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Determining the energy balances of black carrot cultivation in Türkiye

Keziban Yalçın Dokumacı[1]

[1] Department of Agricultural Machinery and Technologies Engineering, Agriculture Faculty, Selcuk University, Konya, Türkiye

Abstract
Black carrot (known as *Daucus carota* ssp. sativus var. atrorubens Alef.) production of Turkey is increasing day by day. New production fields are added to existing ones and production are ever increasing. Black carrot is processed as concentrated and used as a natural colorant for the color of purple and tones in food and beverage industries. Black carrot is also consumed as a fermented beverage. However, the studies carried out on black carrot culture in Turkey are highly limited. This study was carried out to determine energy balances in black carrot production since it is a significant source of income. Results revealed that direct and indirect total energy input in black carrot cultivation was 58 014.8 MJ/ha, total energy output was 119 560 MJ/ha, Output/input ratio (OI) was 2.06 and net energy ratio (NER) was 1.06.
Keywords: Black carrot, Net energy ratio, Energy balance, Energy output, Energy input

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Corresponding Author:
Keziban Yalcin Dokumaci
E-mail: kezibanyalcin@selcuk.edu.tr

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INTRODUCTION

Carrot belongs to the Daucus carota L. species of Apiacea family. Among the carrot species, black carrot (Daucus carota ssp. sativus var. atrorubens Alef.), is consumed as a fresh vegetable and concentration. Black carrot is a plant originating from Turkey, Middle and Far East and it is known that it has been cultivated for at least 3000 years. Black carrot contains various beneficial substances such as sugar, vitamin A and carotene. A previous study revealed the ascorbic acid content of black carrot as 26.40 mg/100 ml (Kirca, 2004). In recent years, black carrot has drawn attention with its rich anthocyanin content (1 750 mg/kg) and specific quality criteria (Kirca et al. 2006). Black carrot has high antioxidant activity and is a potential anthocyanin pigment source. Anthocyanins are the most popular natural food colorings providing the carmine color to foods and commonly preferred as an alternative of synthetic food dyes.

Anthocyanins were proved to have threpuatic effects on vascular diseases especially on artery thickening, cancers and diabetes, nerve degenerations and some eye diseases (Kong et al. 2003; Wrolstad, 2004). The fruits colored with black carrot juice provide several benefits with their high anthocyanin contents to chronicle diseases. There are also several anthocyanin-containing pharmaceutical products on market.

The anthocyanin pigment of black carrot is formulized together with ferulic, p coumaric, sinapic acid and p-hydroxybenzoic acid. The such formulation makes it more resistant against hydration, food pH and light (Khrandare et al. 2011).

Black carrot provides a wonderful strawberry red color with acidic pH values.

The extract is used in fruit juice coloring, softening, preservation, jellifying and pastry sector. Since it is a natural additive, it is not indicated with an e-number on the food and beverage labels. It also contains non-anthocyanin phenolics compounds and these compounds help to get pure and fresh fruit juices (Downham and Collns, 2000).

Black carrot is highly consumed as a fermented beverage in Turkey and India. Fermented carrot juice has an appetizing characteristic (Canbas and Deryaoglu, 1993). It also contains lactic acid. Lactic acid provides the sour taste of the juice, it is a peptic refresher, regulates pH of digestive system and allows the body to benefit more from some minerals (Misoglu, 2004).

There are many researches related energy balances for different vegetables and fruits, previously. Those are rose oil (Gokdogan and Demir, 2013), pumpkin seed (Haciseferogullari and Acaroglu, 2012), apple (Strapatsa et al. 2006; Rafiee et al. 2010; Yilmaz et al. 2010), potato (Hamedani et al. 2010; Mohammadi et al. 2008), cucumber (Mohammadi and Omit, 2010), barley (Mobtaker et al. 2010), cherry (Kizilaslan, 2009), grape (Kocturk and Engindeniz, 2009), apricot (Gezer et al. 2003), camelina (Şeflek et al. 2018) and sugar beet (Erdal et al. 2007; Haciseferogullari et al. 2003). However, researches carried out on black carrot culture are highly limited (Celik et al. 2010).

In addition to these, subsoil crops are examined, Allali et al. (2017) conducted in Morocco, the energy consumption value in onion production was found to be 107 483 MJ/ha, while this value was found as 74 270 MJ/ha in potato production. Özgöz et. al, (2017) determined that Chisel + Disk harrow spring tillage system in potatoe production, net energy value 102 217,25 MJ/kg, energy use efficiency 2.29, energy productivity 0,64 kg/MJ and specific energy is 1.57 MJ/kg. In another research on root edible vegetables, Çelik et al. (2010), compared organic and traditional cultivation of black carrot in Turkey conditions. In that study, the energy requirements obtained in the production of black carrots were stated that as 37 758.82 MJ/ha in organic farming and 75 335.72 MJ/ha in traditional.

Eregli town of Konya has the first place in black carrot production in Turkey. It was recorded that black carrot trading firms contracted for about 150-160 thousand tons production in the year 2018. Such contracted amount corresponds to about 4000 ha of production site.

Beside the yield increases in black carrot culture, production costs should also be reduced for profitable production. Agricultural machinery activities constitute the greatest cost item in black carrot culture and energy balances should be evaluated to reduce the machinery and energy costs in black carrot culture. Therefore, it was studied the energy balance of black carrot cultivation that is sustained traditionally. In line with all these, the relations between the energy output and input parameters of the black carrot were calculated in this study and compared in energy units.

MATERIALS AND METHODS

This research was carried out in Kuzukuyusu village of Eregli in 2018. The villagers intensely deal with black carrot culture. Trials were performed in 3 replications on 3m x 50 m plots according to randomized block design. Soil texture of the experimental field was loam. Soils were alkaline (pH=8.44) and nonsaline, and had sufficient potassium, deficient phosphorus, and highly lime content.

In the region, black carrot is sown in the same fields every year. Traditional production processes are summarized in Figure 1.

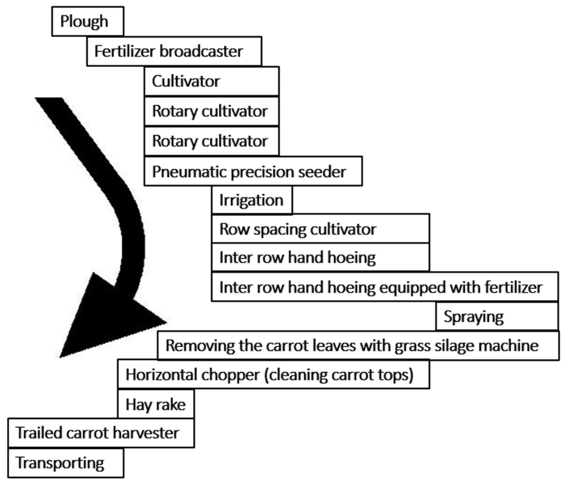

Figure 1. Black carrot production processes

The experimental field was plowed on 10 March 2018 with a moldboard plough. Diammonium phosphate fertilizer was applied to the field at 400 kg/ha using a disc fertilizer broadcaster. The field was tilled by a cultivator, and the seedbed was prepared with a rotary tiller. The ridge cultivation sites were formed with a ridger roller. Sowing was performed on 25 March 2018 using a high precision vacuum sowing machine at 2 cm in-row spacing. Black carrot seeds were sowed to the narrow row sowing surface with three rows in a ridge with 7.5 cm row spacing. Sprinkler irrigation was performed four times and for 2 hours in the first month to ensure of seed emergence. A cross-sectional view of a ridge is presented in Figure 2. Un-coated black carrot seeds were used in the experiments, and the sowing norm was 3,500 g/ha.

Interrow weeding was performed 4 times with a four-foot cultivator arranged to 75 cm row spacings. Manual weeding was made for the weeds growing in the rows also 4 times. A fertilizing rotary hoe was used to provide 200 kg/ha urea and 15 kg/ha ammonium nitrate separately. Herbicide was applied two times with a sprayer. Sprinkler irrigation was performed 13 times and each of them took

6 hours. A submerged 45 kW pump and a total of 8,630 m^3/ha irrigation water were used in irrigations.

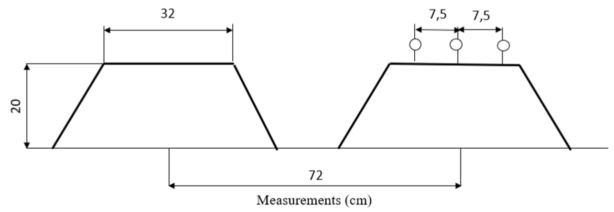

Figure 2. Cross-section of a ridge sowing

Greens were cut before the harvest with a weed silage machine. Heads were cleaned with a horizantal weed chopper, and greens were collected with a finger disc hay rake. Carrots were pulled with a carrot harvester, and harvested carrots were transported to a washing facility in a trailer. An average yield of 61,000 kg/ha was obtained in experiments.

During the experiments, tractor fuel consumption was evaluated by using a fuel gauge (a Rudolf Schmitt-brand, ±0.5%). Effective work performances were calculated by taking into account forward speeds and work widths.

The parameter provided in Table 1 were taken into consideration to define the energy balance of the black carrot. The values of energy equivalents of black carrots are indicated in Table 2.

The energy balances of all inputs in all cultivation processes which are hoeing, tillage, sowing, irrigation, herbicide application, fertilizing, harvest, and transport were measured. As the Table 3, input energy and output energy values were either measured by field conditions or quoted from the former literature.

Machine manufacturing energies of each implement used in black carrot culture were calculated as Equation 1 (Yavuzcan, 1994).

$$M_p = (M_u + F) \times 0.82 + Y_d \text{ (MJ)} \qquad (1)$$

M_p : Machinery manufacturing energy
M_u : Material production energy
F : Factory energy
Y_d : Replacement energy

Table 1. Definition of energy parameters

Parameter	Definition	Unit
Direct energy inputs (E_d)	Diesel input	MJ/ha per year
Indirect energy input (E_i)	Machinery + seed + fertilizers + herbicides, etc.	MJ/ha per year
Total Energy input (E_T)	$E_T = E_d + E_i$	MJ/ha per year
Energy Output (EO)	Biomass energy	MJ/ha per year
Energy use efficiency	Energy Output (MJ per ha) / Energy Input (MJ per ha)	-
Energy productivity	Yield (kg per ha) / Energy input (MJ per ha)	kg/MJ per year
Specifit energy	Energy Input (MJ per ha) / Yield (kg per ha)	MJ/ha per year
Net Energy	Energy Input (MJ per ha) - Energy input (MJ per ha)	MJ/ha per year

Table 2. Energy equivalents

Input	Energy equivalents	Reference
Human labor	1.87 MJ/kg	Fluck (1992)
Water*	2.95 MJ/m^3	Calisir (2007)
Seed	2.5 MJ/kg	Kaltschmitt and Reinhardt (1997)
Transporting	9.22 MJ/t.km	Kaltschmitt and Reinhardt (1997)
Herbicide	290 MJ/kg	Canavate and Hernanz (1999)
N	78.1 MJ/kg	Canavate and Hernanz (1999)
P_2O_5	17.40 MJ/kg	Canavate and Hernanz (1999)
Material production coefficient of tractor	49.453	Acaroglu (1998)
Material production coefficient of steel	35.216	Acaroglu (1998)
Fuel and oil	40.035	Kaltschmitt and Reinhardt (1997)
The output energy equivalent of black carrot	1.96 MJ/kg	Celik et al. (2010)

Table 3. Machinery used in black carrot cultivation and manufacturing energies of this machinery

Agricultural Practices	Work performance (h/ha)	Characteristics	Machine manufacturing energy (MJ/kg)
Tractor	-	61 kW, 0.155 kg kW/h, 3340 kg, 6000 h/life	71.36
Plough	1.42	350 kg, 2300 h/life, 20 l/ha, work width 1.4 m	49.35
Cultivator	0.91	400 kg, 2300 h/life, 8 l/ha, work width 2.75 m	48.96
Disc fertilizer broadcaster	0.14	100 kg, 1000 h/life, 2.5 l/ha, work width 10 m	104.93
Rotary cultivators	1.25	700 kg, 2300 h/life, 21 l/ha, work width 2.35 m	48.96
Sprayer x 2	0.29	140 kg, 750 h/life, 1.5 l/ha, work width 10 m	102.26
The vacuum-type pneumatic precision seeder	2.5	525 kg, 1200 h/life, 6 l/ha, work width 2.8 m	63.34
Disc ridge	1.43	1200 kg, 2300 h/life, 10 l/ha, work width 2.1 m	49.15
Inter row hoeing x 4	1	250 kg, 2300 h/life, 7 l/ha, work width 2.8 m	56.76
Fertilizing inter row hoeing x 2	1.33	350 kg, 1200 h/life, 4 l/ha, work width 2.8 m	57.24
Forage harvester	2.85	500 kg, 1000 h/life, 25 l/ha, work width 1.3 m	105.09
Horizontal weed chopper	2	200 kg, 2000 h/life, 15 l/ha, work width 1.3 m	101.09
Finger disc hay rake	0.55	150 kg, 1000 h/life, 7.5 l/ha, work width 2.1 m	105.09
Pulled carrot harvester	10	2500 kg, 2500 h/life, 80 l/ha, work width 0.7 m	74.88

Energy inputs per unit area were calculated using manufacturing energies, the mass of the machine, economic life and work performance of the machines (Yavuzcan, 1994). The equation 2 was used in calculations:

$$M_{pe}=\frac{G.M_p}{T.W} \quad (2)$$

M_{pe} : Machine energy (MJ/ha)
G : Machine mass (kg)
T : Machine economic life (h)
W : Work performance (ha/h)

RESULTS AND DISCUSSION

The energy inputs in the mechanization of black carrot production were shown in Table 4. The ratio of tillage practices was 22.38% in total, sowing was 3.48%, maintenance operations were 17.92% in total, and harvesting operations were followed by 56.22%. The harvesting process is carried out in four stages (grass silage, scooping with a horizontal shredder, grass silage and digging up roots). High energy inputs in the harvesting process were followed by the harvester 36.78%, grass silage 10.71%, horizontal shredder 5.93% and grass rake 2.79%. Fuel-oil energy constituted 55.43% of the mechanization processes. In the region, modified potato harvesters and intensive labor are used in black carrot harvest. However, because of increasing labor costs and problems in finding available labor, pull-type or self-propelled storage-type black carrot harvesters

Table 4. Energy inputs values in the mechanization of black carrot culture

Agricultural practices	Tractor Manufacturing Energy (MJ/ha)	Tool-Machine Manufacturing Energy (MJ/ha)	Fuel + oil Energy (MJ/ha)	Labor Energy (MJ/ha)	Total (MJ/ha)
Tractor (MJ/h)	39.72	-	-	-	-
Plow	56.40	10.74	800.70	2.65	870.49
Single disc fertilizer spreader	5. 56	2.12	100.09	0.26	108.03
The second tillage in spring (Cultivator)	48.96	8.51	320.28	1.70	379.45
Rotary cultivators	48.96	21.29	840.75	2.34	913.34
Disc ridger	56.80	32.05	400.35	2.67	491.87
The vacuum-type pneumatic precision seeder	99.30	69.28	240.21	4.68	413.47
Inter row hoeing x 4	158.88	24.68	1,120.96	7.48	1,312.00
On-row hoeing x 4	-	-	-	314.16	314.16
Fertilizing inter row hoeing	52.83	20.86	160.14	2.49	236.32
Sprayer x 2	23.04	10.90	120.10	1.08	155.12
Forage harvester	113.20	151.31	1,000.87	5.33	1,270.71
Horizontal weed chopper	79.44	20.21	600,53	3.74	703.92
Finger disc hay rake	21.85	8.41	300,26	1.03	331.55
Pulled carrot harvester	397.20	745.20	3,202.,0	18.70	4,363.90
Total	**1,162.42**	**1,125.56**	**9,208.04**	**368.31**	**11,864.33**

Table 5. Direct and indirect energy inputs in black carrot culture

Direct Energy Inputs	**MJ/ha**	**(%)**
Tractor Energy	1,162.42	2.00
Fuel-oil Energy	9,208.04	15.87
Labor Energy	368.31	0.63
Tool-machine Energy	1,125.56	1.94
Indirect Energy Inputs		
Fertilizer Energy	1,987,5.95	34.26
Herbicide Energy	272.51	0.47
Seed Energy	8.75	0.02
Irrigation Energy	25,458.85	43.88
Transportation Energy	534.76	0.92
Total Input	**58,014.8**	**100**

Table 6. Consumption of energy and energy ratios in black carrot culture

Total input (MJ/ha)	58,014.8
Total output (MJ/ha)	119,560
Net Energy (MJ/ha)	61545,2
Energy use efficiency	2,06
Energy productivity (kg/MJ)	1,05
Specific energy (MJ/kg)	0,95

have started to be imported. These harvesters should be modified and made suitable for regional conditions. Also, to reduce this energy input, combined carrot harvesters that complete the harvest in one pass can be used. For this, it is necessary to invest in mechanization in enterprises. Among the other mechanization implementations, tillage-group machines constitute 2,655 MJ/ha energy input (22%). Such a case was because of the small-granulation seed bed requirement of black carrot seeds. The third group was composed of maintenance-care processes.

According to the Table 5, direct and indirect energy inputs of black carrot cultivation were given. Considering the general energy inputs, irrigation energy comprised the most energy input with 44%, and it was followed by fertilization energy with 34% and fuel-oil energy with 16%. Regional black carrot cultivated soils contain low organic matter and high lime. Therefore, fertilization and irrigation energy inputs of the present study were relatively high. Fuel-oil energy input may be reduced especially by using vertical rotary cultivator and combined tillage combinations. In this study, the total energy input was found to be 58 014, 8 MJ/ha, and this value which was determined by Celik et al. (2010) was found to be lower than the input value (75,335 MJ/ha) obtained in traditionally produced black carrots in the same region.

It was shown in Table 6, some basis indicators of the energy performance of black carrot production using the energy accounting approach commonly used in the energy literature. The net energy balance was determined as 61 545.2 MJ/ha in black carrot. When this value is evaluated in terms of energy use, it reveals that black carrot agriculture has passed the sustainability test. Among the energy inputs, the high level of irrigation and fertilization energy inputs draws attention.

Energy use efficiency, energy productivity and specific energy values were determined as 2.06, 1.05 kg/MJ and 0.95 MJ/kg, respectively. Celik et al. (2010) reported the energy use efficiency and energy porductivity in ten conventional black carrot agriculture as 1.30 and 0.66 kg/MJ. The energy use efficiency and energy productivity values obtained from the research were found to be high. This is due to the higher yield value of black carrot and the low total energy input.

It has been reported that the energy use efficiency, energy productivity and specific energy values are between 1.70 and 1.77, 0.47 and 0.49 kg/MJ, and 2.03 and 2.12 MJ/kg in potato production in different soil cultivation systems in Central Anatolian conditions (Özgöz et al., 2015). When compared with potato, the value of energy use efficiency and energy productivity was found to be higher, and the amount of energy (specific energy) required to obtain one kg of product was found to be lower. It was reported that the specific energy for vegetable production in Turkey is 1.14 MJ/kg for tomato, 0.98 MJ/kg for melon and 0.97 MJ/kg for watermelon (Çanakçı et. al., 2005).

CONCLUSION

To increase the energy output rate, it is necessary to increase the yield of black carrots. For this, the solution of the seed problem is necessary. The local population in the region produces black carrot seeds and is used in the planting process. Calibration and coating of these seeds are not performed. For this reason, yield values remain low due to field exit. On the other hand, research should be carried out especially about ridge-sowing, smooth sowing, on-row sowing distances, ridge dimensions and closing wheels of the seeders. In this way, field yield levels may ebe improved. Despite all these unfavorableness, energy use efficiency value being 2,06 indicates that black carrot agriculture is sustainable in Turkey. Research should be conducted on the use of seeds with a shorter vegetation period. Thus, a reduction in irrigation energy input can be achieved. At the same time, with the modification studies on the combined self-propelled potato harvesters, the mechanization energy input will be able to reduce by harvesting the black carrot at once.

COMPLIANCE WITH ETHICAL STANDARDS

Peer-review
Externally peer-reviewed.

Conflict of interest
The author announced that for this research article, I have no actual, potential or perceived conflict of interest.

Author contribution
The author read and approved the final manuscript. The author confirms that they have not been published before and that the Text, Figures, and Tables are original.

Ethics committee approval
Ethics committee approval is not required. This article does not contain any studies with human participants or animals performed by any of the authors.

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Data availability
All data obtained or generated during the investigation appear in the published article.

Consent for publication
Not applicable.

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