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Comparison of material and energy indicators in sunflower and pumpkin seed production systems

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ABSTRACT

Introduction: Seed production is one of the main steps in the agricultural sector. Comparing the material and energy amounts of inputs and outputs of seed production systems in a region allows for better management of agricultural fields. Sunflower and pumpkin are among the most important oilseeds and nut crops in the world, whose cultivation has expanded greatly in recent years. The production of these two crops, whether for oil production in industrial applications or as nuts, requires the use of various inputs.

Materials and Methods: In the present study, the flow of material and energy in sunflower and pumpkin seed production systems, the main oilseed crops, was examined and compared. The amount and equivalent energy of input-output, the share of input energy, and the energy indicators of sunflower and pumpkin seed production farms were calculated in the present study. Information on the production of these products were collected through face-to-face interviews with 50 sunflower seed producers and 30 pumpkin seed producers.

Results and discussion: The input energies in sunflower cultivation included human power, machinery, fuel, chemical fertilizer, animal manure, electricity, and seeds. In pumpkin cultivation, fewer inputs were used in the field, including human power, machinery, fuel, and seeds. In order to obtain the amount of energy input to the farms in various agricultural operations and the energy output from the farms, the consumption of each input per hectare was calculated and multiplied by their energy equivalent. Direct energy sources whose energy is directly released into the system included human power, fuel, and electricity, and indirect energy sources whose energy was consumed for their production included seeds, fertilizers, chemical pesticides, and machinery. Human power, seeds, and animal manure were placed in the category of renewable energies, and electricity, fuel, pesticides, chemical fertilizers, and machinery were placed in the category of non-renewable energies. Based on the energy equivalents of inputs and outputs, different indicators including energy ratio, energy efficiency, energy intensity, and net energy gain were calculated. The amount of input energies in sunflower and pumpkin production systems were 19.95 and 10.53 GJ.ha-1, respectively, and the amounts of material and energy output in sunflower production were 1192.66 kg. ha-1 and 32440.31 MJ ha-1, respectively, and in pumpkin seed production farms were 898.64 kg ha-1 and 23184.98 MJ ha-1, respectively. The amounts of energy for labor, machinery, fuel, animal manure, and electricity in the sunflower seed production system were higher than that of pumpkin; however, the amounts of energy consumed for chemical fertilizer and seed were higher than that of sunflower. In the sunflower production system, the most energy used was related to fuel input, which was 6974.26 MJ ha-1. The value of the energy intensity indicator in the sunflower production system was equal to 16.72 MJ.kg-1, while the value of this indicator in the pumpkin seed production was calculated as 11.72 MJ.kg-1. Although the average energy input in the sunflower production farms was higher than that in the pumpkin production farms, the seed productivity in the sunflower seed production (68.19 kg seed output/kg seed input) was better than that in the pumpkin production farm (32.20 kg seed output/kg seed input). Although the energy output of the sunflower seed production was higher than that of the pumpkin seed production system, the energy efficiency of the pumpkin seed production (2.20) was higher than that of the sunflower seed production system (1.62). In the sunflower farms, the largest share of energy belonged to diesel fuel (34.95%), while chemical fertilizer had the largest share (73.54%) in the pumpkin production farms.

Conclusion: Renewable energy in the sunflower production system constituted only 8% of the total energy input to the farm. This low share indicates a low use of inputs that can be returned to the environment. The ratio of renewable energy to total energy input in the pumpkin production system was also similar to that of sunflower. The share of renewable energy in pumpkin and sunflower production systems can be increased by reducing the share of nonrenewable energy such as fuel

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consumption, by improving the management of mechanized operations on farms. Also, solar and wind energy can be considered in the generation of electricity for irrigation and animal manure and compost can be used instead of chemical fertilizers as much as possible. The results obtained in the present research are useful for managing inputs and outputs by optimizing consumptions and operations in the production of the studied products.

1 Introduction

Increasing food production due to growing population has led to increasing energy consumption in different sectors such as agriculture. On the other hand, environmental protection is one of the most important aspects of production, which together with economic, technical and social performance allows to move towards sustainable production. Material and energy are the main components of the environmental aspect of sustainable production. Also, material and energy consumption in the production of various products is important in point of economic, which should be reduced to the minimum values [1]. Moreover, investigating the quantities of consumables and production materials in the production of agricultural and food products is necessary to investigate the state of energy flow and environmental impacts [2, 3]. The state of energy and its indicators in order to reduce consumption and increase their productivity in the production of various agricultural and food products such as cotton [4], sugar beet [5], wheat [6, 7], barley [8], potato [9], coriander [10], meat [1, 11], bread [12], and sugar [13] has been investigated.

Sunflower and pumpkin seeds are among the world's most important oil crops, and their cultivation has expanded in recent years. The production of sunflower and pumpkin seeds, both for oil consumption in factories and as nuts, requires the use of various inputs. The status and energy consumption and indicators of sunflower [14] and pumpkin [15] production have been studied in Turkey. However, the energy status of sunflower and pumpkin seeds in Iran has not been reported, till now.

The purpose of the present research is to investigate the consumption state of material and energy of their productivity in the production of sunflower and pumpkin seeds by determining the amounts of inputs and outputs and their energy and calculating their indices to find strengths and weaknesses in the production of these two products and provide some suggestions to improve their production. Also, energy forms based on equivalent and resource for two production systems have been investigated. The innovation of the current research is the calculation of the values of input to total output indicator (as material indicators).

2 Materials and Methods

Kermanshah Province is one of the main Iranian producers of seeds. The largest area of sunflower cultivation is in Sanghar and Keliai townships of Kermanshah, Iran, which is 1-1.5 thousand hectares. The cultivation of pumpkin is mainly done in Bilwar region located in the center of Kermanshah city. The cultivated area of this seed is estimated at 26.2 ha [16].

The input-output information of the studied production systems in the present research was collected through face-to-face interviews with 50 sunflower and 30 pumpkin seed farmers in 2018 crop year by random sampling method. The number of statistical samples was determined based on the following equation [17]:

$$n = \frac{(\sum N_h S_h)}{N^2 D^2 + \sum N_h S_h^2} \tag{1}$$

n: sample size

N: population size

S: standard deviation

D: allowable error (5%)

2-1 Input to total output indicator

Inputs in the production of sunflower seed included: labor, machinery, fuel, chemical fertilizers, manure, electricity, and seed. In the production of pumpkin seed, fewer inputs have entered the field, which included labor, machinery, fuel, chemical fertilizers, and seed. Average inputs and outputs of farms were calculated. The values of the input to total output indicator for all inputs in the two production systems were calculated according to Eq. 2 [7].

$$ITO = \frac{I_i}{TO} \times 1000 \tag{2}$$

where IOT is the input to total output indicator (unit input/1000 output unit), I_i is the amount of input I (unit of input i), and TO is the total output (output unit).

2-2 Energy equivalent

In order to calculate the energy of inputs and outputs in a production system, the consumption of each input and output per hectare of the farms was specified and multiplied by the corresponding energy equivalent (Table 1).

Table 1. The energy equivalents of inputs and output in sunflower and pumpkin production systems.

In/out	Unit	Energy equivalent (MJ.Unit^{-1})	Reference
Input			
Human	h	1.96	[10]
Fuel	l	47.8	[10]
Machinery			
Plow	kg	180	[28]
Disk	kg	149	[28]
Planter	kg	133	[28]
Harvester	kg	116	[28]
Fertilizers			
N	kg	78.1	[28]
P_2O_5	kg	17.4	[28]
K_2O	kg	13.7	[28]
Manure	kg	0.3	[29]
Electricity	kWh	11.93	[24]
Sunflower seed	kg	27.2	[30]
Pumpkin seed	kg	25.8	[28]
Output			
Sunflower seed	kg	29.2	[30]
Pumpkin seed	kg	25.8	[28]

In general, there are two types of energy equivalent for each input. The first type of energy is that one used for the producing an input in the related factory. For example, 11.93 MJ energy is used for generating 1 kWh electricity in the power plants [14]. The second energy equivalent type is the amount of energy that is released when the input is consumed. For example, 3.6 MJ energy is released when 1 kWh of electricity is consumed. In energy calculations, that type of energy equivalent with a higher value is considered (11.93 MJ/kWh for electricity). It should be noted that water does not has the second type of energy equivalent; but because different inputs such as machinery, labor, and fuel/electricity is used for irrigation or water supply, it has the first type of energy equivalent.

As machinery and equipment are used not consumed, it was calculated based on the Eq. 3. of working hours of those in the fields to their useful life. As can be seen in Eq. 2, the machinery mass [11] was multiplied by the corresponding energy equivalent and since the whole machine is not used in the fields, the obtained number must be multiplied by a decimal number. This decimal number is the result of dividing the hours of use of the machinery per hectare over its useful life time.

$$ME = \frac{m.I.t}{T} \tag{3}$$

Where ME is the machinery energy[18], m is the machinery mass[19], I is the machinery energy equivalent ($MJ.kg^{-1}$), t is the machinery working time (h), and T is the machinery useful life time (h).

2-3 Energy indicators

In the energy systems some energy indicators are defined and calculated to specify energy usefulness and obtaining applicable indexes in energy management. According to the energy values of inputs and outputs in the production of the two seeds, energy indicators including energy ratio, energy efficiency, energy intensity, and net energy gain were calculated based on the following equations [20-22].

$$ER=OE(MJ.ha^{-1})/IE(MJ.ha^{-1}) \tag{4}$$
$$EP=Y(kg.ha^{-1})/IE(MJ.ha^{-1}) \tag{5}$$
$$EI= IE(MJ.ha^{-1})/Y(kg.ha^{-1}) \tag{6}$$
$$NEG= OE(MJ.ha^{-1})-IE(MJ.ha^{-1}) \tag{7}$$

Where EE is the energy ratio (energy efficiency), OE is the output energy ($MJ.ha^{-1}$), IE is the input energy ($MJ.ha^{-1}$), EP is the energy productivity ($kg.MJ^{-1}$), Y is the crop yield ($kg.ha^{-1}$), EI is the energy intensity ($MJ.kg^{-1}$), and NEG is the net energy gain ($MJ.ha^{-1}$).

2-4 Energy forms

Input energies in a production system are divided into direct and indirect energies in terms of energy equivalent type [1, 14, 22]. As stated, there are two energy equivalent types and that equivalent with higher value is considered in energy calculations. If this quantity is related to the energy that is released from the consumption of the input, it is called direct energy. If the input is of the second energy equivalent type, i.e. it is consumed for the production of the input in the relevant factory, it is indirect energy. According to Table (1), because the energy equivalent of electricity was considered as 11.93 MJ (the energy consumed in the power plant to generate 1 kWh electricity) and not 3.6 MJ (the energy released from the consumption of 1 kWh electricity), so electricity is an indirect type of energy. Table 2 lists different energy forms in the both production systems. Direct energy resources in the present research included labor and fuel, and indirect energy resources that have been used for their production in the related factory included seeds, fertilizers, chemicals, machinery, and electricity.

Considering the importance of reducing the consumption of fossil energy resources, in another division, energy is categorized in two forms based on energy resource as renewable and non-renewable [1, 14]. In the present study, renewable resources include labor, seeds, and manure, which are replaced naturally in a short time (Table 2). Nonrenewable resources of energy included electricity (produced in natural gas-fired power plants), diesel (fossil fuel), chemicals, and machinery that cannot be replaced naturally (e.g., machinery, chemicals, and electricity) or take a long time to be replaced naturally (e.g. fossil fuels).

Table 2. The energy equivalents of inputs and output in sunflower and pumpkin production systems.

Energy form	Sunflower	Pumpkin
Direct equivalent	Human Fuel	Human Fuel
Indirect equivalent	Seed Fertilizer Manure Machinery Electricity	Seed Fertilizer Machinery
Renewable resource	Human Seed Manure	Human Seed
Nonrenewable resource	Fuel Fertilizer Machinery Electricity	Fuel Fertilizer Machinery

3 Results and discussion

3-1 Materials

3-1-1 Input-output

The mean values of input and output materials per hectare for sunflower and pumpkin seed production systems were listed in Table 3. The results showed that 1192.66 and 898.64 kg of seeds were produced in one hectare of sunflower and pumpkin farms, respectively. The mean values of human, machinery, fuel, fertilizer and electricity inputs were 154.12 h, 5.67 kg, 123.85 l, 2866.66 kg, 520.55 kWh, per hectare of sunflower farms. These values were higher than those of pumpkin seed production farms as 68.99 h, 0.95 kg, 45.15 l, 0.00 kg, 0.00 kWh per hectare, respectively. Conversely, the amount of fertilizer in sunflower farms (109.54 kg) was lower than that in pumpkin farms (167.09 kg). Since no manure was used in pumpkin farms, the amount of fertilizer was higher than in sunflower farms. Also, the amount of seed input in sunflower farms (17.49 kg) was lower than that in pumpkin farms (27.91 kg) due to the difference in seed mass. Since pumpkin farms are located near a river and irrigation is based on gravity, no electricity was used for irrigation in the production system.

Table 3. The mean input-output of material in sunflower and pumpkin farms.

In/Out (Unit)	Sunflower	Pumpkin
Input		

Human (h)	154.12	68.99
Machinery [4]	5.67	0.95
Fuel (l)	123.85	45.15
Fertilizer [4]	109.54	167.09
Manure [4]	2866.66	0.00
Electricity (kWh)	520.55	0.00
Seed [4]	17.49	27.91
Output		
Seed [4]	1192.66	898.64

3-1-2 Material indicator

The values of input to total output indicator for all inputs of the two seed production systems were calculated and reported in Table 4. This index makes it easy to compare the productivity of inputs in different production systems.

According to the results of Table 2, for the production of 1000 kg of sunflower seed, 129.20 h labor, 4.80 kg machinery, 103.80 l diesel fuel, 91.80 kg chemical fertilizers, 2403.60 kg manure, 436.50 kWh electricity, and 14.70 kg seed were consumed/used. In pumpkin seed production system, lower amount of labor (76.80 h/1000 kg output), machinery (1.10 kg/1000 kg output), diesel fuel (50.20 l/1000 kg output), and manure and electricity (without consumption) was used/consumed compared to the sunflower seed production system. But more chemical fertilizers (185.90 kg/1000 kg output) and seeds (31.10 kg/1000 kg output) have been consumed. According to the values of this index, it can be generally said that the amount of inputs in the production of sunflower were more than those of pumpkin seed.

Table 4. The values of the input to total output indicator (input unit/1000 output unit) for all inputs.

Input	Sunflower	Pumpkin
Human	129.20	76.80
Machinery	4.80	1.100
Fuel	103.80	50.20
Fertilizers	91.80	185.90
Manure	2403.60	0.00
Electricity	436.50	0.00
Seed	14.70	31.10

According to the results of Table 4, it can be said that the material productivity in the pumpkin was better than sunflower farms except for seed and chemical fertilizer.

3-2 Energy

3-2-1 Input-output

The average value of input and output energy per one hectare of sunflower and pumpkin seed production systems were listed in Table 5. The results showed that in one hectare of sunflower and pumpkin farms, 19951.17 and 10533.51 MJ of energy were consumed, respectively. The mean value of output energy in sunflower farms was equal to 32440.31 MJ.ha^{-1}, while the corresponding value for pumpkin seed production system was 23184.98 MJ.ha^{-1}. As the values of labor, machinery, fertilizer and electricity inputs per hectare in sunflower farms were higher than in pumpkin farms, their energy values were correspondingly higher. As an exception, the values of fertilizer and seed in sunflower were lower than those in pumpkin systems.

In a study on soybean oilseed cultivation in Golestan province, Iran, it was reported that the total energy input to the farm was equal to 18.03 GJ.ha^{-1} [22] which shows that energy consumption in soybean farms are more than that of pumpkin, but somewhat less than sunflower seed production system. The study of the input-output energy status in the production of pumpkin seeds in Turkey showed that the total energy consumed was equal to 10.97 GJ.ha^{-1} [15]. This study shows that the amount of energy consumption in the production of pumpkin seeds in Iran and Turkey is almost equal.

Table 5. The mean input-output of material and energy in sunflower and pumpkin farms.

In/Out (Unit)	Sunflower		Pumpkin	
	Energy (MJ.ha^{-1})	Share (%)	Energy (MJ.ha^{-1})	Share (%)
Input				
Human	302.08	1.51	135.22	1.28
Machinery	355.26	1.78	98.70	0.94
Fuel	6974.26	34.95	1832.01	17.39
Fertilizer	4773.57	23.96	7746.26	73.54
Manure	860	4.31	0.00	0.00
Electricity	6210.27	31.13	0.00	0.00
Seed	475.73	2.38	720.23	6.83
Total input energy	19951.17	100.00	10533.40	100.00
Output				
Seed	32440.31	-	23184.98	-

The amount of output obtained in the sunflower production system is equal to 1192.66 kg.ha^{-1}, which is more than the pumpkin production system (898.64 kg.ha^{-1}) whereas the amount of energy output in the production of sunflower is more than that of pumpkin. The amount of energy output in sunflower production was equal to 32.44 GJ.ha^{-1} and in pumpkin seed production was equal to 23.18 GJ.ha^{-1}. Researchers reported the amount of energy output in the production of pumpkin seeds in Turkey was equal to 10.05 GJ.ha^{-1} [15], which was less than the production of the same product in Iran.

3-2-2 Input contribution

The energy contributions of different inputs in the production of the two studied products have presented in Table 5 and Fig. 1. In sunflower production system, the most used energy was related to fuel input, which is equal to 6.97 GJ.ha^{-1}. This amount constitutes 34.95% of the total input energy in the sunflower production system. After fuel, electricity and chemical fertilizer were in the next ranks with a share of 31.13 and 23.96% in sunflower production farms. The electricity value in pumpkin fields was zero because most of pumpkin production fields in Kermanshah township are located close to the irrigating rivers and irrigation was done based on the gravity, so the electricity was not consumed in the farms.

In the production of pumpkin seeds, chemical fertilizer with amount of 7.75 GJ.ha^{-1} had the highest energy share (73.54%). In the investigation of the energy situation in the production of pumpkin seeds in Turkey, it was found that the most important energy input was diesel fuel with a share of 30.94% [15]. This result shows that energy consumption in the production of similar products is different regions are different and should be investigated separately. In the production of pumpkin seed in the present study, fuel and seed were in the second and third ranks with the share of 17.39 and 6.83%, respectively. These results show the priority of examining inputs in order to reduce their consumption in the production of the studied products.

3-2-3 Indicators

Table 6 and Fig. 2 show the values of energy indicators in sunflower and pumpkin seed production systems. According to the table, the value of energy ratio in pumpkin seed production (2.20) was higher than that of sunflower (1.62). This result shows that the efficiency of energy consumption in the production of pumpkin seed is higher than that of sunflower. Since the values of this index for these two products are greater than one, these values indicate that the energy gain in the production of both products is greater than the energy consumed. The positive values of the Net Added Energy Index in Table 6 confirm this result. The net energy gain of sunflower pumpkin farms were +12.49 and +12.65 GJ.ha^{-1}, respectively, which indicates that energy was generated in crop production. Although in the production of pumpkin seed, the values of total input and output energy were less than those of sunflower, the amount of net energy gain index for pumpkin seed (12.65 GJ.ha^{-1}) was relatively higher than that of sunflower (12.14 GJ.ha^{-1}). This result shows the higher efficiency of pumpkin fields compared to sunflower in terms of energy. Investigating the energy status in sunflower production in Turkey showed that the value of the net energy gain index was equal to 67.26 GJ.ha^{-1} [23].

The value of energy productivity index in sunflower production is equal to 0.06 kg.MJ^{-1}, while the value of this index was higher for pumpkin seed production farms (0.08 kg.MJ^{-1}). These results show that by consuming 1 MJ energy in the field, 0.06 kg seeds are produced, while by consuming this amount of energy in the pumpkin field, 0.08 kg seed are obtained.

The amount of energy intensity in the sunflower production system was calculated as 16.72 MJ.kg^{-1} which shows that 16.72 units of energy in terms of MJ were consumed for each unit of produced product in kg. The amount of energy intensity in pumpkin seed production was equal to 11.72 MJ.kg^{-1}, which is lower than that of sunflower. These results show that for the production of one kilogram of pumpkin seed, 5 MJ energy have been consumed less than sunflower seed. The amount of energy intensity in soybean oilseed production was 9.86 MJ.kg-1 [24]. This data shows that in the production of one kilogram of soybean, less energy has been consumed compared to sunflower and pumpkin seeds. A study conducted in Turkey showed that the value of energy intensity index in sunflower production was 4.68 MJ.kg^{-1} [15].

Table 6. Energy indicators in sunflower and pumpkin production systems.

Energy indicator	Unit	Value	
		Sunflower	Pumpkin
Energy ratio	-	1.62	2.20
Energy productivity	kg.MJ^{-1}	0.06	0.08
Energy intensity	MJ.kg^{-1}	16.72	11.72
Net energy gain	MJ.ha^{-1}	12489.14	12651.60

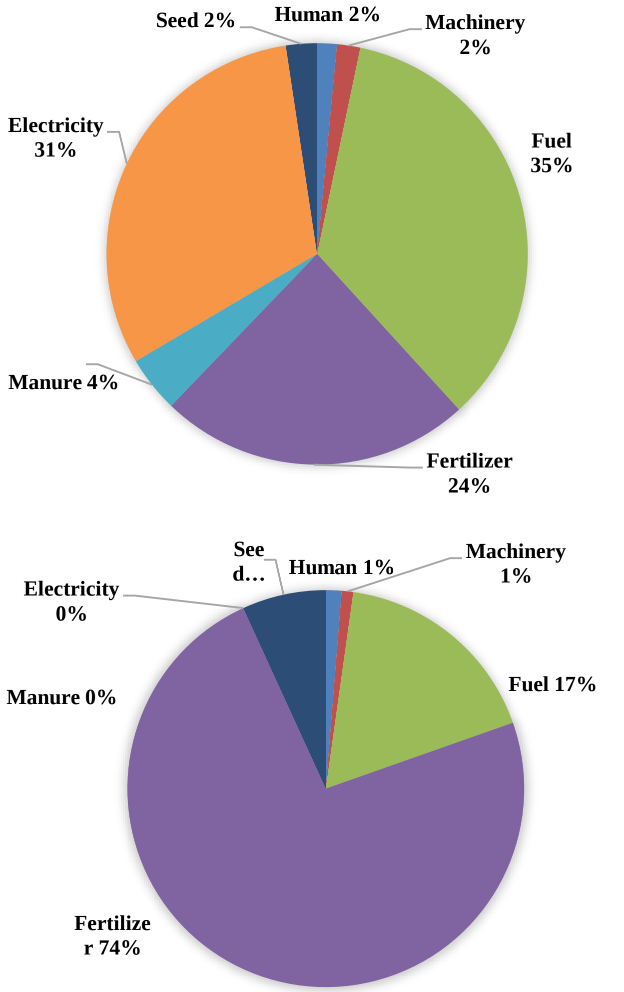

Fig. 1. Share of inputs in sunflower (top) and pumpkin (bottom) farms.

3-2-4 Energy forms

3-2-4-1 Equivalent-based

The values of equivalent basic energy forms in the studied production systems are presented in Table 7 and Fig. 3. The share of direct energy in the production of sunflower seeds and pumpkin seeds was 67.59% and 18.67%, respectively. The proportion of direct energy in the production of sunflower seed was higher than that of pumpkin. This result is due to the high proportion of fuel and electricity input in the production of sunflower seed compared to pumpkin. The investigation of direct and indirect energy in sunflower production in Turkey showed that their shares were 24.69 and 75.31%, respectively [23].

Table 7. The energy forms (MJ.ha^{-1}) in sunflower and pumpkin production systems.

Energy form	Value		Share (%)	
	Sunflower	Pumpkin	Sunflower	Pumpkin
Direct energy	13486.61	1967.23	67.59	18.67
Indirect energy	6464.56	8566.18	32.40	81.32
Renewable energy	1337.81	855.46	8.21	8.12
Nonrenewable energy	18313.36	9677.96	91.79	91.87

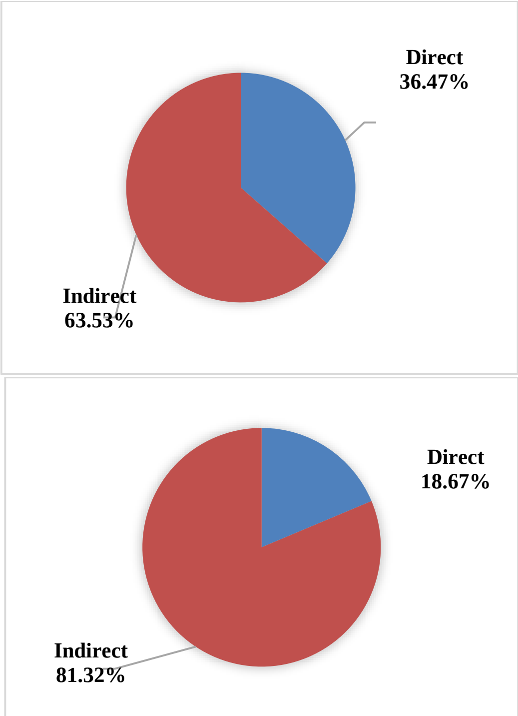

Fig. 3. Equivalent-based energy forms in sunflower (top) and pumpkin (bottom) production.

3-2-4-2 Resource-based

According to Table 7 and Figure 4, the share of renewable energy in the sunflower production system was 8.21% of the total energy input. This small amount indicates the low use of inputs that can be returned to the environment naturally in a short time. The ratio of renewable energy to the total energy input in the pumpkin production system (8.21%) was close to that of the sunflower farms. These results highlight the use of renewable energy resources such as sun and wind to produce electricity.

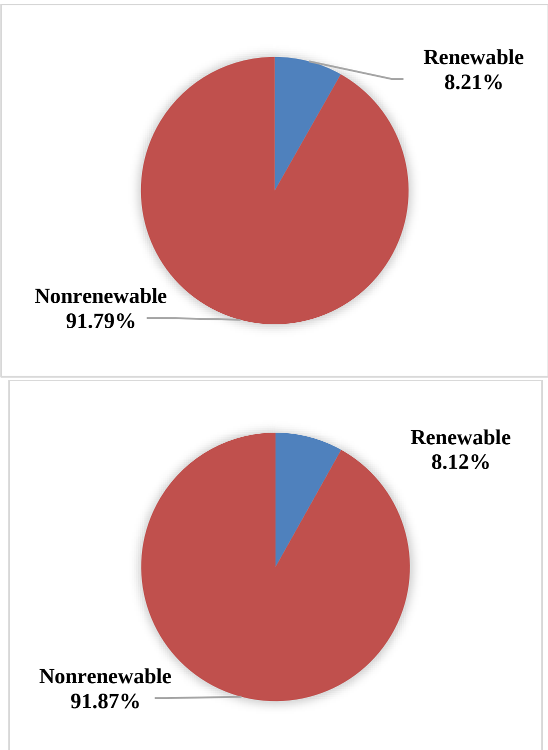

Fig. 4. Resource-based energy forms in production of sunflower (top) and pumpkin (bottom).

4 Conclusions

Quantity and energy equivalent of input-output, proportion of input energy and energy indicators of sunflower and pumpkin seed production fields were calculated.

In sunflower seed production, seed productivity (68.19 kg seed output/kg seed input) was better than that of pumpkin seed (32.20 kg seed output/kg seed input). Whereas, pumpkin seed production was better than sunflower seed production systems due to lower input energy (energy consumption). Although, output energy of sunflower seed production was higher than that of pumpkin seed production systems, but energy efficiency of pumpkin seed production was better than that of sunflower seed production systems.

The proportion of renewable energy in both production systems was low (8%), which must be considered to be improved by applying renewable energy resources.

The amount of material and energy equivalent of inputs and outputs, the share of input energies, and the indicators of material and energy and different forms of energy in sunflower and pumpkin seed production fields were studied in the present research. The results obtained are useful for the management of inputs and outputs by optimizing consumption and improving the efficiency of operations in the production of the studied products.

The amounts of all inputs and their energies and the values of the input to total output index in sunflower production were higher than those in pumpkin production farms, except for seeds and chemical fertilizers. Also, the value of pumpkin seed output was lower than that of sunflower seed production system and therefore seed productivity in sunflower field was higher than pumpkin field.

The total input energy of sunflower seed production was higher than that of pumpkin seed production. Although the output energy of sunflower seed production was higher than that of pumpkin seed production system, the energy efficiency and net energy gain of pumpkin seed production was higher than that of sunflower seed production system.

The share of renewable energy in both production systems was low (8%), which should be increased by using renewable energy resources such as solar and wind energy to generate the electricity needed for irrigation and by using more animal manure and compost instead of chemical fertilizers as much as possible. Improving the management of mechanized operations on farms can help reduce fuel consumption and thus the use of non-renewable direct energy.

Ethical Statement

Interventional studies involving animals or humans and other studies requiring ethical approval should include in this section the authorities that have provided the appropriate ethical approval code.

Declaration of competing Interest

The authors declare that they have no known financial interests or personal relationships that might affect the work reported in this article.

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