Post-Harvest Pistachio Waste: Methods of Its Reduction and Conversion

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Abstract

Introduction: Since some of the pistachio wastes are left in the environment, their collection and use in producing byproducts, in addition to creating added-value, reduces environmental contamination.

Materials and Methods: In this article, 38 references extracted from Scopus, Web of Science, and final reports of the Pistachio Research Center were reviewed.

Results: The waste to dry pistachio crop ratio is within 1.25 to 2 ranges. The waste components are 64.5% of hulls, 25% of clusters, 10% of leaves, and 0.5% of kernels and shells. The hull extract considered as antioxidant and antimicrobial is applied in processing industries (e.g., jam and marmalade), dyeing, animal feed, edible mushroom culture media, as well as producing lactic acid, furfural, and tannin. The shell has the potential of generating activated carbon, tar, and cellulose nanocrystals. The small nuts are used in producing pistachio milk and oil.

Conclusion: Producing jam, pickle, and milk from peels and kernels, extracting oil from kernels, as well as processing its waste as the edible mushroom production culture substrate and animal feed are some solutions for converting the pistachio waste to value-added materials.

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1. Introduction

Food Loss and Waste (FLW) affects both nutrition and food security, as well as the stability of food systems. Food loss is related to the weight loss of foodstuffs throughout their supply chain for human consumption, being manifested during production, after harvest, and in the process steps. Food loss that occurs at the end of the chain is called food waste, related to the behavior of consumers and retailers [1].

Food loss represents the waste of resources, such as water, land, energy, and inputs, used in production. Production of food not consumed, in addition to losing its economic value, leads to unnecessary CO2 emissions. The inevitable loss of food has a negative effect on the farmer and consumer income [2].

Waste of agricultural products should be considered the cost of missed opportunities for food security. Therefore, to compensate for the cost and make the best use of the opportunity, it is necessary to reduce waste and turn it into valuable materials. Sometimes waste may be more valuable than raw materials; however, in most cases, their importance is not clear because of not being used or optimized [3].

Pistachio is one of the most popular tree nuts in the world. The natural waste of hulling is perishable, i.e., after a few days, they turn to black mold rot, leading to the swamp of insects thereabouts. This phenomenon causes widespread environmental contamination. Moreover, they provide a proper breeding ground for Aspergillus fungus, which not only makes it difficult to challenge the spread of aflatoxin poisoning but also assists its development. Unfortunately, some gardeners apply these substances as green fertilizer and introduce aflatoxins to the garden. Aspergillus fungal spores are easily spread by the wind; consequently, their accumulation around pistachio orchards or terminals can have the same effect as their introduction into gardens. Moreover, the cost of removing these materials from the terminals should be considered [4].

Given the above, the study of wastes and strategies to reduce them is of particular importance. Due to the importance of the pistachio tree in food, medicine, and industry, humans have long used its fruit, skin, leaves, stems, roots, and gums. The amount of pistachio waste is inversely related to the gardener experience and the area under cultivation. Most damage occurs in the garden due to climatic factors and pistachio pests, increasing post-harvest waste. Further, some wastes are caused by traditional processing devices and as a result, the pistachio skin is broken. Of course, other

factors, such as frost, heat, storage condition, dehydration, and crop type, are also effective in breaking the pistachio skin, thus resulting in waste. Studies show that 27.7% and 24.7% of the wastes are caused by climate change and various pests, respectively [5].

In this article, pistachio processing wastes are discussed, and the necessary solutions to reduce or convert them into more valuable products are presented.

2. Materials and Methods

In this article, 38 related references extracted from Scopus, Web of Science, and final reports of the Pistachio Research Center were reviewed, and the results were classified. The keywords of the search were pistachio waste, pistachio hull, pistachio shell, pistachio kernel, biogas, biomass, compost, jam, pickle, vegetable milk, oil extraction, edible mushroom culture substrate, and animal feed.

2.1- Pistachio hull waste

The natural waste of pistachio hulling is perishable, i.e., after a few days, they turn to black mold rot, leading to the swamp of insects thereabouts. This phenomenon causes widespread environmental contamination. Moreover, they provide suitable conditions for Aspergillus fungus growth, which not only makes it difficult to challenge the spread of aflatoxin poisoning but also assists its development. Aspergillus fungal spores are easily spread by the wind; consequently, their accumulation around pistachio orchards or processing factories can have the same effect as their introduction into gardens [6]. Moreover, the cost of removing these materials from the processing units should be considered.

The waste to dry pistachio nut ratio is 1.25- 2. The pistachio waste components are 64.5% of hulls, 25% of clusters, 10% of leaves, and 0.5% of kernels and shells (Fig. 1) [4]. The percentage of these components differs from each other in different conditions.

2.2- Use of pistachio hull

The percentage of nutrients in the pistachio green hull is tabulated in Table 1. In the following, some applications of the pistachio hull will be discussed.

Fig.1- Pistachio waste components

Table 1- Percentage of nutrients in pistachio green hull

Nutrient type	Percentage
Protein	11
Fiber	15
Ash	12
Dry matter	23
Nitrogen-free extract	55.5
Fat	6

2.2.1- Antioxidant, antibacterial, and anti-inflammatory source

The pistachio hull is known as a source of natural antioxidants consumed in herbal medicine. The existing synthetic antioxidants (synthesizers), such as BHA, BHT, TBHQ, and gallate esters, are being deleted from the antioxidants list due to adverse effects, including mutation and cancer in the human body. Therefore, the preparation and production of natural antioxidants as a substitute is essential. Pistachio green hull, as one of such antioxidants, is consumed since it contains phenolic compounds. Methods, including Soxhlet, ultrasonic, and supercritical fluids, are applied to extract these phenolic compounds. Soxhlet and ultrasonic have higher extraction efficiency, i.e., about 35 mg of phenolic/g of the sample's dry weight. Different concentrations of phenolic compounds in pistachio hull can slow down the oxidation process well [7].

Eleven phenolic compounds, including gallic acid, protocatechuic acid, catechin, epicatechin, rutin, eriodictyol 7-O-glucoside, naringin, luteolin, quercetin, and naringenin, are identified in pistachio hull. The concentration of phenolic and polyphenolic compounds in the hull is reported as 9482 and 31.4 mg/kg, respectively. The gallic acid, catechins, rutin, and eriodictyol 7-O-glucoside are the dominant phenolic compounds in this hull. The 7-glucoside erriodictiol is the most important compound with antioxidant at 1326.2 mg/kg [8, 9].

Barreca et al. (2016) extracted the pistachio hulls with methanol and ethanol solvents and characterized them by phenolic composition, antioxidant power, and cytoprotective activity. They identified 20 derivatives. The highest yields were observed by methanol extraction for all compounds, showing a higher scavenging activity. They also found the strong antioxidant and cytoprotective activity of the two extract components [10].

The effect of aqueous and solvent extracts (hexane, ethyl acetate, acetone, and methanol) of pistachio peel (3-5%) on aflatoxin is assessed, indicating a reduction in its production. The antimicrobial and antimutagenicity activity of aqueous extract of pistachio hull has been proven by Rajaei *et al.* [11].

According to Abolhasani *et al.* [12], pistachio green hull extract may be recommended as an antibrowning agent in foods or cosmetic products due to its antityrosinase potential.

2.2.2- Jam, marmalade, and pickle production

The soft hull is the major waste of pistachio processing, averagely estimated to be 60% of the production. The fresh and non-damaged hand-picked pistachio hulls (Fig. 2) are industrially processed in making jam, marmalade, and pickle [13].

Fig.2- Dried pistachio hull

2.2.3- Natural dyeing

Natural colorants are environment-friendly and safer; thus, their application should be considered a better substitute for synthetic dyes. Some researchers indicate that the pistachio hull dye can be used in commercial dyeings, such as wool yarns and carpet piles [14-16].

2.2.4- Animal feed

The byproduct of pistachio peeling consists of the soft outer hull, clusters, leaves, as well as freshly harvested pistachio kernels and bony shells to a lesser extent, with an average of 32.64% dry matter [4]. Pistachio nuts are harvested every year for a relatively short period (about two months). The high humidity rate and the high volume of such residues, especially in large processing centers, make them spoiled and useless rapidly. Any attempt to reuse these residues as animal feed requires proper scientific and practical storage methods. The physicochemical properties and a good proportion of dry matter allow pistachio byproducts to be stored in siloes. Though the residues are proportionally rich, their ability of carbohydrate formation in an anaerobic state is not determined yet; therefore, molasses are consumed as an additive in silage [17].

Pistachio green hull can be consumed as feed livestock; however, the presence of different tannin components makes it difficult to be used. Therefore, this tannin should be reduced through soaking and cooking to reach where the dry matter is free of it within about 20% to 70%. Adding polyethylene glycol to this product improves digestion. Dried pistachio peel is recommended at 10% in the diet of ruminants [4, 18].

SoltaniNezhad *et al.* [19] have reported that feeding 21% pistachio byproducts silage with the wasted date to the lambs increases their lean meat yield. Shakeri *et al.* [20] indicate that partial substitution of corn silage with pistachio byproducts silage (6% or 12%) has no adverse effects on total chewing activity, nutrient digestibility, and ruminal fermentation parameters.

2.2.5- Biogas production

Biogas is produced from different plant materials, such as maize, grass silage, and green waste. Anaerobic digestion is used for agricultural wastes management [21]. Pistachio waste anaerobic digestion and biogas production are both possible. The main barrier in this method is the low biodegradation rates during hydrolysis of cellulosic material. Different pre-treatment techniques, including enzymatic, thermal, mechanical, and chemical, increase the soluble organic content [21, 22]; a combination of these methods is used. Different temperatures and times are used for thermal pre-treatment of different materials. Celik and Demirer [21] state that the observed percentage of chemical oxygen demand (COD) removal of the pistachio waste is higher than the raw pistachio waste; the highest methane yield is 213.4 ml CH4/g COD.

2.2.6- Compost production

Composting is one of the economic and environmental approaches to treat and control organic waste from agriculture. Pistachio hull, a byproduct of pistachio processing, can be a source of environmental pollution [23]. Therefore, it is suggested to be treated by proper, sanitary, and economical methods. According to the measurements, the pistachio peel ratio, (peeled pistachio/ dried pistachio), is at least 1.25 and at most 2 times [24].

Incorporation of plant residues in soils is an important agricultural practice for maintaining its fertility under organic management systems. Plant residues quality, soil physical/chemical properties, and soil microbial population diversity, are key factors influencing the decomposition of added organic matter to soils. The decomposition rate of pistachio hull compost is higher than municipal waste compost of vermicompost and manure. There is a positive correlation between the rate of organic matter decomposition and the K value. The results also show that a high decomposition rate based on the K value belongs to pistachio hull compost, manure, municipal waste compost, and vermicompost, respectively [25].

2.3. Use of pistachio shell

2.3.1- Tar production

In pyrolysis of the hard shell, decomposition begins at above 100°C; for intense decomposition, this temperature can reach 250°C, and for industrial application, it rises to 500°C. Above

270°C, decomposition does not need a specific heat source since the process generates heat. Tar is the most important and valuable yield of this pyrolysis. On average, about 15-20 ml of tar is yielded from every 100 g of dry pistachio shells. It is a viscous liquid with an unpleasant odor containing different chemical compounds. Tar content in pistachio shells is more expensive than that in woods due to its high nutritional value to economic value. Tar is obtained from the coke of hard pistachio shell and consumed in the pharmaceutical industry for the anti-flatulence purpose. It contains the hydroxyanthraquinone ingredient, consumed in oral medicine to control bacteria and fungi growth in the mouth. Since the structure of hydroxyquinones contains phenolic compounds yielded through pyrolysis, pistachio waste can be a proper source of some drugs, antiseptics in specific [4, 26].

2.3.2-- Activated carbon production

What remains after pyrolysis is a type of charcoal, ready to be formed as activated carbon, with a valuable small porous carbon adsorbent. This substance is yielded from the precipitation of plant materials containing carbon and is applied in the activation process. Many toxic gases can be separated from the air when passed through activated carbon; for example, carbon monoxide is one of them separated from the air by injecting chemicals, such as silver, copper, and chromium salts, into the activated carbon. In general, activated carbon is consumed as a filter for dyeing and removing smell in the oil refinement and beverage industry [26-28].

2.3.3-- Cellulose nanocrystals

Kasiri and Fathi [29] have produced cellulose nanocrystals from pistachio shells. They show a high potential of cellulose nanocrystals as an environmentally friendly material to prepare food emulsions.

2.3.4- Dye biosorption

Deniz and Kepekci [30] investigate the possibility of using pistachio shells for removing a reactive-azo dye from water. They suggest that the pistachio shell can be low-cost and effective in removing unsafe dyes from the water.

2.4. Use of pistachio kernel

2.4.1- Extraction of oil from pistachio kernel waste

Very small and non-marketable pistachios are considered waste. Pistachio kernels contain about 50-62% oil; thus, their oil extraction capacity is about 50% [31]. This oil is consumed in medicinal and hygienic products with of high price worldwide. It contributes to developing the brain and nervous system, strengthening the heart and stomach, intelligence, and memory, as well as treating bone pain, anemia, wound, and post-surgery issues [32]. The meal (a byproduct of oil

extracting processes) is rich in protein, and if prepared well, at below 50ºC during the pressing process, is suitable for livestock and poultry feed [33].

2.4.2- Production of pistachio milk

Today, all over the world, consumers are more inclined to consume vegetable milk, one of which is pistachio milk obtained from pistachio kernel extract. Very small pistachios considered waste after the peeling process can be turned into milk. Shakerardekani *et al.* [34] describe a process for preparing pistachio milk from unsplit and small-sized pistachios, not proper for direct human consumption. Pistachio milk can be served as a replacement for cow milk.

2.5. Other uses

2.5.1- Substrate for edible mushroom production

The pistachio green skin may be used as a substrate in preparing edible mushrooms. Culture media produced with a mixture of hard and soft pistachio skins (25% to 75%) have a higher yield of 1% to 5% than the sample without pistachio waste. Since pistachio soft skin is more abundant than other its waste, the best combination of waste used is to add hard and soft pistachio skin up to 50% to the compost. This substrate is higher in terms of quality characteristics, such as protein and phenol; it is also suitable for samples without pistachio wastes [35, 36].

2.5.2- Lactic acid production

Lactic acid is natural and organic, produced through the chemical or fermentation processes. Its chemical process consists of sugar decomposition, propylene glycol oxidation, aldehyde acid reaction with carbon monoxide and water at high temperatures subjected to pressurized, propionic acid hydrolysis, and propylene nitric acid oxidation processes; however, none are scientific to be economically and technically practical [37]. The biological fermentation process is highly contributive to waste disposal.

Food processing wastes, including that of soft pistachio skin, usually contain beneficial substances to produce lactic acid. The amount of lactic acid production, depending on the molasses amount used with the pistachio's soft skin (1 to 5%), varies between 23% to 37%. Compared to the chemical process, the biotechnological production of lactic acid requires low-cost materials, low temperature, and low energy [38].

Generally, using agricultural waste by recycling is the strategy of returning capital to the agricultural sector. One of the agricultural wastes is pistachio waste after crop processing, being used differently; its main component is the hull. The green hull extract is considered as an antioxidant and antimicrobial applied in processing industries, textile, animal feed, edible mushroom culture media, and production of lactic acid, furfural, and

tannin. With a well-written plan and an appropriate mechanism for planning, access to the related technology would allow dealing with pistachio waste; if not, in most cases, it would lead to acute information problems.

3. Conclusion

Converting the pistachio waste into valuable products would contribute to the agriculture industry. To reduce environmental contamination, the moisture in pistachio waste must be reduced by drying and pressing them. Producing jam, pickle, and milk from peels and kernels, extracting oil from kernels, as well as processing its waste as the edible mushroom production culture substrate and animal feed are some solutions for converting the pistachio waste to value-added materials.

Conflict of Interest

The authors declare no conflict of interest.

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