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ORIGINAL ARTICLE

Determination of Energy Balance in Organic Wolfberry (*Lycium barbarum* L.) Production in Turkey

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Abstract
The aim of this study is to determine the energy balance of organic wolfberry. This study was performed at the organic wolfberry producing facilities during the 2015–2016 production seasons in Aksaray province of Turkey. The agricultural input energies and output energies were used in organic wolfberry production were calculated to determine the energy balance. According to the study findings, the energy inputs in organic wolfberry production were calculated respectively as 3044.23 MJ ha^{-1} (39.26%) human labour energy, 1694.93 MJ ha^{-1} (21.86%) diesel fuel energy, 1145.66 MJ ha^{-1} (14.78%) machinery energy, 984.38 MJ ha^{-1} (12.70%) organic fertilizers energy, 306 MJ ha^{-1} (3.95%) irrigation energy, 289.50 MJ ha^{-1} (3.73%) organic chemicals energy and 289.08 MJ ha^{-1} (3.73%) transportation energy. Total input energy was calculated as 7753.78 MJ ha^{-1}. Production output organic wolfberry yield were calculated as 10,862.40 MJ ha^{-1}. The energy output/input ratio, specific energy, energy productivity and net energy were calculated respectively as 1.40, 2.66 MJ kg^{-1}, 0.38 kg MJ^{-1} and 3108.62 MJ ha^{-1}. The consumed total energy input in organic wolfberry production could be classified as 65.07% direct, 34.93% indirect, 59.64% renewable and 40.36% non-renewable.

Keywords Energy balance · Organic wolfberry · Energy productivity · Specific energy

Ermittlung der Energiebilanz bei biologisch angebauten Wolfsbeeren (Goji-Beeren, *Lycium barbarum* L.) in der Türkei

Schlüsselwörter Energiebilanz · Biologisch angebaute Wolfsbeeren · Goji-Beeren · Energieproduktivität · Spezifische Energie

Introduction

Lycium barbarum fruit, usually called goji berry or wolfberry, is a well-known herb in traditional Chinese medicine (The Pharmacopoeia of the People's Republic of China). Nowadays, Goji berries are being used not only in China but also worldwide as a popular health food ingredient in various forms such as soups, drinks and a variety of solid foods (Amagase and Farnsworth 2011; Potterat 2010; Yang et al. 2015). *Lycium barbarum* L. is one of the important traditional Chinese medicinal plant species. It has been produced in Northwest China and used as daily functional food in China, Southeast Asia and many European countries. (Amagase and Nance 2008; Chang and So 2008; Istrati et al. 2013). The dry fruit of *L. barbarum* (also called the goji berry fruit in traditional medicine) is an important component of traditional medicines and medical diets and has indicated multiple pharmacological functions including antioxidant, antiaging, immune promoting, and antitumorigenic activity (Yu et al. 2007; Amagase et al. 2009; Potterat 2010; Reeve et al. 2010; Zhang et al. 2011). More than 100 human diseases have been reported to be related with free radicals (Gutteridge 1993; Dong et al. 2009).

The origin of goji berry is rooted back to Asia and mostly it is being grown in the Himalayas, the highest mountains in the world, placed in Tibet and Mongolia (Song et al. 2011; Oğuz and Erdoğan 2016). Goji berry (*Lycium bar-*

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barum L.), also known as Lycium fruit or wolfberry and by a number of other local names has been recognized as latest 'super food or fruit' and sometimes also refer as 'berry of youth' due to its anti-aging and several others health benefits (Yao et al. 2011; Jatoi et al. 2017). It is a deciduous woody and thorny shrub of family *Solanaceae*, can tolerate the extreme temperatures ranging from –15 °C to +40 °C, usually 3 to 6 feet tall in commercial field conditions due to pruning (Demchak 2014; Jatoi et al. 2017). The most extensively consumed berry-type products (commonly called superfoods) in Spain are derived from goji (*Lycium barbarum*), pomegranate (*Punica granatum*), chia (*Salvia hispanica*), açaí (*Euterpe oleracea* M.), and mangosteen (*Garcinia mangostana*). The dietary intake of berry fruits has a positive and profound impact on human health, performance and disease. All these fruits support the immune system and are nutrient dense. In general, they have an extraordinary concentration of antioxidants, monounsaturated fats, dietary fiber, phytosterols, essential amino acids, valuable trace minerals, and vitamins (A, C, B1, B2, B6, B12, etc.) (Llorent-Martínez et al. 2013).

A number of applicable alternatives that could reduce energy use without decreasing yields or increasing labour intensity are possible (Esengün et al. 2007). The energy input-output analysis is generally performed to measure the energy efficiency and environmental aspects (Rafiee et al. 2010). To evaluate the sustainability of agriculture, its energy efficiency must be considered, and major sources of energy waste must be identified and evaluated (Pervanchon et al. 2002). To manage a rising energy-consumption rate, consuming of natural resources and environmental corruption, energy efficiency should be developed (Dovì et al. 2009). An important objective in agricultural production is to reduce costs and increase yield. In this respect, the energy budget is important (Gezer et al. 2003). Efficient use of energy is one of the main requirements of sustainable agriculture. Energy use in agriculture has become more intense in response to increasing population, limited supply of arable land, and a desire for higher standards of living. Efficient use of energy in agriculture will minimize environmental problems, prevent destruction of natural resources, and improve sustainable agriculture as an economical production system (Erdal et al. 2007; Omer 2007; Rafiee et al. 2010).

Different studies were done on energy balance of agricultural production. For example, studies were done on energy input-output analysis of citrus (Özkan et al. 2004), organic raisin (Gündoğmuş and Bayramoğlu 2006), greenhouse and open-field grape (Özkan et al. 2007), grape (Koçtürk and Engindeniz 2009), apple (Yılmaz et al. 2010), kiwifruit (Mohammadi et al. 2010), pomegranate (Çanakçı 2010), banana (Akçaöz 2011), pear (Tabatabaie et al. 2013), quince (Gündoğmuş 2013), orange (Mohammadshirazi et al. 2015), organic grape (Baran et al. 2017a), organic strawberry (Baran et al. 2017b), organic mulberry (Gökdoğan et al. 2017) etc. Although many studies were done on energy balance in agriculture, there has no study on the energy balance of wolfberry and organic wolf berry production in Turkey. In this study, it was aimed to done the energy balance of organic wolfberry.

Materials and Method

This study was performed in Aksaray province of Turkey (*N* 38–39; E 33–35). Aksaray province is located in the Central Anatolian Region and is bordering Nevşehir in the east, Konya in the west, Niğde in the south-east and Ankara in the north. Aksaray is cover an area 7997.00 km^2, the annual average temperature of the province is 10 °C and the average

Table 1 Energy equivalents in agriculture production

Inputs and outputs	Unit	Energy equivalent (MJ/unit)	References
Human labour	h	1.96	Mani et al. (2007); Karaağaç et al. (2011)
Machinery	h	64.80	Singh (2002); Kızılaslan (2009)
Organic fertilizers	kg	10.50	Guzman and Alonso (2008); Bilalis et al. (2013)
Organic chemicals	kg	77.20	Guzman and Alonso (2008); Bilalis et al. (2013)
Diesel fuel	l	56.31	Singh (2002); Demircan et al. (2006)
Irrigation	m^3	1.02	Acaroğlu (1998); Azizi and Heidari (2013)
Transportation	MJ (ton km)$^{-1}$	4.50	Fluck and Baird (1982); Kitani (1999)
Outputs	Unit	Energy equivalent (MJ/unit)	Reference
Fruit	kg	3.72 (fresh)	Gökdoğan et al. (2017)

Table 2 Energy input-output in organic wolfberry production

Inputs	Unit	Energy equivalent (MJ/unit)	Input used per hectare (unit ha^{-1})	Energy value (MJ ha^{-1})	Ratio (%)
Human labour	h	1.96	1553.18	3044.23	39.26
Tillage	h	1.96	12.18	23.87	0.31
Pruning	h	1.96	212.50	416.50	5.37
Hoeing and furrow	h	1.96	117.50	230.30	2.97
Spraying	h	1.96	5.50	10.78	0.14
Harvesting	h	1.96	1133.00	2220.68	28.64
Other application	h	1.96	72.50	142.10	1.83
Machinery	h	64.80	17.68	1145.66	14.78
Tillage	h	64.80	12.18	789.26	10.18
Spraying	h	64.80	5.50	356.40	4.60
Organic fertilizers	kg	10.50	93.75	984.38	12.70
Organic chemicals	kg	77.20	3.75	289.50	3.73
Diesel fuel	l	56.31	30.10	1694.93	21.86
Irrigation	m^3	1.02	300	306	3.95
Transportation	MJ (ton km)$^{-1}$	4.50	64.24	289.08	3.73
Total inputs	–	–		7753.78	100.00
Outputs	Unit	Energy equivalent (MJ/unit)	Output per hectare (unit ha^{-1})	Energy value (MJ ha^{-1})	Ratio (%)
Yield	kg	3.72	2920.00	10,862.40	100.00
Total output	–	–	–	10,862.40	100.00

rainfall of the province 340 mm per year. Aksaray has cold black climate type. It is hot and dry in summers, cold in winters (Anonymous 2017a). Aksaray has two soil type; these are brown soil and alluvium soil type. Aksaray soil structure is 50% brown soil, 30% other soil and 20% alluvium soil (Anonymous 2017b). This study was performed on trials and measurements area of 0.685 ha organic wolfberry garden, located at Aksaray in 2015–2016 production season. Randomized Complete-Block Design with three replicates was performed in this study.

By calculating the agricultural input energies and output energies were used in organic wolfberry production, the energy balance was composed. Total energy input in unit area (ha) constitutes the total energy inputs. Human labour energy, diesel fuel energy, machinery energy, organic fertilizers energy, irrigation energy, organic chemicals energy and transportation energy were calculated as inputs. The units shown in Table 1 were used to calculate the values of the inputs of organic wolfberry production. Previous energy analysis studies were used when calculating the energy equivalent coefficients. The total energy equivalent was determined by adding energy equivalents of all inputs in MJ unit. In order to determined the energy input-output in organic wolfberry production, "Energy usage efficiency, energy productivity, specific energy and net energy were calculated by using the following formulates (Mandal et al. 2002; Mohammadi et al. 2008, 2010)".

$$\text{Energy efficiency} = \frac{\text{Energy output}\,(\text{MJ ha}^{-1})}{\text{Energy input}\,(\text{MJ ha}^{-1})} \quad (1)$$

$$\text{Energy productivity} = \frac{\text{Yield output}\,(\text{kg ha}^{-1})}{\text{Energy input}\,(\text{MJ ha}^{-1})} \quad (2)$$

$$\text{Specific energy} = \frac{\text{Energy input}\,(\text{MJ ha}^{-1})}{\text{Yield output}\,(\text{kg ha}^{-1})} \quad (3)$$

$$\text{Net energy} = \text{Energy output}\,(\text{MJ ha}^{-1}) - \text{Energy input}\,(\text{MJ ha}^{-1}) \quad (4)$$

The results were tabulated in Table 2 and related to organic wolfberry production input-output values and the relevant calculations were given in Table 3. Koçtürk and Engindeniz (2009) reported that, "The input energy is also classified into direct, indirect, renewable and non-renewable forms. The indirect energy consists of pesticide and fertilizer, while the direct energy includes human and animal labour, diesel and electricity used during the production process. On the other hand, non-renewable energy includes petrol, diesel, electricity, chemicals, fertilizers, machinery, while renewable energy consists of human and animal labour (Mandal et al. 2002; Singh et al. 2003)". Energy inputs of organic wolfberry production, in the form of direct and indirect, as well as renewable and non-renewable energy were given in Table 4.

Table 3 Energy input-output analysis indicators in organic wolfberry production

Calculations	Unit	Values
Organic wolfberry yield	kg ha^{-1}	2920.00
Energy input	MJ ha^{-1}	7753.78
Energy output	MJ ha^{-1}	10,862.40
Energy usage efficiency	–	1.40
Specific energy	MJ kg^{-1}	2.66
Energy productivity	kg MJ^{-1}	0.38
Net energy	MJ ha^{-1}	3108.62

Table 4 Energy inputs in the forms of energy for organic wolfberry production

Energy groups	Energy input (MJ ha^{-1})	Ratio (%)
Direct energy [a]	5045.16	65.07
Indirect energy [b]	2708.62	34.93
Total	7753.78	100.00
Renewable energy [c]	4624.11	59.64
Non-renewable energy [d]	3129.67	40.36
Total	7753.78	100.00

[a] Includes human labour, diesel and irrigation
[b] Includes machinery, organic fertilizer, organic chemicals and transportation
[c] Includes human labour, organic fertilizer, organic chemicals and irrigation
[d] Includes machinery, diesel and transportation

Results and Discussion

During the studies in the wolfberry farm, the average amount of organic wolfberry produced per hectare for 2015–2016 production seasons was calculated as 2920.00 kg. As it can be seen in Table 2, energy inputs in organic wolfberry production were as follows, respectively: the energy inputs in organic wolfberry production were calculated respectively as 3044.23 MJ ha^{-1} (39.26%) human labour energy, 1694.93 MJ ha^{-1} (21.86%) diesel fuel energy, 1145.66 MJ ha^{-1} (14.78%) machinery energy, 984.38 MJ ha^{-1} (12.70%) organic fertilizers energy, 306 MJ ha^{-1} (3.95%) irrigation energy, 289.50 MJ ha^{-1} (3.73%) organic chemicals energy, 289.08 MJ ha^{-1} (3.73%) transportation energy. Total input energy was calculated as 7753.78 MJ ha^{-1}. Production output of organic wolfberry yield was calculated as 10,862.40 MJ ha^{-1}. The results determined that 1553.18 h of human labour and 17.68 h of machinery energy are required per hectare of organic wolfberry production. Human labour energy and diesel fuel energy were consumed for machineries and farm operations. Harvesting was the highest in human labour input (28.64%). Human labour was used in tillage, pruning, hoeing-furrow, spraying, harvesting and other application. Machinery energy was used in tillage and spraying. Organic fertilizer aplication was performed with irrigation and organic chemicals was performed with atomiser.

Organic wolfberry yield, energy input, energy output, energy output/input ratio, specific energy, energy productivity and net energy in organic wolfberry production were calculated as 2920.00 kg ha^{-1}, 10,862.40 MJ ha^{-1}, 7753.78 MJ ha^{-1}, 1.40, 2.66 MJ kg^{-1}, 0.38 kg MJ^{-1} and 3108.62 MJ ha^{-1}, respectively (Table 3). In previous agricultural studies, Gündoğmuş (2006) determined (organic apricot) energy output/input ratio as 2.22, Baran et al. (2017a) determined (organic grape) energy output/input ratio as 6.57, Baran et al. (2017b) determined (organic strawberry) energy output/input ratio as 0.25, Gökdoğan and Erdoğan (2017) determined (organic olive) energy output/input ratio as 2.72 and Çelik et al. (2010) determined (organic carrot) energy output/input ratio as 1.90.

The distribution of inputs was used for the production of organic wolfberry, in accordance to direct, indirect, renewable and non-renewable energy groups were given in Table 4. The consumed total energy input in organic wolfberry production could be classified as 65.07% direct, 34.93% indirect, 59.64% renewable and 40.36% non-renewable. Similarly (direct energy > indirect energy), organic apricot (Gündoğmuş 2006), organic black carrot (Çelik et al. 2010), organic lentil (Mirzaee et al. 2011), organic mulberry (Gökdoğan et al. 2017) etc. In this study, renewable energy sources composed 59.64% (4624.11 MJ ha^{-1}) of the total energy input, which was higher than that of the non-renewable resources 40.36% (3129.67 MJ ha^{-1}). Energy output/input ratio were raised, because usage of organic fertilizers was used instead of chemical fertilizers.

As a result, in this study, the energy balance of organic wolfberry production was determined. According to the results, organic wolfberry production is a profitable activity in terms of energy output/input ratio (1.40). Total input energy was calculated as 7753.78 MJ ha^{-1}. Production output organic wolfberry yield were calculated as 10,862.40 MJ ha^{-1}. The energy output/input ratio, specific energy, energy productivity and net energy were calculated respectively as 1.40, 2.66 MJ kg^{-1}, 0.38 kg MJ^{-1} and 3108.62 MJ ha^{-1}. The consumed total energy input in organic wolfberry production could be classified as 65.07% direct, 34.93% indirect, 59.64% renewable and 40.36% non-renewable. The ratio of renewable energy was higher than the ratio of non-renewable energy in organic wolfberry production.

According to Göktolga et al. (2006), "Some of the benefits desired to be obtained through energy input/output analysis are summarized as: being able to determine whether energy has been used effectively or not. Once this is determined, then energy waste will be prevented, as use of excessive energy will be prevented, which in turn, will lower the negative effects caused by environmental exposure of excessive energy (fertilizer, pesticide etc.)". On the other hand, the consumption of fossil energy results in direct negative environmental effects through release of CO_2 and other combustion gases (Özkan et al. 2004). The use of inputs is still rising, and energy related problems associated with agricultural production are still occurring. For this reason, it is necessary to advance development of new technologies and use of alternative energy sources. Within this system, energy analysis is important to make improvements that will lead to more efficient and environmentally friendly production systems (Gündoğmuş and Bayramoğlu 2006). Organic farming, by having lower energy inputs and bigger energy efficiency, costs less than conventional farming particularly when the production coefficients increase (Kavargiris et al. 2009).

Conflict of interest H.I. Oğuz, O. Gökdoğan and M.F. Baran declare that they have no competing interests.

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