ENERGY AND COST EVALUATION OF FOUR CONVENTIONAL PISTACHIO DRYERS

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ABSTRACT

Drying, as a process, demands significant input energy because of the high latent heat needed for water evaporation and the relatively low efficiency of available industrial hot air dryers. Energy consumption in Iranian agriculture exceeds international norms for crop production, surpassing even the calculated estimates for worst-case scenarios. One of the most critical challenges in the production of dried foods is the reduction of energy resource costs for producing high-quality dry products. This study aims to compare four conventional pistachio dryers in Iran: Diesel-fueled Carriage Dryer, Gas-fueled Carriage Dryer, Gas-fueled Wagon Dryer and Diesel-fueled Wagon Dryer, in terms of energy consumption, energy efficiency and economic factors. The findings indicate that: The fuel consumption volume per unit weight of evaporated water in wagon dryers is approximately 50% less than that in carriage dryers. Gas-fueled wagon dryers have lower overall costs compared to other dryers. Gas-fueled wagon dryers exhibit higher energy efficiency (around 15%) than other dryers.

1 INTRODUCTION

Pistachio (*Pistacia vera L.*) is a nut crop of great nutritional value with considerable economic and commercial importance in various countries, such as Iran, Turkey and America (Dowlati *et al*., 2023). Pistachios are recognized as one of the most popular nuts in the world. Recent statistics show that the United States accounts for 67% (406,646 tons), Iran for 17% (103,179 tons), and Turkey for 11% (66,763 tons) of total pistachio production, making them the leading pistachio producers (Morshedi *et al*., 2023). It is important to reduce the initial moisture content from about 40-50% (d.b.) at harvest to between 4-6% (d.b.) by drying processes carried out in processing units. Hence, this is necessary to ensure the preservation of the nuts for long periods of storage and consumption (Dowlati *et al*., 2023). In practical terms, the energy demand for drying food grains encompasses two key aspects: firstly, the energy needed to vaporize the water content, and secondly, the energy necessary for eliminating the water content linked with the raw material (Delgado-Plaza et al., 2020). Drying generally accounts for approximately ten percent of the overall energy consumption in the food industry (Smith, 2007). Drying necessitates a substantial amount of input energy because of the great latent heat of evaporation of water and the relatively low efficiency of existing industrial hot air dryers to enhance the quality of crops (Aghbashlo *et al.,* 2009; Golpour *et al.,* 2021). The drying stage of pistachios consumes more energy compared to other processing stages, and it is the most energy-intensive step in all pistachio processing facilities, accounting for over 80 percent of the total energy consumption. Because of the low thermal conductivity of pistachios (0.1-0.2 $W.m^{-1}°C^{-1}$), heat transfer to the interior of the pistachio kernel occurs very slowly. Consequently, pistachio kernels demand more drying energy compared to perishable fruits and vegetables (Mokhtarian, et al., 2016). Anyway, energy is a quantitative measure identified as the amount of external work performed by a system. Furthermore, one of the most crucial challenges in the production of dried fruits, including pistachios, is the reduction of energy costs for producing high-quality dried products (Mokhtarian et al., 2021). Refining the selection process and employing effective drying techniques significantly influence the ultimate quality of the product. Numerous studies have

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been done on the energy evaluation of several types of dryers, including an examination of the energy assessment of a hybrid fluidized bed-infrared dryer for Terebinth (Golpour *et al*., 2022), an analysis of moisture diffusivity and specific energy consumption in the drying of potato, cantaloupe and garlic using a convective hot air dryer (Kave *et al*., 2018), and an investigation into effective moisture diffusivity, specific energy consumption (SEC), and shrinkage during microwave-convective drying of quince (Taghinezhad *et al.,* 2022). Carrera-Escobedo et al. (2020) carried out a cost assessment of the drying process by examining its kinetic factors. Their study focused on determining the drying kinetics of two varieties of Mexican Capsicum annuum (Puya and Mulato) and modeling these parameters at various temperatures with two distinct levels of ventilation. As anticipated, increased ventilation increased the drying rate, shortened the drying time, and subsequently lowered the cost of the drying process. In another study, Motevali et al. (2017) conducted a comparison of energy parameter metrics among different drying systems. The study aimed to investigate the energy output, drying efficiency, thermal output, and specific energy for different methods of drying process used on chamomile. The assessment revealed that the vacuum drying method had the highest specific energy requirement at 318.42 MJ/kg, while the microwave drying method had the lowest at 4.32 MJ/kg.

Based on our knowledge, there are insufficient studies in the literature that extensively explore the comparison of prevalent types of conventional industrial dryers for pistachio drying to examine energy parameters and associated costs. Hence, according to the existing gap research in this section, this study aimed to assess and introduce the most suitable pistachio dryer among four common types of dryers in Kerman province, considering two types of round pistachios and elongated pistachios. The four types of pistachio dryers included a diesel-fueled carriage dryer, a gas-fueled carriage dryer, a gas-fueled wagon dryer, a diesel-fueled wagon dryer, and a control treatment (sun or solar drying). In this study, the comparison criteria encompassed the uniformity of drying, fuel consumption, energy efficiency, and economic factors.

2 MATERIALS AND METHODS

2.1 Types of used dryers

Four types of pistachio dryers (based on the type of fuel and the structural model of the device, commonly known in the Kerman province, Iran) were selected and examined due to their higher production and prevalence in the region, as follows:

Diesel-fueled Carriage Dryer: This type of dryer features a fan, a diesel burner, a furnace, and a large wagon with a capacity of seven tons. The reservoir bottom is made of a meshed plate and is connected to the furnace by a canvas or a metal intermediary. Hot air at 60°C is directed into the pistachio mass through the channels and the openings of the meshed plate inside the reservoir, with a thickness of 40 cm. This two-stage dryer allows pistachios to enter with a moisture content of 31.4% and exit with a moisture content of 12.2%, reducing moisture from 12.2% to 6% by spreading them in a smooth mosaic field and exposing them to sunlight as depicted in Figure 1.

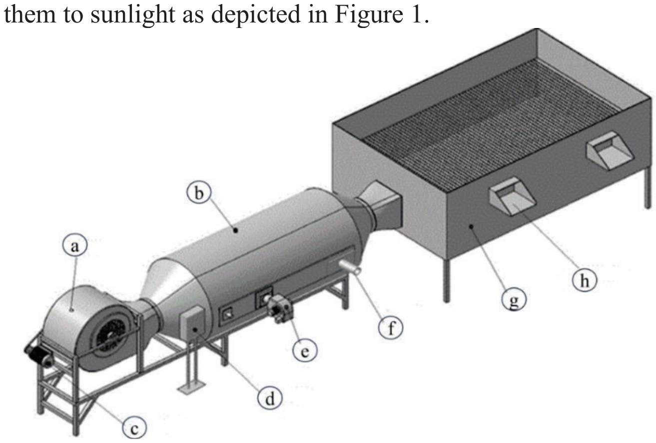

Figure 1: Schematic view of the designed diesel-fueled carriage dryer: (a) fan, (b) furnace, (c) electromotor, (d) electrical panel, (e) diesel burner, (f) exhaust, (g) wagon, (h) outlet path

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Gas-fueled Carriage Dryer: Different components of this type of dryer resemble the diesel-powered carriage dryer, with the distinction of having a reservoir capacity of five tons, spanning dimensions of 11.5 by 11 meters, a gas burner, silo, conveyor, and an additional fan. Hot air at 75°C is directed into the seven-centimeter-thick pistachio mass. It is a single-stage dryer, allowing pistachios to enter with a moisture content of 37.8% and exit with a moisture content of 5% (see Figure 2). After the moisture content of the pistachios is declined, the burner is turned off and the air with the ambient temperature is blown into the pistachios to reduce the temperature of the product. During drying, the product is moved and covered with an electric stirrer for uniform drying. Afterward, the pistachios transition straight from the drying phase to either storage, grading, or packaging.

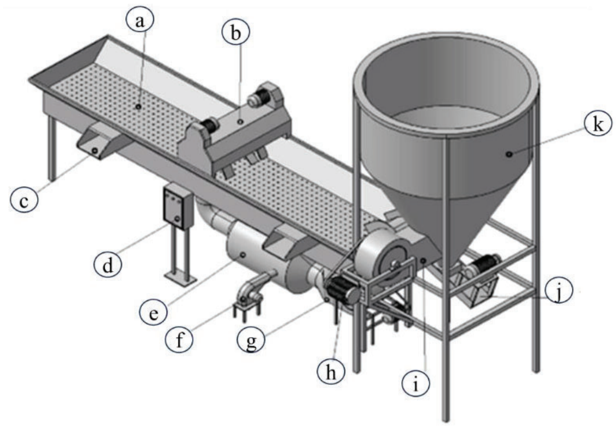

Figure 2: Schematic view of the designed gas-fueled carriage dryer: (a) reservoir, (b) mixer, (c) outlet path, (d) electrical panel, (e) furnace, (f) gas burner, (g) fan, (h) electromotor, (i) main fan, (j) conveyor and (k) silo

Gas-fueled Wagon Dryer: This wagon dryer comprises a fan, a gas burner, a furnace, channels, and wagons similar to trolleys. The wagon bottoms are made of a meshed plate, placed over a variable-depth chamber. Wagons are connected to the channels by canvas or a metal intermediary. Hot air at 80°C is directed into the 25-centimeter-thick pistachio mass through the channels and openings of the meshed plate inside the reservoir as shown in Figure 3. The capacity of the wagons is 250 kg and the number of wagons is three. This type of dryer is a two-stage dryer, that is, pistachios enter with a moisture content of 43.5% and leave the dryer with a moisture content of 21.5%. They are exposed to the sun in a wide single layer on a mosaic field, and after approximately one day (depending on the moisture content that was removed from the dryer), the moisture content of the pistachio will decrease to five percent and at the same time its temperature will also decrease. Next, the product is gathered from the field and proceeds to either storage, grading, or packaging.

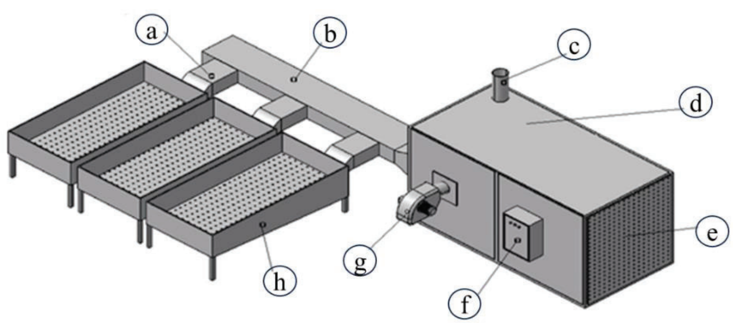

Figure 3: Schematic view of the designed gas-fueled wagon dryer: (a) sub channel, (b) main channel, (c) exhaust, (d) furnace, (e) fan, (f) electrical panel, (g) burner and (h) wagon

Diesel-fueled Wagon Dryer: Similar to the gas-powered wagon dryer, this diesel-powered version directs hot air at 90°C into the 20-centimeter-thick pistachio mass. There are a total of eight wagons. It

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is a two-stage dryer, allowing pistachios to enter with a moisture content of 31.5% and exit with an approximate moisture content of 20.5% (see Figure 4).

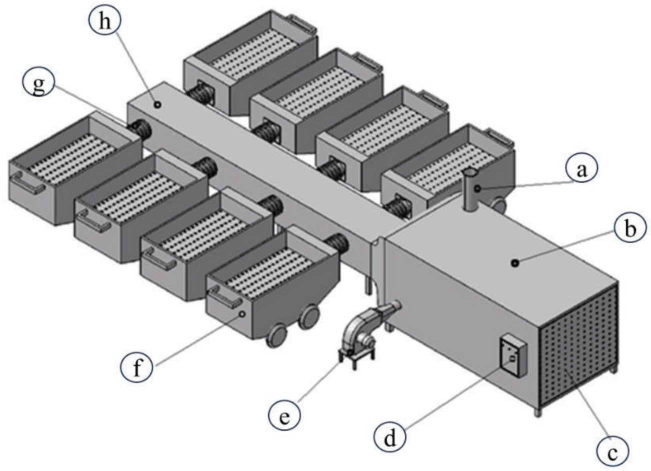

Figure 4: Schematic view of the designed diesel-fueled wagon dryer: (a) exhaust, (b) furnace, (c) fan, (d) electrical panel, (e) burner, (f) wagon, (g) sub-channel, and (h) main channel

In the control treatment process as shown in Figure 5, the sun drying method was applied so that pistachios were laid in a single layer in a smooth mosaic field, and exposed to direct sunlight. Typically, the drying duration is contingent upon sunlight and local temperature conditions, averaging approximately three days. Throughout this timeframe, it is advisable to periodically invert the pistachios to ensure uniform coloration of the shells.

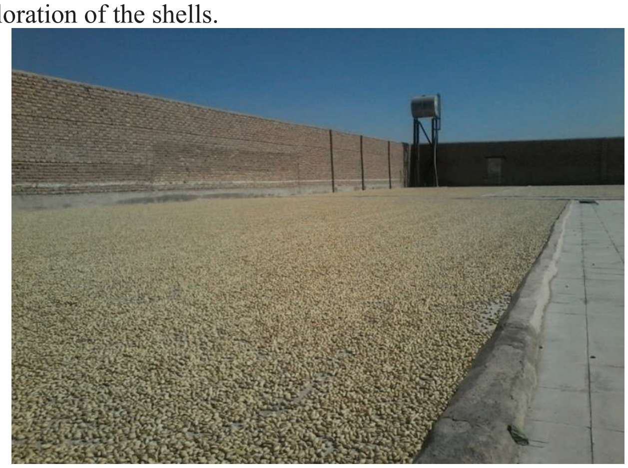

Figure 5: Control treatment process by using the sun drying method

2.2 Determining the fuel consumption volume per weight of evaporated water

2.2.1 Diesel fuel consumption volume

Utilizing a small graduated reservoir designated for the burner, the diesel fuel consumption volume was obtained.

2.2.2 Gas consumption volume

Since the gas meter was shared among the dryer and other consumers, using the meter readings directly was not feasible. So, equation (1) was employed to determine the gas consumption weight:

$$\dot{Q}_1 = \dot{Q}_2 \quad (1)$$

In this equation, $\dot{Q}_1$ represents the heat power (rate of heat transfer) of hot air (W), and $\dot{Q}_2$ is the chemical power of fuel.

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It should be noted that this study did not account for gas losses and instead calculated gas consumption based on pertinent gas consumption equations.

The heat power (heat flow rate) of hot air ($\dot{Q}_1$) was calculated utilizing the subsequent equation:

$$\dot{Q}_1 = \dot{m} c_p \Delta T \quad (2)$$

where $\dot{m}$ denotes the mass flow rate of hot air in kg/s, c_p is the specific heat capacity of the air at constant pressure in kJ/kg.K, and ΔT is the temperature change in Kelvin.

$\dot{m}$ was calculated by applying the equation shown below:

$$\dot{m} = \rho \dot{V} = \rho v A \quad (3)$$

Where $\dot{V}$ is volume flow rate, v is the velocity of hot air in m/s, ρ is the density of air in kg/m^3, and A is the cross-sectional area of the hot air inlet to the dryer in m^2.

Air density (ρ) was obtained as follows:

$$\rho = (MP)/(RT) \quad (4)$$

where M represents the molar mass of air measured in kg/mol, P stands for the air pressure in Pa, R denotes the specific gas constant 8.314 for dry air in kJ/kmol·K, and T signifies the air temperature measured in Kelvin.

The heat flow of fuel ($\dot{Q}_2$) was also computed according to equation (5):

$$\dot{Q}_2 = (\dot{m}_F) HV \quad (5)$$

where $\dot{m}_F$ is fuel consumption in kg/s and HV is the lower heating value of the fuel in kJ/kg.

Using the above equations, the fuel consumption in kg/s was determined, and considering the total time of the drying process, the overall fuel consumption was subsequently obtained.

2.2.3 Weight of evaporated water

By assessing the moisture content on a dry basis (d.b.) of both incoming (m_{di}) and outgoing (m_{do}) pistachios to the dryer, the amount of evaporated water was calculated using equations (6-11). The initial moisture content of pistachios (MC_{W1}) on a wet basis was obtained as:

$$MC_{W1} = (100\ m_{di}) / (100 + m_{di}) \quad (6)$$

The final moisture content of pistachios (MC_{W2}) on a wet basis was determined as below:

$$MC_{W2} = (100\ m_{do}) / (100 + m_{do}) \quad (7)$$

Also, equation (8) can be applied to calculate the total water content (W_a) in the product as follows:

$$W_a = m^* MC_{W1} \quad (8)$$

where m is the weight of pistachios entering the dryer.

The weight of dry matter (m_{di}) was computed using the following equation:

$$m_{di} = m - W_a \quad (9)$$

Also, the weight of the product (m_{do}) at the final moisture content was found as follows:

$$m_{do} = (100\ m_{di}) / (100 - MC_{W2}) \quad (10)$$

Finally, the amount of evaporated water (m_a) during the drying process in kg was obtained as follows:

$$m_a = m - m_{do} \quad (11)$$

Therefore, by considering the total fuel consumption (in kilograms for gas and liters for diesel, respectively) alongside the weight of evaporated water (kg), it becomes feasible to calculate the amount of gas weight or diesel volume required to evaporate one kilogram of water.

2.3 Energy efficiency and energy consumption (EC) for pistachio drying

The energy efficiency was computed by applying equation (12) (Jahanbakhshi et al., 2020).

Energy efficiency = (Latent heat of evaporation×the amount of evaporated water in drying process)/(fuel energy+electricity energy+labor energy) (12)

The energy consumed for pistachio drying could be determined according to equation (13) (Jahanbakhshi *et al*., 2020).

$$E_d = E_e\ m_a \quad (13)$$

E_d represents the energy consumed (kJ), m_a stands for the quantity of water evaporated during the drying procedure (kg), and E_e denotes the constant latent heat of evaporation. E_e assumes fixed values of 2358.5, 2321.4, 2308.8, and 2283.2 (kJ/kg) corresponding to drying air temperatures of 60, 75, 80, and 90°C, respectively (Borgnakke, and Sonntag, 2020). The weight of evaporated water (kg) during the process was calculated using the equations (6-11).

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2.4 Thermal energy, electricity energy and human work

Thermal energy for diesel was calculated using the equation (14) (Behroozi Lar *et al*., 2012).

$$E_h = Q_F \times E_F \times t \tag{14}$$

where E_h is thermal energy (kJ), Q_F is diesel fuel consumption (L/s), E_F is the lower heating value (kJ/L), and t is the duration of the process (s). In addition, the heat value of diesel is 40240 (kJ/L) (Izadkhah Shishvan, 2010).

The thermal energy of gas was also computed based on equation (14), considering the respective units so that E_h is thermal energy (kJ), E_F is heat value (kJ/kg), and t is the duration of the process (s). Additionally, a heat value of 44661 (kJ/kg) is considered for gas (Kent *et al*., 2013).

Electric power was obtained in accordance with the following equation (Hepbasli *et al*., 2010):

$$W = \frac{VI\sqrt{3}\cos\varphi}{1000}\eta_{mech}\eta_{elec} \tag{15}$$

so that the energy (E) was obtained as $E = W \times t$.

In this equation, W represents electricity power measured in kW, V denotes voltage in volts (V), I stands for current intensity in amperes (A), t signifies the duration of the process in seconds (s), cosφ represents the motor power factor, E denotes energy measured in kJ, and η represents the efficiency of the motor. Furthermore, subscripts *elec* and *mech* denote the electrical and mechanical aspects, respectively.

Human work (labor energy) was determined by applying equation (16), with the labor duration measured in seconds. The labor value was considered as 545 kJ/s (Zare Nazari Bayaz *et al*., 2013).

$$E_L = E_{LV} \times t \tag{16}$$

Here, E_L represents the human work measured (kJ), E_{LV} denotes the power value measured (kJ/s), and t signifies the duration of labor measured (s).

2.5 Uniformity of the final dried pistachios

The standard deviation provides a measure of the variation or dispersion of moisture content values around the mean. A lower standard deviation indicates more uniformity in the moisture content of the dried product**.** To assess the uniformity of the final dried product in a drying system based on moisture content and standard deviation, you would typically follow these steps (a) sample collection: collect multiple samples from different locations within the drying chamber or from different batches of the dried product, (b) moisture content measurement: measure the moisture content of each sample using a moisture analyzer or another appropriate method and (c) statistical analysis: calculate the mean moisture content of the samples and then calculate the standard deviation of the moisture content (Mujumdar, 2007).

2.6 Economic factor analysis

In this section, an examination of economic factors has been undertaken for a general comparison between the four types of dryers. In this study, the costs related to pistachio dryers are categorized into two main groups: fixed costs and variable costs. Fixed costs remain relatively stable regardless of the dryer's operational level throughout the year. These include depreciation, capital interest, shed rent, insurance, and taxes. Variable costs are expenses that directly correlate with the dryer's usage throughout the year, such as maintenance costs (preventive and incidental), oil and fuel, labor, and services.

2.6.1 Fixed Costs

Depreciation: It refers to the reduction in the economic value of a machine over time and is calculated linearly using equation 17 (Yousefi, 2013):

$$D = (P - S) / L \tag{17}$$

where D is the annual depreciation amount, P is the initial price of the machine, S is the salvage value of the machine (10% of the initial price), and L is the useful life of the machine.

Capital Interest: A portion of the annual interest is attributed to the capital spent on purchasing machinery and should be considered in cost calculations. Equation 18 is employed for this calculation (Yousefi, 2013).

$$I = ((P+S)\ 2) \times i \tag{18}$$

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where I is the annual capital interest, P is the annual depreciation amount, S is the salvage value of the machine (10% of the initial price), and i is the interest rate, set at 20% based on the central bank statistics at the time of the research.
Warehouse or terminal building for pistachio storage: The annual cost of the warehouse is considered based on the total square footage of each dryer and the warehouse's useful life while the assumed useful life of a warehouse is 20 years (Bahrouzi Lar, 2012).

2.6.2 Variable Costs

2.6.2.1 Maintenance Costs

Preventive Maintenance: In these scheduled maintenance activities, the components and equipment of the machine are inspected, and if any defect is observed, it is addressed.
Breakdown Maintenance: These repairs occur when a machine or part suddenly fails, and repairing it becomes essential. Typically, an average of 7% of the machine purchase price is considered for repair costs over the useful life of the machine (Yousefi, 2013).

2.6.2.2 Fuel Consumption Costs

Based on the diesel fuel consumption per hour and the weight of gas consumed per hour calculated using Equation 1, the cost of consumed fuel is determined using Equation 19.

Fuel consumption cost (IRR/year)=Fuel consumption cost (IRR/hour)×The number of working hours of the device (hour/day)×The duration of time the dryer remains operational (day/year) (19)

Finally, the total operating costs in a year were computed by applying Equation 20:

$$AC=D+I+P+R+F+L+E \quad (20)$$

Where C represents the total annual costs, D denotes depreciation, I signifies capital interest, P stands for shed cost, R represents repair cost, F denotes fuel cost, L stands for labor cost, and E represents electricity cost.

3 RESULTS AND DISCUSSION

3.1 Fuel consumption volume

The fuel consumption volume was investigated for dryers with similar fuel types concerning the weight of evaporated water. Table 1 presents the results of these parameters for the dryers under consideration.

Table 1: Results of Fuel Consumption Volume per Weight of Evaporated Water

Treatment	Evaporated water (kg)	Gas or diesel consumed (L or m³)	The volume of fuel consumed per weight of evaporated water $\frac{L}{kg}$ or $\frac{m^3}{kg}$
Diesel-fueled wagon dryer (round pistachio, two-stage)	86.94	15.23 (L)	0.175 ($\frac{L}{kg}$)
Diesel-fueled wagon dryer (elongated pistachio, two-stage)	84.45	15.92 (L)	0.188 ($\frac{L}{kg}$)
Gas-fueled carriage dryer (round pistachio, single-stage)	395.8	96.12 (m^3)	0.438 ($\frac{m^3}{kg}$)
Gas-fueled carriage dryer (elongated pistachio, single-stage)	394.32	97.41 (m^3)	0.437 ($\frac{m^3}{kg}$)
Gas-fueled wagon dryer (round pistachio, two-stage)	138.41	32.90 (m^3)	0.211 ($\frac{m^3}{kg}$)
Gas-fueled wagon dryer (elongated pistachio, two-stage)	139.38	32.54 (m^3)	0.218 ($\frac{m^3}{kg}$)
Diesel-fueled carriage dryer (round pistachio, single-stage)	1022.82	195.50 (L)	0.192 ($\frac{L}{kg}$)

Diesel-fueled carriage dryer (elongated pistachio, single-stage)	1021.36	196.23 (L)	0.192 ($\frac{L}{kg}$)

The results of fuel consumption volume concerning the evaporated water in dryers with similar fuel types indicate that the fuel consumption of single-stage dryers (carriage dryers) is approximately twice that of two-stage dryers (wagon dryers), which is in line with the findings of Rostami and Mirdamadiha (2013). This observation can be attributed to several factors: a) Initially, dryers are not optimal in terms of energy consumption. Additionally, they lack a furnace, hot air duct, and insulation chamber. Furthermore, the chamber of dryers remains uncovered, allowing hot air to escape into the environment after interacting with the product mass. Consequently, single-stage dryers, utilizing fuel for longer durations compared to two-stage dryers, lead to increased fuel consumption and subsequent wastage. (b) are effective in absorbing high humidity levels, whereas single-stage dryers are more efficient in absorbing low humidity. The absorption of high humidity requires less fuel compared to low humidity absorption. (c) In wagon dryers compared to carriage dryers, the fuel consumption per kilogram of evaporated water is lower, which is consistent with the results of Shaker Ardekani (2008) and Hedayat *et al*. (2015).

3.2 Energy efficiency

Energy efficiency is determined by the proportion of output energy to input energy, with a ratio approaching one indicating greater energy efficiency. Table 2 demonstrates the results of energy efficiency for the dryers. Based on the findings of this table, it is obvious that dryers using natural gas have higher energy efficiency compared to those using diesel, aligning with the findings of Joudzadeh *et al.* (2013). Additionally, gas-fueled wagon dryers have higher energy efficiency compared to gas-fueled Carriage dryers while two-stage dryers (wagon dryers) have higher energy efficiency compared to single-stage dryers (carriage dryers). Based on the results obtained, the highest proportion (99.80%) of fuel energy is attributed to the Gas-fueled wagon dryer (for both round and elongated pistachios), as well as the Diesel-fueled carriage dryers (for round pistachios). Conversely, the Gas-fueled carriage dryer (for round pistachios) exhibited the lowest proportion of fuel energy, with a value of 99.36%. The findings indicate that the highest labor energy values are associated with the Diesel-fueled carriage dryer for both round and elongated pistachios, each accounting for 0.02%. The lowest and highest proportions of electric energy were found to be 0.64% for the Gas-fueled carriage dryer (round pistachio) and 0.28% for both the Diesel-fueled carriage dryer (round pistachio) and the Diesel-fueled carriage dryer (elongated pistachio), respectively.

Table 2: Energy efficiency obtained for four conventional dryers

Treatment	**Fuel energy (kJ)**	**Labor energy (kJ)**	**Electric energy (kJ)**	**Evaporated water (kg)**	**Energy efficiency (%)**
Diesel-fueled wagon dryer (round pistachio)	803664	-	2557.60	86.40	0.244
Diesel-fueled wagon dryer (elongated pistachio)	797400	-	2772	86.40	0.246
Gas-fueled carriage dryer (round pistachio)	3145824	-	21217.60	388.80	0.285
Gas-fueled carriage dryer (elongated pistachio)	3188376	-	20088	388.80	0.281
Gas-fueled wagon dryer (round pistachio)	1077984	-	2066.40	136.80	0.292
Gas-fueled wagon dryer (elongated pistachio)	1066320	-	2080.80	136.80	0.295
Diesel-fueled carriage dryer (round pistachio)	7889184	980	14536.80	864	0.257

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Diesel-fueled carriage dryer (elongated pistachio)	7911648	950	14472	864	0.257

As can be seen in Table 2, the energy efficiency of all dryers is low. The energy efficiency of dryers improves when a significant portion of the outgoing hot air is directed back to the air inlet, as also stated by Roustapour *et al.* (2015).

3.3 Economic analysis

Table 3 presents the findings regarding the economic feasibility of the dryers. The results indicate that gas-powered wagon dryers exhibit reduced expenses due to their lower initial purchase cost compared to alternative dryers. Moreover, depreciation, capital expenses, and repair costs are all influenced by the initial purchase cost. Additionally, gas is more readily available than diesel and demonstrates higher efficiency. Moreover, the results show that gas-fueled wagon dryers have higher economic viability compared to gas-fueled carriage dryers due to their lower purchase cost, depreciation, capital cost, and repair costs. Also, the results demonstrate that two-stage dryers (wagon dryers) have higher economic viability compared to single-stage dryers (carriage dryers) due to their lower purchase cost, depreciation, capital cost, and repair costs. The results obtained indicate that the economic feasibility of all dryers is limited. However, connecting most of the outgoing hot air back to the air inlet enhances the economic viability of dryers, a point also affirmed by Rostapour *et al*. (2015).

Table 3: Economic feasibility factors

Treatment	Fixed Cost (IRR/EUR)	Variable Cost (IRR/EUR)	Total Cost in Year (IRR/EUR)
Diesel-fueled Wagon Dryer (round pistachio)	134800000/225	145500000/242	280300000/467
Diesel-fueled Wagon Dryer (elongated pistachio)	134800000/225	145400000/242	280200000/466
Gas-fueled Carriage Dryer (round pistachio)	170100000/283	172080000/286	342180000/569
Gas-fueled Carriage Dryer (elongated pistachio)	170100000/283	172200000/287	342300000/570
Gas-fueled Wagon Dryer (round pistachio)	110800000/185	97500000/163	208300000/348
Gas-fueled Wagon Dryer (elongated pistachio)	110800000/185	97400000/162	208200000/347
Diesel-fueled Carriage Dryer (round pistachio)	19330000/322	290380000/484	483680000/806
Diesel-fueled Carriage Dryer (elongated pistachio)	19330000/322	290500000/483	483800000/805

3.4 Uniformity of the drying process

Table 4 indicates that sun dryers exhibit high uniformity in drying pistachios as the pistachios are spread in a single layer, receiving heat uniformly. This aligns with the results of Rostami and Mirdamadiha (2013) and Shakar Ardakani (2008). The thinner the product layer within the dryer, the greater the uniformity in heat absorption and drying. Additionally, dryers equipped with a mixer rank second in terms of uniformity in drying. This corresponds to the findings of Rostami and Mirdamadiha (2013).

Table 4: Results of standard deviation for four dryers based on the initial and final moisture contents

Treatment	Standard deviation
Diesel-fueled Wagon Dryer (round pistachio)	0.89
Diesel-fueled Wagon Dryer (elongated pistachio)	0.74

Gas-fueled Carriage Dryer (round pistachio)	0.23
Gas-fueled Carriage Dryer (elongated pistachio)	0.26
Gas-fueled Wagon Dryer (round pistachio)	0.71
Gas-fueled Wagon Dryer (elongated pistachio)	0.74
Diesel-fueled Carriage Dryer (round pistachio)	1.21
Diesel-fueled Carriage Dryer (elongated pistachio)	1.01
control treatment (round pistachio)	0.23
control treatment (elongated pistachio)	0.14

4 CONCLUSIONS

In this study, a detailed energy and cost analysis of four conventional pistachio dryers was performed. The objective of this study was to assess four conventional pistachio dryers, namely the Diesel-fueled Carriage Dryer, Gas-fueled Carriage Dryer, Gas-fueled Wagon Dryer, and Diesel-fueled Wagon Dryer, within Iran. The comparison was focused on criteria such as fuel consumption, energy efficiency, and economic considerations. The survey's closing findings could be summarized as follows:
(1) In total, the volume or weight of consumed fuel per unit weight of evaporated water in wagon dryers was about two-thirds of that in belt dryers.
(2) Gas-fueled belt dryers, due to the continuous use of a mixer, exhibited higher uniformity in drying.
(3) Gas-fueled belt dryers had higher energy efficiency compared to other dryers.
(4) Gas-fueled wagon dryers had lower operational costs for pistachio drying compared to other dryers.
(5) Two-stage dryers (wagon dryers) have higher economic viability compared to single-stage dryers (carriage dryers)
Therefore, the results of this study indicate that among conventional dryers, Gas-fueled wagon dryers are the most preferable option in terms of energy efficiency and cost-effectiveness.

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