 80%), and particle size (0.5 and 1 mm) on anti-nutritional compounds and mechanical properties of pellets were studied. The factorial experiments, based on a completely randomized design (CRD), revealed significant reductions in phenolic and tannin content, with the greatest decrease (79% and 81%) at 80°C and 80% additives. Mechanical properties like durability and toughness improved most at 80°C, 50% additives, and 0.5 mm particle size. These findings highlight the potential to reduce livestock feed costs and environmental pollution through optimized pellet production.

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INTRODUCTION

The lack of proper care after the harvest of agricultural products, in addition to the loss of products, leads to harmful effects on the health of the products, environmental destruction, and instability in providing food security and the national security of the country (Xue et al., 2017).

Therefore, controlling and reducing agricultural product waste is considered one of the fundamental strategies for improving efficiency and ensuring food security in the country. In general, paying attention to this issue as a fundamental challenge in progress and development is necessary and undeniable. According to Laei et al. report, the special status of pistachios in Iran has led to its cultivation area exceeding 500,000 hectares (Laei, Haji Agha Alizadeh, et al., 2023b). This figure indicates the growing importance of this product in Iran's agricultural economy. Overall, statistics show a significant increase in the cultivated area and production of pistachios in Iran in recent years. This has doubled the importance of this strategic product in Iran's agricultural economy and emphasizes the need for more attention to. The amount of pistachio harvest residues in Iran is estimated to be more than 755,000 tons.

Based on the information provided, most of the pistachio waste is related to peeling, and by planning and using appropriate technologies, these materials can be used optimally. Because livestock inputs account for about 70% of livestock breeding costs on average, and millions of foreign currency dollars are spent annually to import livestock feed inputs. Since there is currently no proper use for these wastes and farmers bury them after burning them (Salihoglu et al., 2018), in the case of pistachio wastes, there are two main inhibiting factors in livestock feeding, which include high amounts of tannins and the presence of aflatoxin. The presence of aflatoxin in livestock feed can lead to physiological disorders in livestock and cause this toxic substance to enter livestock products. Tannins and phenolic compounds have also been identified as limiting factors in the use of these wastes in animal feed (Barahona et al., 1997).

Among the obstacles hindering the management of green pistachio shell waste are the low bulk density of this waste, high transportation costs, and storage difficulties arising from the separation of rotten portions of the primary raw materials and the inability to utilize existing equipment and transfer machinery (Terrill et al., 2007). Pelleting is a common method in animal husbandry, which is used to reduce the volume of bulk materials with low density, to facilitate transportation, storage and adding nutrients to them. This process involves compressing the milled product by pressure through several orifices (with or without steam) to form compressed pellets (Tumuluru et al., 2011). The most important difference between pelleted product storage and raw materials is its low moisture content, which limits the growth of microorganisms. The use of pelleted products for feeding livestock provides the possibility of enrichment with a uniform and certain ratio of nutritional supplements (Tumuluru et al., 2011). In a study by Sahoo et al. the use of garden waste and vegetables as a source of sustainable and environmentally friendly animal feed was investigated. The results showed that fruit and vegetable waste can be a potential feed for ruminants (Sahoo et al., 2021). Since more than 18,000 types of feed for livestock and poultry have been identified, the need to use agricultural waste in livestock and poultry rations from various and numerous aspects can be checked and given special attention. The purpose of this research is to investigate the optimal use of green pistachio skin waste in animal diets and to identify strategies to reduce the negative effects of anti-nutritional substances and improve the quality of animal feed. Considering the existence of more than

18,000 types of food for livestock and poultry, this study seeks to provide solutions for the optimal use of agricultural waste and ensure sustainable food security. This research can help to identify and eliminate shortcomings in agricultural waste management and act as an economic and sustainable solution for animal feed production and reducing environmental risks caused by waste. Finally, this work aims to improve productivity and improve the quality of animal feed through the optimal use of pistachio waste and reduce the costs associated with providing animal inputs.

MATERIALS AND METHODS

Preparation of green pistachio skin scraps

According to the fact that Sabzevar city of Razavi Khorasan province is one of the cities in the country in pistachio production, raw materials were prepared (Figure 1). The collected materials were stored outdoors for two weeks in early October in Sabzevar County, characterized by a hot and arid climate, to reduce their initial moisture content. Then, the remains of the pistachio green shell were transferred to the laboratory of Agricultural Technical Department, Faculty of the Agricultural Technology **(Abu Raihan),** and University of Tehran for processing and pellet production

Figure 1. Pistachio green shell waste

The pistachio residue prepared on average consisted of 62% green shell, 26% cluster, 11% leaf, 1% kernel, and wood shell, and a hammer mill was used to reduce the particle length to 0.5 and 1mm mesh size 16 and 30. The sieves were placed on top of each other in the shaker device with large to small holes (Figure 2). A laboratory electric sieve shaker (Model, KG 531, and Royan Iran Company) was used to measure the geometric mean. First, 100 grams of green pistachio shells were poured on the highest sieve and the machine was turned on. After vibrating the sieves for 30 seconds, the amount of pistachio green shell remaining on top of each sieve was measured by a digital scale with precision (0.01 gr), and the geometric mean of the length of the particles was calculated using Formula (1).

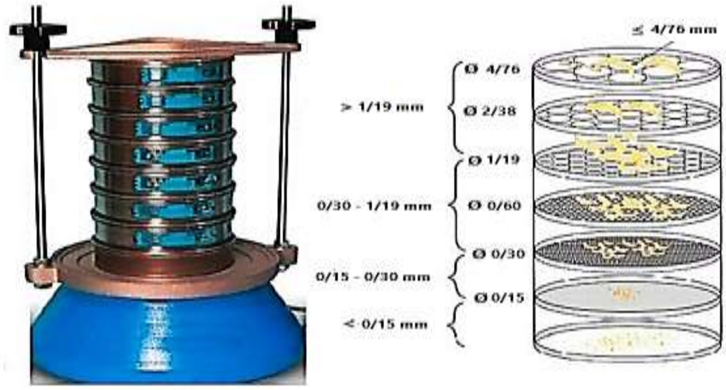

Figure 2. Electric sieve shaker to determine the geometric mean of particle length

$$d_{gw} = \log^{-1}\left[\frac{\sum_{i=1}^{n}\left(w_i \log \bar{d}_i\right)}{\sum_{i=1}^{n} w_i}\right] \qquad (1)$$

In formula (1): dgw, geometric mean particle length (mm); wi, weight on the i-th sieve (gr); n, the number of sieves plus one; and $\bar{d}_i$ is the size of the i-th sieve hole (mm).

Additives

To improve the nutritional value of pistachio shells, materials such as barley, corn and beet pomace have been used in different proportions (0, 20, 50 and 80 kg for every 100 kg of pistachio shell). Also, to increase adhesion, bentonite and urea were used in all treatments at 2 and 3 kg per 100 kg of pistachio shells, respectively, based on trial and error.

Determining the moisture content of raw

To determine the initial moisture content of the standard AACC (Approved Methods of the American Association of Cereal Chemists) was used and the initial moisture content of the material was determined to be 9%; which was calculated based on according wet weight to formula (2). After the initial moisture content of the material was determined, its moisture content was standardized to 12% (Laei, Hajiagha Aliazdeh, et al., 2023).

$$MC(\%) = \frac{m_i - m_f}{m_i} \times 100 \qquad (2)$$

In formula 2: MC is the Moisture content based on wet weight (percentage), m_i is the initial mass of materials (gr), m_f is the final mass of oven-dried materials (gr).

Physical and mechanical properties evaluation test of pellets produced from pistachio green skin

Determination of bulk density

In order to determine the mass density, the ground pistachio shell was poured into a container with specific dimensions until it was filled. Then, the excess amounts of the food that overflows from the mentioned container were drained from it by a ruler with a zigzag movement on the mouth of the container, so that a completely full container without initial compression of the material was obtained. Taking into account the dimensions of the container, the volume of the container was calculated and the mass of the material inside the container was also measured using a digital scale (model, LUTRON GM-300P, Germany) with an accuracy of 0.01 grams, the mass density value from the formula (3) for pistachio residues was calculated as 489 kg/m^3 (Laei, Hajiagha Aliazdeh, et al., 2023).

$$\rho = \frac{M}{V} \quad (3)$$

In formula 3: ρ equals the mass density of the sample (kg/m^3); M: sample mass (kg); V: is the sample volume (cubic meters).

Device for measuring the physical properties of biological material

The biological material testing device shown in Figure 3 was used to measure the fracture energy, fracture force and toughness of the pellets. The pellet was placed on the fixed jaw of the machine along the horizontal axis. The movable jaw was connected to the load cell and moved downward at a speed of 25 mm/min. Then the force was applied by the load cell on the cylindrical surface of the pellet until a crack or failure (which can be seen in the form of a drop point in the force-displacement diagram).

Figure 3. a. Mechanical testing device for biological materials **b.** How to apply force along the horizontal axis of the pellet

Fracture energy and toughness of produced pellets

The biological yield point is the point on the force-deformation curve where the force momentarily decreases and then increases. This point shows a break in the material. Also, the area under the force-displacement diagram indicates the amount of energy needed to break the pellet and was calculated using formula (4) (Laei, Hajiagha Aliazdeh, et al., 2023).

$$E=\frac{1}{2}Fr \times Dr \quad (4)$$

In formula 4: E, the energy required to break the pellets (mill joules); Fr, the maximum force required to break the pellets (Newton); Dr, displacement equivalent to the maximum force value (mm).

Toughness is the amount of work that is applied to the volume of the object to break. Considering that the area under the curve represents the work done to break the samples, therefore, according to the estimation of the pellet volume by the calculation formula mentioned in the previous sections, the apparent toughness for the pellet produced by formula (5) was obtained (Laei, Hajiagha Aliazdeh, et al., 2023).

$$TO = \frac{E_a}{V} \tag{5}$$

In formula 5: TO toughness (mJ/m3); V, sample volume (mm3); Ea is the energy absorbed by the samples (mill joules).

Durability test of production pellets

Pellet durability testing methods are: 1- sieving pellets with a standard sieve of about 0.8 mm. 2- Putting 500 grams of the sample inside the durability test machine and turning on the machine for 10 minutes by setting the speed to 50 rpm. 3- Re-sieving the samples taken out of the device chamber. 4- Weighing the remaining materials on the sieves. The durability of the pellets (DU) was calculated as a percentage using the mass values of the remaining healthy pellets (Mc) and the total mass of the initial healthy pellets (Mi) according to formula 6 (Laei, Hajiagha Aliazdeh, et al., 2023).

$$DU = \frac{M_c}{M_i} \times 100 \tag{6}$$

Pellet production process with an optimized pellet machine for pistachio green shell waste

To produce pellets using the green pistachio shell pellet machine, first the animal feed mixture obtained from the green pistachio shell was prepared and then it was poured into the extruder tank (Figure 4). This device is equipped with 5 ceramic thermal belts that show the temperature of the material and control the temperature using a temperature sensor (K) installed at the outlet of the material from the extruder to the inlet tank of the pellet machine. In this experiment, three temperature levels (50, 70 and 80 degrees Celsius) were used. The materials inside the extruder are transferred by the rotation of the kneading screw and are turned into a uniform paste and are directed into the tank of the pellet machine. In the pistachio green shell pellet machine, three cone-shaped rollers start to rotate to create a layer of edible material on the surface of the fixed die with the diameter of the holes of 8 mm. Each time the rollers pass (repetition of this cycle), more material is released into the die holes and in the form of cylindrical pellets of the same diameter as the die holes, and by changing the position of the cutting blade under the die, it creates pellets of the desired length.

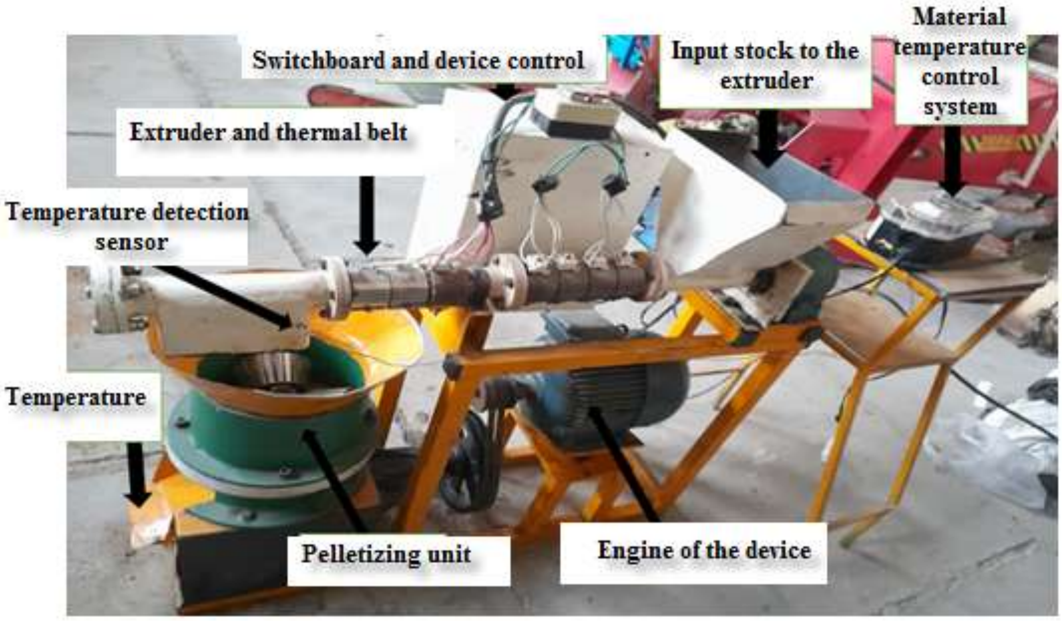

Figure 4. Pellet making machine for pistachio green shell

Investigating the anti-nutritional properties of the pellets produced from pistachio green skin

Phenolic and tannin compounds

The amount of total phenolic compounds was measured by Folin-Shikalto method (Makkar & Singh, 1993). The amount of total tannin was obtained by calculating the difference of phenolic compounds before and after the reaction with polyvinyl pyrrolidone. 10 ml of 70% acetone was added to the test tube containing 100 mg of dried sample to extract phenolic compounds. Then sodium carbonate 20%, Folin Chicalto phenol (one molar) and 0.9 ml of distilled water were added to 0.1 ml of acetone extract after mixing and kept at room temperature for 35 minutes and then in the wavelength 725 nm (A725) its absorption number was read by spectrophotometer. Using tannic acid solution in different concentrations, a standard curve was drawn and then the amount of phenolic and tannin compounds in the sample was calculated.

Statistical analysis

Data analysis was done using $SAS_{9.3}$ statistical software and analysis of variance and comparison of means using Duncan's test at 5% level based on complete random design with three replications. Also, to investigate the effect of independent variables (additives, particle size and temperature) on dependent variables (toughness, fracture energy, fracture force, durability, phenolic compounds and tannins of the produced pellets), two methods of coefficient determination were used.

RESULTS AND DISCUSSION

Investigating the mechanical properties of pellets produced from pistachio waste in animal feed

The results of the variance analysis and the significance of the variables of particle size, temperature and additives on the mechanical properties of the pellets produced from pistachio green shell waste show the importance of optimizing these parameters in improving the quality of the final product (Table 1). The analyzes showed that the independent variables of temperature, additives and particle size significantly affected the fracture energy, maximum fracture force and toughness of the produced pellets. Also, in particular, the increase in temperature and additives in combination with the decrease in particle size caused a significant improvement in the mechanical properties of the pellets. This means that by carefully controlling these parameters in the production process, a product with high strength and durability can be obtained. In addition, the coefficient of variation is less than 2.84% and the determination coefficient is more than 96% for all variables, indicating the high accuracy of the tests and the validity of the obtained results.

Table 1. Analysis of variance the effect of particle size ,additives and temperature on pellets produced from pistachio shell waste with different levels in animal feed

Sources of variation	**df**	**Mean squares**		
		Energy Failure	**Force of Failure**	**Toughness**
Particle size	1	0.00004384**	54115**	8.21E-30**
Additives	3	0.00006211**	54553**	2.35E-29**
temperature	2	0.00004966**	38038**	2.54E-29**
Additives*temperature	6	0.00001624**	9108.3**	1.18E-29**
Temperature* Additives	2	0.00000228**	2469.9**	1.18E-30**
Temperature*particle size	3	0.00000193**	2538.4**	1.18E-30**
Additives* particle size *particle size	6	0.00000158**	778.36**	8.00E-31**
Error	48	0.00000033	219.57	9.60E-32
coefficient of variation (CV)		2.84	2.04	2.27
coefficient of determination (R2)		0.96	0.97	0.98

ns, * and ** non-significant and significant at the probability levels of 5% and 1%, respectively.

The influence of independent variables on the mechanical properties of pellets

The results of this research showed that the variables of particle size, temperature and additives have a significant effect on the mechanical properties of pellets produced from pistachio green shell waste. Optimizing these parameters can play an important role in improving the quality of the final product (Table 2). Particle size: reducing the particle size from 1 to 0.5 mm caused a significant increase in the fracture energy, maximum fracture force and toughness of the pellets. This result shows that the use of finer particles improves the mechanical properties of the product. Temperature: increasing the temperature from 50 to 80 degrees Celsius significantly increased the breaking energy, maximum breaking force and toughness of the pellets. This means that a higher temperature in the manufacturing process improves the mechanical properties of the product. Additives: Adding 50% of additives had the greatest effect on improving the breaking energy, maximum breaking force and toughness of the pellets. This shows that the use of suitable additives can significantly improve the mechanical properties of the product. According to Duncan's multi-range test, the numbers with the same letters in each column do not have a significant difference.

Table 2. Comparison of mean the main effect of particle size, temperature and additives on pellets produced from pistachio waste in animal feed

Main effects	Failure Energy (J)	Force of Failure (N)	Toughness (J/M^3)
	Mean± Std.Error	Mean± Std.Error	Mean± Std.Error
Particle size			
0.5	0.021±0.000 a	751.768±12.304 a	0.000000000000013883±3.1302E-16 a
1	0.02±0.000 b	696.938±10.212 b	0.000000000000013208±2.5836E-16 b
Temperature			
50	0.019±0.00 c	688.442±10.99 c	0.000000000000012412±1.669E-16 c
70	0.02±0.001 b	717.455±13.837 b	0.000000000000013802±3.1194E-16 b
80	0.022±0.001 a	767.162±15.218 a	0.000000000000014422±4.1673E-16 a
Additives			
0%	0.018±0.000 c	645.001±9.312 c	0.000000000000011864±4.4224E-17 c
20%	0.021±0.001 b	737.486±17.639 b	0.000000000000013881±4.6742E-16 b
50%	0.022±0.001 a	772.133±15.57 a	0.000000000000014407±4.3177E-16 a
80%	0.021± 0.00b	742.792±7.382 b	0.00000000000001403±2.6036E-16 b

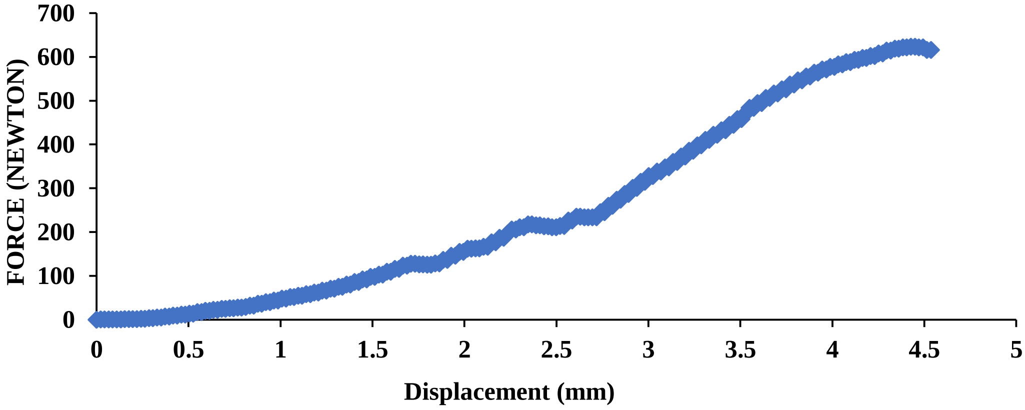

Figure 5. Force-displacement diagram of the fracture of the produced pellets

The results of comparing the averages showed that additives, particle size and temperature significantly affect the failure energy of pellets produced from green pistachio shell waste with different levels (Figure 6). These findings indicate that the optimization of these parameters can play an important role in improving the quality of the final product. The highest breaking energy of pellets was observed in the treatment with 50% additives, particle size 0.5 mm and temperature 80 degrees Celsius and treatment with 20% additives, particle size 0.5 mm and temperature 50 degrees Celsius. These results show that the use of suitable additives (20-50%) in combination with smaller particle size (0.5 mm) and high temperature (80 degrees Celsius) significantly improves the mechanical properties of the product. On the other hand, the lowest breaking energy of the pellets was related to the treatment with no additives (zero percent), particle size of 1 mm and temperature of 50 degrees Celsius. This may be due to the lack of additives to create proper bonds between particles, larger particle size, and lack of favorable changes in particle structure under low temperature. Also, based on the results of previous studies, suitable additives can improve the mechanical properties of pellets by creating strong bonds between particles and improving adhesion (Laei, Haji Agha Alizadeh, et al., 2023a). On the other hand, smaller particle sizes can also increase the surface area. Contact between particles and improve mechanical properties. Also, high temperature can cause favorable structural changes in materials and improve mechanical properties. Based on these results, it can be said that with the increase of additives, the amount of fracture energy of the produced pellets. In other words, additives, particle size and temperature have a significant effect on the fracture energy of the produced pellets.

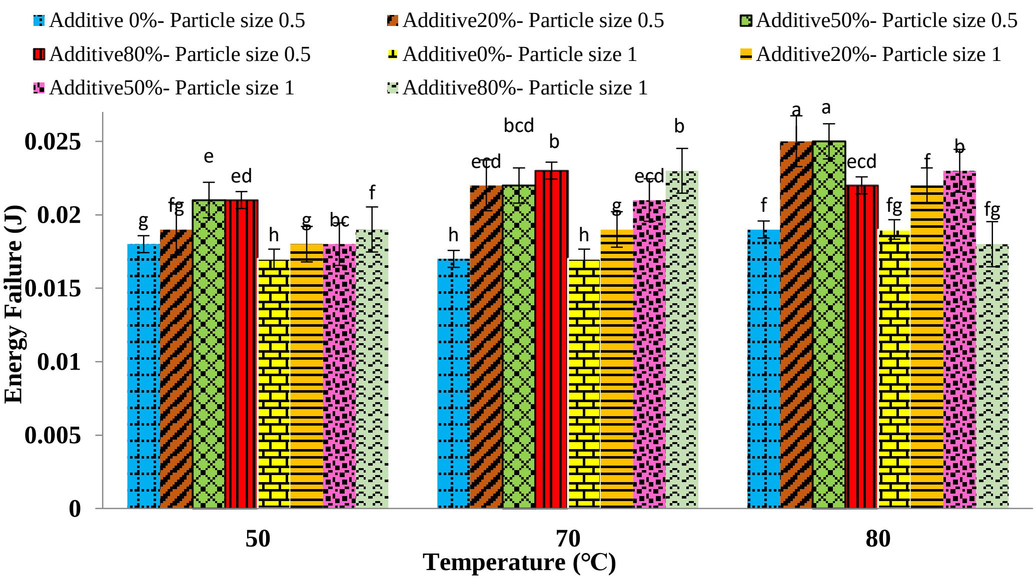

Figure 6. The interaction effect of additives, particle size and temperature on the failure energy of pellets produced from pistachio green shell in animal feed.

The interaction of additives, particle size and temperature on the maximum breaking force of pellets

The results of comparing the averages showed that additives, particle size and temperature have a significant effect on the maximum breaking force of pellets produced from green pistachio shell waste with different levels (Figure 7). These findings indicate that the optimization of these parameters can play an important role in improving the quality of the final product. The maximum breaking force of pellets was observed in the treatment with 50% additives, particle size 0.5 mm and temperature 80 degrees Celsius and treatment with additives 20%, particle size 0.5 mm and temperature 80 degrees Celsius. These treatments had the most significant difference at the probability level of 1% compared to other treatments. The results showed that the use of suitable additives (20-50%) in combination with smaller particle size (0.5 mm) and optimal temperature (80 degrees Celsius) significantly improves the mechanical properties of the product. On the other hand, the lowest amount of maximum breaking force of the pellets was related to the treatment with 0% additives, particle size of 1 mm and temperature of 50 degrees

Celsius. This may be due to the lack of additives to create proper bonds between particles, larger particle size, and lack of favorable changes in particle structure under low temperature. The results showed that by reducing the size of the particles to 0.5 mm, increasing the additives and the optimal temperature, it can soften the particles of the material and lead to a stronger bond between the particles of the material and the distance between the particles is minimized and the maximum breaking force of produced pellets will increase.

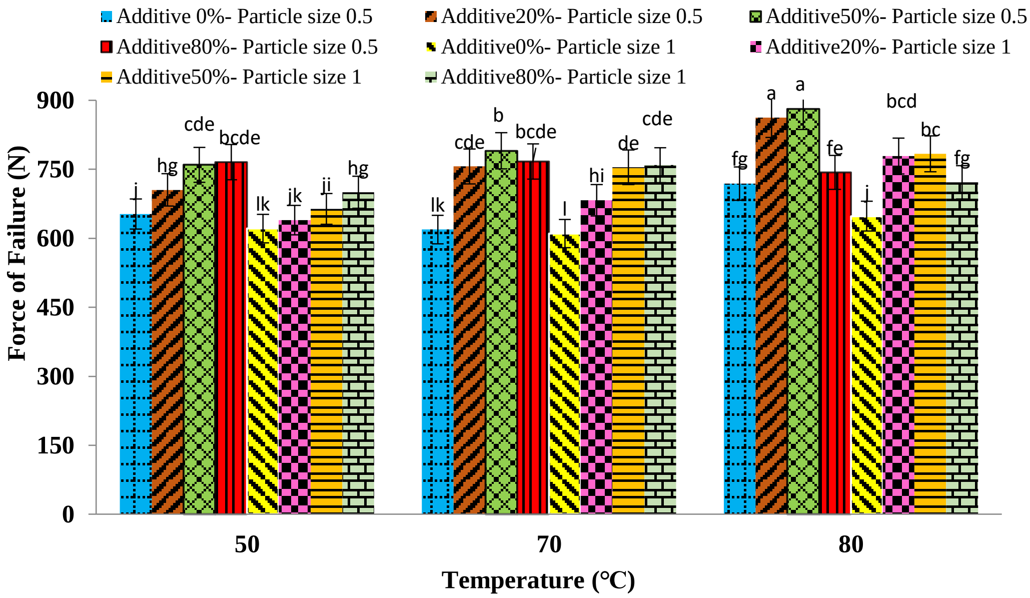

Figure 7. Interaction effect of additives, particle size and temperature on the amount of maximum breaking force of pellets produced from pistachio green shell in animal feed.

The mutual influence of additives, particle size and temperature on the fracture toughness of pellets

The results of comparing the averages showed that additives, particle size and temperature significantly affect the toughness of pellets produced from green husk waste with different levels. These findings indicate that the optimization of these parameters can play an important role in improving the quality of the final product (Figure 8). The highest hardness of pellets was obtained in two treatments: treatment with 50% additives, particle size of 0.5 mm and temperature of 80 degrees Celsius, treatment with additives of 20%, particle size of 0.5 mm and temperature of 80 degrees Celsius was observed. These treatments had the most significant difference at the probability level of 1% compared to other treatments. These results show that the use of suitable additives (20-50%) in combination with smaller particle size (0.5 mm) and high temperature (80 degrees Celsius) significantly improves the toughness of the product. On the other hand, the lowest hardness of the pellets was related to the treatment with zero percent additives, particle size of 1 mm and temperature of 50 degrees Celsius. This may be due to the lack of additives to create proper bonds between particles, coarser size and lack of favorable changes in particle structure under low temperature. Also, based on the results of previous studies, suitable additives can improve the toughness of pellets by creating strong bonds between particles and improving adhesion. On the other hand, smaller particle size can increase the contact surface between particles and improve toughness. Also, high temperature can cause favorable structural changes in materials and improve toughness (Laei, Hajiagha Aliazdeh, et al., 2023). In general, by reducing the additives, temperature and increasing the particle size, and vice versa, by increasing the additives, temperature and decreasing the particle size, the biggest change in the toughness value of the produced pellets is achieved. Therefore, the results of this study show that the interaction of additives, temperature and particle size is effective on the toughness of produced pellets. It has been observed, if the particle size is reduced, additives and temperature are increased, the best results can be expected in the production of higher quality pellets.

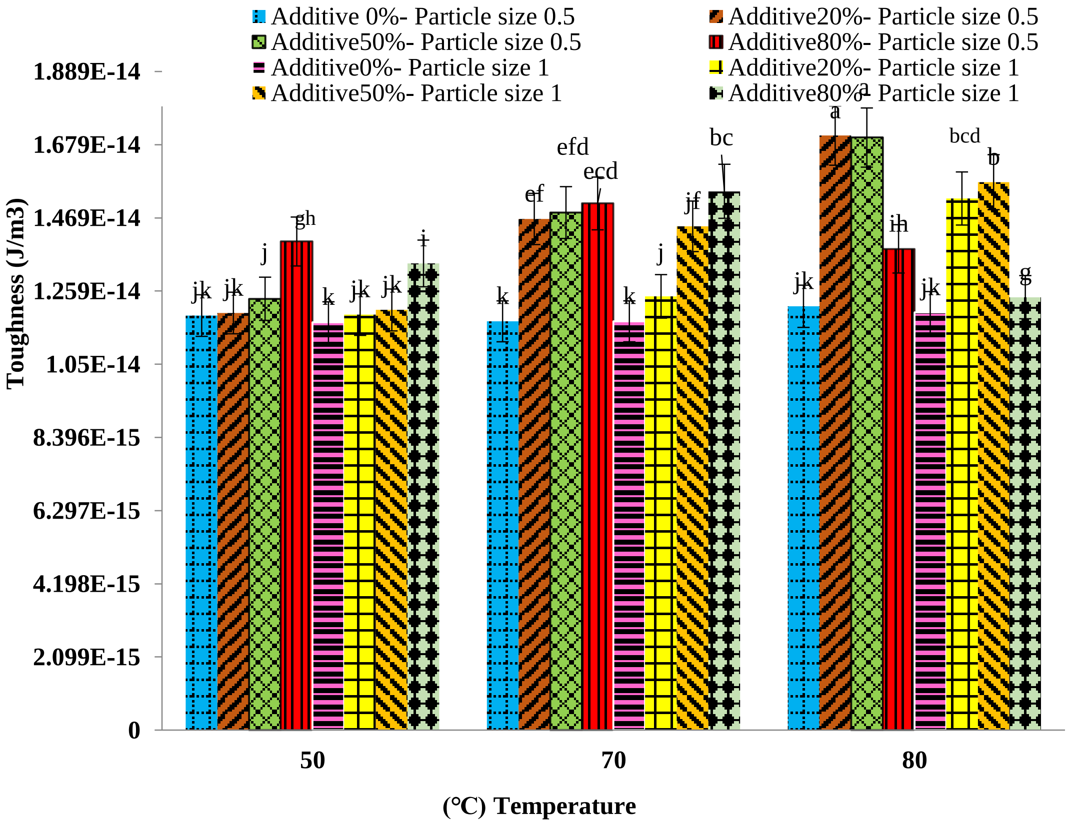

Figure 8. The interaction effect of additives, particle size and temperature on the hardness of pellets produced from pistachio green shell in animal feed

During the compression process under high temperature and pressure, the moisture present in the material turns into steam and during the hydrolysis process, hemicellulose and lignin are converted into carbohydrates and sugar polymers. Under high temperature and pressure, these materials act as adhesives and bind particles together, which improves the stability of the produced pellets (Tumuluru et al., 2011). These results were consistent with the findings of the maximum breaking force, breaking energy and toughness of the produced pellets in the current research result

Investigating the anti-nutritional properties of pellets produced from pistachio waste in animal feed

The results of the analysis of variance and the significance of the variables of particle size, temperature and additives on phenolic compounds, tannins and durability of the pellets produced from pistachio green shell waste by the pellet machine for animal feeding showed (Table 3). That the independent variables of particle size, temperature and additives had a significant effect on phenolic compounds, tannins and durability of pellets produced from pistachio green shell waste. The results showed that the interaction effect of temperature and additives on phenolic compounds was significant at 5% level and for tannin and durability of produced pellets at 1% level. Also, the effect of temperature and particle size on tannin was significant at the 5% probability level. The effect of additives and particle size on tannin and durability of produced pellets was significant at 1% level. The triple effect of temperature, particle size and additives on the durability of produced pellets was significant at 1% level. Also, the results of the coefficient of variation showed that it was less than 6.15% for all variables and the coefficient of determination (R^2) for all variables was observed to be more than 97%. These results indicate that the test was performed with proper accuracy.

Table 3. Analysis of variance the effect of particle size ,additives and temperature on pellets produced from pistachio shell waste with different levels in animal feed

Sources of variation	df	Mean squares		
		Phenolic Compounds	Tannin	Durability
Particle size	1	0.350^{**}	0.712^{**}	0.009^{**}
Additives	3	52.123^{**}	11.780^{**}	0.090^{**}
temperature	2	0.584^{**}	1.088^{**}	0.064^{**}
Additives*temperature	6	0.061^{*}	0.263^{**}	0.012^{**}
Temperature* Additives	2	0.001^{ns}	0.054^{*}	0.000^{ns}
Temperature*particle size	3	0.025^{ns}	0.303^{**}	0.002^{**}
Additives* particle size *particle size	6	0.041^{ns}	0.017^{ns}	0.002^{**}
Error	48	0.026	0.013	0.000
coefficient of variation (CV)		4.22	6.15	1.68
coefficient of determination (R2)		0.99	0.98	0.97

^{ns}, * and ** non-significant and significant at the probability levels of 5% and 1%, respectively.

The effect of independent variables on anti-nutritional compounds of pellets

In this research, the effect of independent variables of particle size, temperature and additives on phenolic compounds, tannins and the durability of pellets produced from pistachio green shell waste has been investigated (Table 4). The research results show that changes in particle size, temperature and additives have significant effects on the quality of pellets. Reduction of particle size: By reducing the particle size from 1 mm to 0.5 mm, the durability of the pellets has increased. This size reduction has also led to a significant reduction of phenolic and tannin compounds in the pellets. In other words, the smaller size of the particles reduces the anti-nutritional substances in the pellets. Temperature increase: by increasing the temperature from 50 to 80 degrees Celsius, the durability of the pellets is improved and the phenolic and tannin compounds are reduced. This suggests that higher temperatures can help increase shelf life and reduce anti-nutritional substances. Use of additives: by increasing the amount of additives from 0 to 80%, the durability of the pellets increased and the phenolic and tannin compounds were further reduced.

This means that adding ingredients can help reduce anti-nutritional compounds in pellets. In general, these results show that by optimizing the particle size, temperature and the use of additives, the quality of the pellets can be improved and harmful substances can be reduced.

Table4. Comparison of mean the main effect of particle size, temperature and additives on pellets produced from pistachio waste in animal feed

Main Effects	Phenolic Compounds (Dry Matter)	Tannin (Dry Matter)	Durability (%)
	Mean± Std.Error	Mean± Std.Error	Mean± Std.Error
	Particle size		
0.5	3.726±0.247 b	1.764±0.114 b	0.899±0.014 a
1	3.865±0.256 a	1.963±0.139 a	0.876±0.014 b
		Temperature	
50	3.957±0.31 a	2.077±0.167 a	0.835±0.013 c
70	3.784±0.314 b	1.863±0.158 b	0.888±0.02 b
80	3.645±0.305 c	1.651±0.137 c	0.938±0.011 a
		Additives	
%٠	5.353±0.067 a	2.749±0.088 a	0.784±0.015 c
%٢٠	5.064±0.065 b	2.23±0.107 b	0.9±0.018 b
%٥٠	2.953±0.044 c	1.598±0.029 c	0.937±0.012 a
%٨٠	1.811±0.026 d	0.877±0.018 d	0.928±0.008 a

According to Duncan's multi-range test, the numbers with the same letters in each column do not have a significant difference.

The mutual effect of additives and temperature on the amount of phenolic compounds in pellets

The results of comparing the averages of the interaction of additives and temperature on the amount of phenolic compounds of the pellets produced from pistachio green shell waste (Figure 9-a) showed that: The biggest decrease in the amount of phenolic compounds of the pellets was related to the treatment with 80% additives and the temperature of 50 to 80 degrees Celsius. These treatments had the most significant difference at the 1% probability level. This may be due to greater temperature homogenization with additives and kneading by the extruder of the pelletizer. This process can cause chemical changes and molecular structure of materials and as a result reduce the amount of phenolic compounds in the produced pellets. In fact, it can be stated that by increasing the additives by 80% and by increasing the temperature to 80 degrees Celsius, it has been able to more effectively affect the amount of phenolic compounds of the produced pellets.

The mutual effect of additives and temperature on the tannin content of pellets

The results of the comparison of the averages of the interaction of additives and temperature on the amount of tannin in the pellets produced from pistachio green shell waste (Figure 9-b) showed that: The biggest decrease in the amount of tannin of the pellets was related to the treatment with 80% additives and the temperature of 50 to 80 degrees Celsius. These treatments had the most significant difference at the 1% probability level. Also, the results showed that the amount of tannin decreased with increasing temperature. This may be due to greater temperature homogenization of the additives by kneading by the extruder of the pelletizer. This process can cause chemical changes and molecular structure of materials as a result of reducing the amount of tannin in the produced pellets. In fact, it can be said that by increasing the additives by 80% and by increasing the temperature to 80 degrees Celsius, it has been able to more effectively affect the amount of phenolic compounds and tannins of the produced pellets.

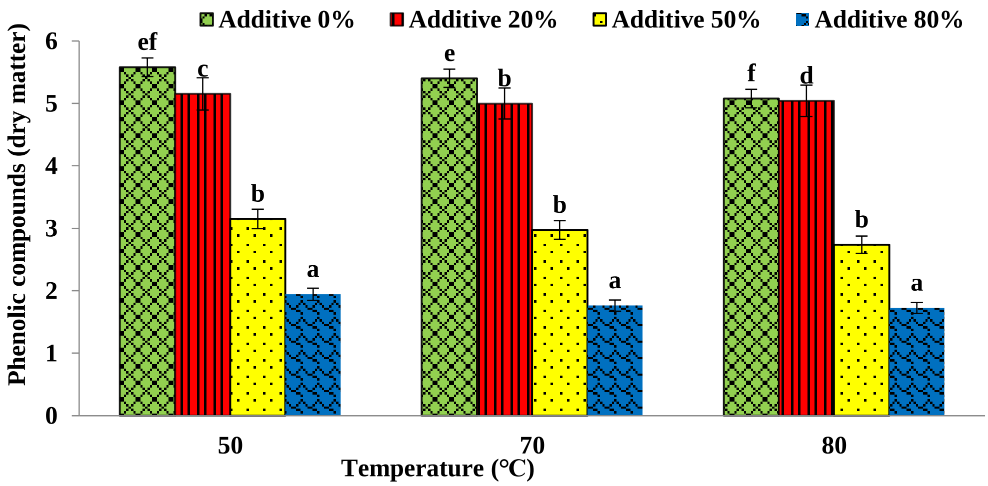

Figure 9. a. The interaction effect of additives and temperature on the amount of phenolic compounds of pellets produced from pistachio green shell in animal feed

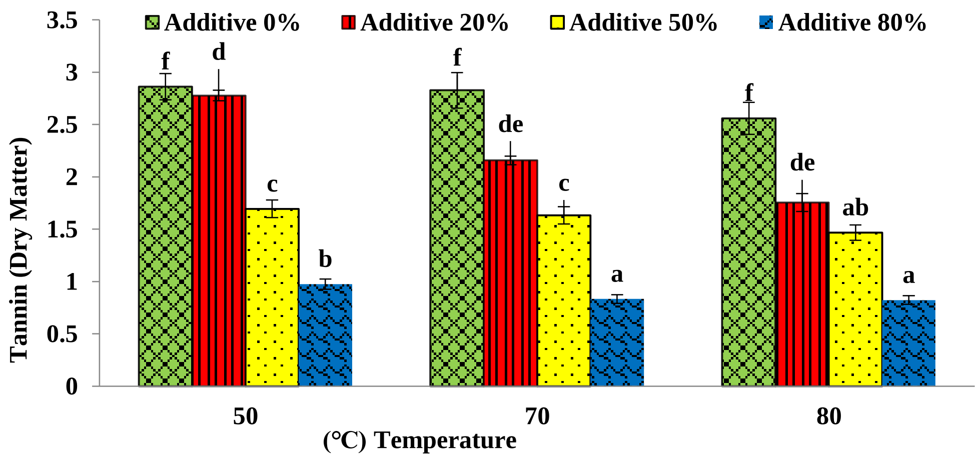

Figure 9. b. The interaction effect of additives and temperature on the amount of tannin in pellets produced from pistachio green shell in animal feed

The mutual influence of additives, temperature and particle size on the durability of pellets

Based on the results of comparing the averages, the effect of temperature variables, particle size and additives on the durability of pellets produced from green pistachio shell waste has been examined (Figure 10). The maximum durability of the pellets was treated with a temperature of 80 degrees Celsius, particle size of 0.5 mm and additives of 50 and 20%. The lowest durability of the pellets was treated with a temperature of 70 degrees Celsius, a particle size of 1 mm and 0%

additives. These results show that the mutual effect of temperature, particle size and additives on the durability of pellets produced in this study was significant. In general, using a temperature of 80 degrees Celsius has had a positive effect on the durability of the produced pellets. Probably, increasing the temperature to 80 degrees Celsius in combination with smaller particle size (0.5 mm) and additives (20-50%), has improved the mechanical properties and increased the durability of the pellets. This improvement may be due to structural and physical changes in the material under the influence of high temperature, smaller particle size and the addition of suitable additives. These changes can lead to an increase in the adhesion and strength of the particles and as a result improve the durability of the pellets. Therefore, optimization of temperature, particle size and additives can be effective in improving the durability and mechanical properties of pellets produced from pistachio green shell waste with different levels.

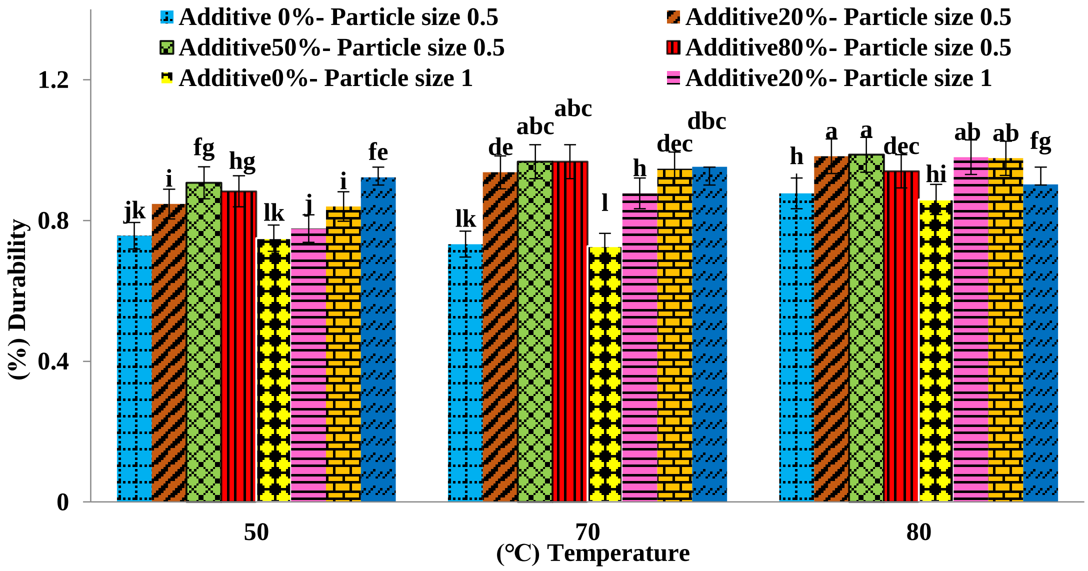

Figure 10. The interaction effect of temperature, additives and particle size on the durability of pellets produced from pistachio green shell in animal feed

Using heat to process raw materials changes the composition and access to nutrients and other compounds in these materials (Valle et al., 1994). In this process, gelatinized starch and proteins are deformed and anti-nutrients are lost. Extruder cooking is one of the effective processing methods that change the structure of starch, protein and improve its digestion by enzymes (Holm & Björck, 1988). These results were consistent with the present results. In the present study, the highest reduction in the amount of phenolic compounds and tannins in the pellets produced from pistachio green shell waste in the temperature treatment of 80 degrees Celsius and 80% additives was 79 and 81% compared to the unprocessed pistachio green shell. The decrease in the amount of phenolic and tannin compounds due to additives, temperature and extruder is consistent with the results of some past experiments (Laei, Haji Agha Alizadeh, et al., 2023a, 2023b; Laei, Hajiagha Aliazdeh, et al., 2023). Also, in the treatment with a temperature of 80 degrees Celsius and without the addition of additives (0%), the phenolic and tannin compounds were reduced by 42 and 43% compared to the unprocessed pistachio green shell (not pelleted). This may be due to the presence of the extruder, temperature and additives, which are effective factors in the degradation of phenolic and tannin compounds in the optimized device. Due to gelatinization of starch, destruction of heat-sensitive ant nutrients, degradation of cell walls and (or) improvement of nutrient availability can be attributed (Silversides & Bedford, 1999). In a similar report, drying of Calliandra forage leaves by high heat reduced free condensed tannin by 21% (Perez-Maldonado & Norton, 1996). These results are consistent with the findings of the tannin content of the produced pellets in the current research result.

CONCLUSIONS

These results show the high accuracy of the tests and confirm that the use of a pellet machine to produce pellets from green pistachio shells with different levels in animal feed can improve the mechanical properties of the pellets. Also, reducing the negative effects of anti-nutritional substances makes this process an economical and suitable solution for animal feed production. In addition, this method helps to reduce pistachio green shell waste and avoid environmental hazards. The results of this research showed that the variables of particle size, temperature and additives significantly affect the mechanical properties and anti-nutritional compounds of the pellets produced from pistachio green shell waste. Optimizing these parameters can lead to the production of higher quality pellets and the reduction of harmful substances in animal feed. Specifically, reducing the particle size to 0.5 mm, increasing the temperature to 80 °C, and adding 20-50% additives significantly increased the fracture energy, maximum fracture force, and toughness of the pellets. Also, these changes led to the reduction of phenolic and tannin compounds in the pellets, which improves the quality of animal feed. In general, the results of this research show that by using appropriate technical knowledge and optimizing the key parameters of the process, it is possible to turn green pistachio shell waste into a product of good quality and superior mechanical properties. In addition to increasing the added value of this waste, this achievement will also help reduce transportation costs and prevent its wastage during livestock feeding and reduce environmental pollution caused by improper disposal

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